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Investigating Sustainability and Waste Management in Blister Packaging: A Comparative Study of Global Production Sites in a Pharmaceutical Manufacturing Company.

A dissertation submitted in partial fulfilment of the requirements for the degree of
MSc in Pharmaceutical Business & Technology

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May 2025

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CANDIDATE DECLARATION


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I certify that the dissertation entitled: “Investigating Sustainability and Waste Management in Blister Packaging: A Comparative Study of Global Production Sites in a Pharmaceutical Manufacturing Company.” submitted in partial fulfilment of the MSc in Pharmaceutical Business and Technology, to the department of Pharmaceutical Business and Technology, Griffith College Dublin, is the result of my own work and that where reference is made to the work of others, due acknowledgement is given.

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LIST OF ABBREVIATIONS

| | | |
|-------|---|--------------------------------------|
| EU | – | European Union |
| GMP | – | Good Manufacturing Practice |
| HDPE | – | High-density polyethylene |
| HPRA | – | Health Products Regulatory Authority |
| KPI | – | Key performance indicator |
| PCTFE | – | Polychlorotrifluoroethylene |
| PET | – | Polyethylene terephthalate |
| PP | – | Polypropylene |
| PVC | – | Polyvinyl chloride |
| PVDC | – | Polyvinylidene chloride |
| SME | – | Subject Matter Expert |

ABSTRACT

Blister packaging is the predominant format for oral solid-dose pharmaceutical products, valued for its protection and compliance benefits; however, its complex construction utilising multiple materials (PVC, PVDC, aluminium) renders most blister waste non-recyclable and harmful to the environment. A review of existing literature demonstrated detailed analyses of material properties and laboratory-scale separation techniques, but revealed four critical gaps: (1) a lack of site-level data on actual blister waste volumes and disposal methods; (2) limited evaluation of recycling technologies under real-world, GMP-compliant conditions; (3) insufficient insight into how regulatory frameworks (e.g., the EU Green Deal) translate into operational practice; and (4) minimal incorporation of packaging experts' perspectives on barriers and enablers for sustainable change.

To address these gaps, this study employed a mixed-method design, conducting an online survey of 30 subject-matter experts across 17 global blister-production sites. Quantitative questions captured annual waste tonnages (90–148,000 kg per site), waste-stream distributions (incineration most prevalent, recycling less common), and material selection drivers (performance rated highest, sustainability ranked lowest). Qualitative responses explored trial outcomes for sustainable alternatives, revealing that 88% of sites had conducted trials but only 11% achieved successful implementation, with performance concerns, lack of suitable alternatives, and high cost cited as primary barriers.

The findings underscore the necessity of strengthening supplier partnerships to enhance alternative material robustness, expanding regulatory engagement to clarify recyclability requirements, and implementing systematic waste-monitoring frameworks to benchmark progress. By using these insights to construct an actionable plan, the pharmaceutical sector can take a crucial first step towards mitigating the environmental impact of blister packaging and fostering long-term sustainability in its global manufacturing network.

1 INTRODUCTION

1.1 BACKGROUND

Within the pharmaceutical industry, the packaging medium has become increasingly important. This is for multiple reasons including protection of the product itself from both contamination and damage, as well as enhanced patient compliance with dosages (Yaren Çapkın and Göknelma 2023).

Blister packaging is a well-established packaging process for oral solid dosage forms, consisting of a thermoformed cavity, which the tablet sits in, with a lidding material sealed over the base. This packaging format is one of the most common packaging formats used for oral solid dosage forms within the pharmaceutical industry, with 85% of solid drugs produced in Europe packaged in blisters (Pilchik 2000a). There are multiple reasons for the popularity afforded to blister packaging in the pharmaceutical industry, including its low cost, well-understood manufacturing process, tamper evidence capabilities and high level of protection against air and moisture which it gives the product (Yaren Çapkın and Göknelma 2023).

As a result, blister packaging contributes to a large volume of overall waste within the packaging industry (4% of total packaging waste) (Pilchik 2000a). It produces this volume of waste as a result of the complexity of the primary packaging materials. This is because the blister is comprised of multiple layers; the aluminium foil used as the lidding material (comprising 15-25% of the weight of each blister) and the PVC (comprising 75-85% of the weight of each blister) used as the forming material (Miękoś *et al.* 2023). These layers allow the blisters to have the protective characteristics that are the very reason for their popularity, however they are also the reason that sustainable blister disposal options are so limited. Separation of these layers for recycling is a very complicated process and is not done in most regions, leading to significant blister waste ending up in landfills, which can cause soil acidification, or being incinerated, resulting in toxic gas release (Pedrosa de Oliveira *et al.* 2021).

1.2 RESEARCH PURPOSE

This research project proposes to survey packaging subject matter experts across multiple blister production sites for a global pharmaceutical company. This company is a market leader in the over-the-counter products industry, with its portfolio including a variety of brands that address oral health, pain management, respiratory health, and nutritional supplements. It is a large-scale company with over 24,000 employees globally.

In total, there are 17 blister production sites in this company’s network, spanning Europe, South America, North America, Asia and Africa. This study functions to assess average blister waste produced at each site, investigating sustainability practices at the sites and any barriers to sustainable packaging implementation.

This research is being conducted to provide recommendations to pharmaceutical companies using blister packaging on how they can potentially implement sustainable initiatives to reduce blister waste at manufacturing sites. Another aim of this research is to give companies who produce blister packaging components insight into the challenges associated with the use of current packaging components and further encourage the development of novel sustainable alternatives.

1.3 RESEARCH SIGNIFICANCE AND JUSTIFICATION

The vast majority of solid dosage forms in Europe (85%) are packed in blister packaging, which are not separated into their individual components due to the complicated nature of this process (Pilchik 2000a). Even when separation of the blister components is explored as a viable option, this can have adverse environmental consequences as the reagents required to separate the layers, such as formic acid and acetic acid, can have negative effects on the environment (Rimšaitė *et al.* 2019). One comparative study assessing the impact of three different reagents used in the wet separation process found that the reagents used in the separation process can also have a negative impact on human health, with this process using reagents which are toxic and carcinogenic (Fig. 1) (Rimšaitė *et al.* 2019).

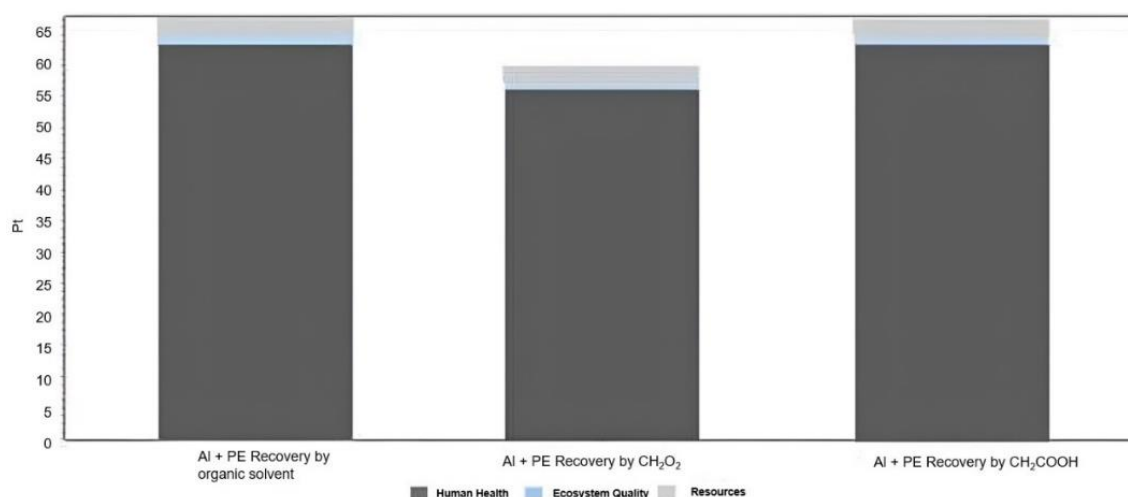


Figure 1: Potential impact to environment and human health of wet separation techniques for blister component separation for recycling (Rimšaitė *et al.* 2019).

As a result, the two remaining options for blister disposal are landfill and incineration. There are numerous negative impacts that result from these methods of disposal. Firstly, the plastic and aluminium elements of the packaging can lead to soil acidification, which negatively impacts plant life and soil microbes (Yaren Çapkın and Gökelman 2023). Incineration has even higher

environmental impacts than landfilling in a number of categories including acidification due to the nature of the emissions from the PVC and PVDC that comprise the forming layer of blisters (Bassani *et al.* 2024). As such, these disposal options have a sizeable detrimental effect on the environment and are thus seen to contribute to climate change.

Climate change is widely considered to be one of the greatest threats facing the human race today (Santos and Bakhshoodeh 2021). A Green Paper published by Health Care Without Harm in 2019 found that the climate footprint associated with the healthcare industry is 4.4% of the global CO₂ emissions (equivalent to 2 gigatons of CO₂) (Karlner *et al.* 2019). Of this, 71% of emissions come from the pharmaceutical supply chain which includes blister packaging, among other activities (Karlner *et al.* 2019). Another study conducted by Unitaid assessing ten major health products found that materials acquisition, preprocessing and manufacturing activities comprise 95% of the greenhouse gas emissions for the products in scope for that research (Unitaid 2023). It is evident from this that the negative environmental impact from pharmaceutical manufacturing is substantial. With the global pharmaceutical output growing year on year (4% increase forecast for 2025 and 3.6% for 2026) it is crucial to understand and implement any opportunities to improve sustainability in this industry (Atradius 2024a).

With climate change at the forefront of many companies' minds due to pressures from governments to reduce greenhouse gas emissions, it is surprising that there is a lack of information readily available as to what are the opportunities and challenges present. This information is vital to making the blister manufacturing process more environmentally friendly and reducing overall waste in this prevalent oral solid dose packaging medium. This research is being carried out with a view to make data available from industry experts in a global pharmaceutical manufacturing company encompassing blister waste quantity, disposal methods, barriers and initiatives, to increase the understanding of the challenges facing the blister packaging industry and future opportunities for improvement.

1.4 RESEARCH QUESTION

The primary research question for this research is as follows:

What are the key challenges and opportunities for improving sustainability in blister packaging production within the pharmaceutical industry, and how can waste reduction and environmentally friendly practices be effectively implemented while ensuring quality and compliance is maintained?

1.5 RESEARCH OBJECTIVES

The objectives of this research are as follows:

1. To quantify the current volume of blister packaging waste generated by all blister production sites in a global pharmaceutical company.
2. To assess how waste is disposed across these sites to examine the environmental impact of pharmaceutical blister waste at these sites.
3. To assess current sustainability practices used in the blister production sites, including recycling, waste reduction initiatives, and disposal practices.
4. To investigate challenges faced by these sites in adopting sustainable blister packaging materials and technologies.
5. To develop compliant recommendations for improving sustainability in blister packaging.

1.6 DISSERTATION STRUCTURE

This dissertation consists of five chapters:

- Chapter 1 - Introduction: This chapter introduces the topic of research for this study and provides some background information on blister packaging, the waste associated with blister packaging and the pharmaceutical industry, and outlines the research plan for this project. The purpose of the research is detailed, and the significance of the research explained in the context of climate change and the positive impact that this study may have through making information on the barriers and opportunities to environmental sustainability in the blister packaging sector of the pharmaceutical industry readily available.
- Chapter 2 - Literature Review: This chapter is a literature review, which further builds upon the background outlined in chapter one to provide further information on blister packaging methodology, components used and the sustainability thereof. This literature review also details the present state of blister waste currently produced by the pharmaceutical industry and what work has been done to date in reducing the carbon footprint of pharmaceutical blister manufacturing. Additionally, the current literature regarding sustainable solutions that have been researched and developed within the packaging industry are discussed and analysed. Further to this, the findings from the literature reviewed are detailed, with gaps being identified and a conceptual framework outlined.
- Chapter 3 - Research Methodology: In this chapter, the methodology for how this research is being conducted is explored. This is completed using the research onion concept which allows the different stages of research strategy development to be fully examined and

understood (Saunders *et al.* 2023). All aspects of the research methodology are further developed in this section including the research philosophy, the survey design, sampling strategy (including Cochran's formula for sample size), participant recruitment across 17 global sites, questionnaire development and pilot testing and data collection procedures. This section also describes the statistical and thematic analysis techniques used to ensure rigor, reliability, and validity in addressing the research objectives.

- Chapter 4 - Findings and Analysis: The results of the primary data gathering and analysis of this data are presented in this chapter. These results are shown in both table and graph form as appropriate for the quantitative data collected. The common themes identified across in the answers given to the open-ended qualitative questions are presented in this section also. The findings of the data collected are presented with the research objectives in consideration in order to provide an answer to the research question being asked.
- Chapter 5 - Conclusions and Recommendations: The final chapter summarises the main findings of the research study and provides recommendations to pharmaceutical companies as well as packaging component manufacturers as to how to improve blister packaging sustainability. This chapter will also include recommendations for future research.

2 LITERATURE REVIEW

2.1 INTRODUCTION TO BLISTER PACKAGING AND COMPONENTS

This chapter explores the key themes surrounding sustainability in pharmaceutical blister packaging, focusing on material composition, waste generation, disposal methods, and emerging sustainable solutions. It begins by outlining the structure and benefits of blister packaging, establishing its role in pharmaceutical supply chains. The review then assesses current disposal practices and their environmental impact, directly supporting the first two research objectives.

Subsequent sections examine the drivers of sustainability, including regulatory and market pressures, and the strategies being investigated to reduce blister waste, addressing the third research objective. Finally, the review identifies the core barriers to adopting sustainable materials and highlights innovative solutions on the horizon, aligning with the last two research objectives. Together, these themes provide the contextual foundation for the primary research detailed in subsequent chapters.

2.1.1 Impact of Packaging in the Pharmaceutical Industry

The pharmaceutical industry has shown continual growth in recent years, with global pharmaceutical output steadily increasing since 2021, and reports forecasting further growth of 4% in 2025 and 2.6% in 2026 (Atradius 2024b; Atradius 2024a). This growth has translated into a huge amount of waste being generated – it has been found that the carbon footprint associated with the pharmaceutical industry is greater even than that of the automotive industry, with the healthcare industry accounting for 4.4% of global CO₂ emissions (equivalent to 2 gigatons of CO₂) (Belkhir and Elmeligi 2019; Karliner *et al.* 2019). At a time where climate change has become increasingly central, sustainability has been one of the primary considerations in many industries including the pharmaceutical industry. Within the pharmaceutical industry, packaging is often targeted as one of the main waste producers, as during the packaging process a large volume of material and energy are consumed (Breton *et al.* 2022).

2.1.2 Blister Packaging Use and Benefits

Blister packaging is one of the most common modes of packaging seen within the pharmaceutical industry as it is low cost and easy to run (Yaren Çapkın and Göknelma 2023). Further to the benefits to the manufacturer, there is the additional benefit for the consumer; blister packaging has the functionality to protect the oral solid dosage form from moisture and air as the seal of each blister is completely airtight. This also provides the additional benefit of blisters being tamper evident, as any opening of the blister will be evident with the lidding being torn (Liu and O'Donovan 2025).

2.1.3 Blister Packaging Components and Manufacturing Process

Pharmaceutical blister packaging generally consists of four main components; forming material, heat seal, lidding material and ink (Pilchik 2000a). The overall weight distribution in a blister pack is generally 80-85% forming material and 20-25% lidding material (Pilchik 2000a).

The tablet sits into the forming material of the blister, which is often comprised of plastic such as PVC (which is the most common), PP and PET. PVC is the most commonly used forming material due to its ability to thermoform with ease, its structural strength, its impermeability to oils and its cost effective nature (Yaren Çapkın and Göknelma 2023). However, the popularity of PVC has fallen due to the hazardous dioxins it produces when incinerated, leading to the increased use of PP as a forming material (Petrlik and Bell 2017).

PP has multiple characteristics which make it a good candidate for a forming material. Of these, the most important are that it acts as an excellent moisture barrier, protecting the tablets inside and being able to be disposed of more sustainably as it is easily recyclable, and not releasing toxins upon incineration (Pilchik 2000a). However, PP has proved somewhat difficult for some manufacturers to adopt as it is more difficult to thermoform than PVC. This difficulty comes from its requirement for a narrow margin of temperatures to function correctly as well, while it is also noted to sag more than its less sustainable counterpart (Lau *et al.* 1998). As such, there is a challenge facing pharmaceutical companies in striking the balance between manufacturability and sustainability when selecting a forming material to use in their blister packaging.

The forming material is thermoformed to form the cavity which the tablet will sit into, and the lidding material is placed over the forming material, which is then heated and sealed with the aid of the heat seal lacquer (Pilchik 2000b). This heat seal lacquer may be solvent-based or water-based and must be sufficiently strong in order to provide an airtight seal when the lidding material is applied to the forming material. The heat seal lacquer, along with a primer, is applied to the lidding material to allow the heat seal to be formed (Yaren Çapkın and Göknelma 2023).

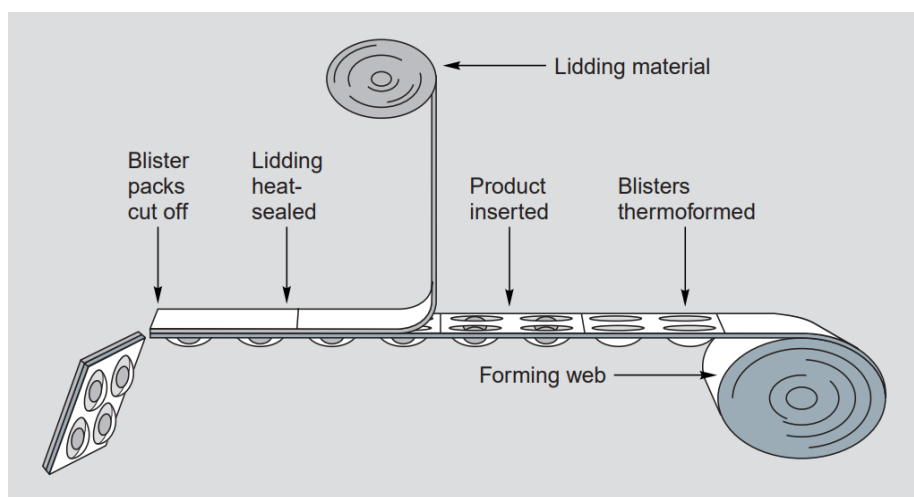


Figure 2: Blister forming process (Pilchik 2000b).

There are three types of lidding materials; aluminium, paper/aluminium and paper/PET/aluminium (Yaren Çapkın and Göknelma 2023) Aluminium is the most common in Europe, while paper/PET/aluminium are used largely in the US (Pilchik 2000a). Aluminium is common to all types of lidding materials as it is considered to have the strongest moisture barrier and as such is used to ensure protection of the drug against the outside environment (Allinson *et al.* 2001).

While the literature highlights the technical strengths of blister packaging, such as product protection and ease of dose administration, it often overlooks the environmental consequences of its material complexity. The continued dominance of PVC/aluminium laminates is typically discussed from a functional standpoint, with little consideration of how these choices affect end-of-life sustainability. Moreover, there is minimal exploration of how material decisions are made within manufacturing environments or how packaging design is linked to waste generation. This limits the ability to assess how upstream packaging strategies contribute to downstream waste challenges, indicating a need for more operational insight from the industry.

2.2 CURRENT BLISTER DISPOSAL METHODS

2.2.1 Recycling of Blisters

The current possibilities for disposal of blister packaging can be categorised into three main options; blister recycling, landfill and incineration (Pedrosa de Oliveira *et al.* 2021). The first option is recycling of the blister, which is not commonly used as this requires separation of metals and plastic which is not routinely carried out by most recycling companies. In Ireland, for example, guidance provided by the Department of Climate Action, Communications and the Environment is to dispose of blister packaging in the general waste bin (Regional Waste Management Offices 2018). The inability to recycle blister packaging is due to the difficulty involved in separating the plastic of the forming material and the aluminium of the lidding material. The sealing of the forming material and lidding material with heat-seal lacquer during the blister manufacturing process is a large contributing factor as it makes separating the two for recycling challenging.

If the challenges of separating the forming and lidding material could be overcome, the benefits of recycling would be significant. Namely, the recovery of aluminium from the blisters would reduce the requirement for primary production of aluminium from bauxite ore, which is known to be an energy demanding process, whereas aluminium recycling has a much lower level of energy consumption (Frees 2008; Nieminen *et al.* 2020) Furthermore, the ability to recover both the aluminium and plastic material for recycling would allow the zero-waste strategy, a waste management system stipulates a requirements for products and their associated byproducts to be reused or recycled, to be adhered to (Song *et al.* 2015). This would be a substantial step forward

for the pharmaceutical industry towards sustainability and away from the negative impacts of the currently utilised options, landfilling and incineration.

Current research into blister recycling has produced a range of innovative separation techniques, including solvent-based and mechanical methods, yet these studies are largely confined to laboratory conditions. There is a notable absence of research evaluating the feasibility of these methods within the constraints of regulated pharmaceutical operations. Critical issues such as scalability, cost, supply chain compatibility, and compliance with GMP standards are underexplored. As a result, it's unclear whether the proposed solutions can be adopted beyond experimental contexts. There remains a significant gap in understanding the practical barriers that prevent these recycling technologies from being implemented at scale.

2.2.2 Landfilling of Blisters

The less desirable blister disposal options, landfill and incineration, both lead to hazardous pollution entering the atmosphere (Pedrosa de Oliveira *et al.* 2021). Landfilling of blisters is considered to be the simplest method of blister disposal due to the complexity of the multi-layer structure of the blisters (Hong *et al.* 2018). However, this method of disposal is far from sustainable, which can be observed through its detrimental effects for the environment. When blister waste is landfilled, the aluminium from the lidding material leaches into the soil, which subsequently inhibits plant growth by prohibiting root growth and mineral uptake, thereby also having a negative impact on crops (Shetty *et al.* 2021).

One review completed by Shetty *et al.* (2021) highlighted these effects, focusing on aluminium as one of the most common suppressors of crop growth. In the case of blisters, blister waste is landfilled, the aluminium from the lidding material leaches into the soil, which subsequently inhibits plant growth by prohibiting root growth and mineral uptake, thereby also having a negative impact on crops (Shetty *et al.* 2021). In addition, the aluminium ions which enter the soil can be washed into bodies of water such as lakes and rivers, as aluminium does not biodegrade (Rahman *et al.* 2018).

This can cause harm to animals and fish, as well as humans – multiple studies on the effects of aluminium intake on the human bodies have shown that high levels of aluminium can lead to malignancies such as include renal failure, encephalopathy and Alzheimer's disease (Bugiani and Ghetti 1990; Alfrey 1993; Kawahara and Kato-Negishi 2011; Rahman *et al.* 2018). As such, landfilling, although cost-effective and simple, is not a viable option for sustainable blister disposal.

2.2.3 Blister Incineration

Blister incineration has numerous benefits associated with it as a process for blister disposal. It has an advantage over landfilling as it greatly reduces the volume that the waste occupies and

mass of the waste itself as well as having the additional benefit of energy recovery through utilisation of the heat energy created from incinerating the blister waste (López *et al.* 2015; Lim *et al.* 2024). However, there are multiple adverse effects of blister incineration which deem it an unsustainable method of disposal.

During the incineration process the aluminium in the blisters is lost, leading to a requirement for primary aluminium production and the large energy consumption associated with it (Agarwal *et al.* 2020). In addition to this, the production of toxic gases including nitrous oxide, sulphur dioxide and toxic dioxins are known to occur when PVC is incinerated, all of which are highly harmful to the environment (Ali and Siddiqui 2005). Furthermore, the incineration of plastics such as PVC can lead to chemical reactions which form polycyclic aromatic hydrocarbons, which are highly dangerous to humans as they are found to be carcinogenic, mutagenic and teratogenic (Wey *et al.* 1998). As such, many companies within the pharmaceutical industry are prioritising the development of a sustainable blister packaging solution which does not pose a risk to the environment or indeed to human health.

Landfilling and incineration are often identified as the predominant disposal methods for blister waste, yet most literature does little to investigate why these environmentally detrimental practices persist. The continued reliance on these routes is generally presented as a default, rather than critically analysed with a view to developing an innovative and more sustainable way forward. Furthermore, little is known about how these methods vary across regions, or what internal site-level factors sustain their use. This lack of nuance hinders a full understanding of the systemic barriers to change and suggests the need for deeper examination of operational disposal behaviours within pharmaceutical manufacturing sites.

2.3 BLISTER SUSTAINABILITY: DRIVERS AND ACHIEVEMENTS

2.3.1 Legislative Requirement for Sustainable Blister Production

On a global scale, sustainability extends beyond an ideal; it is a legally mandated objective. On 4 December 2016, the Paris Agreement came into effect. This document is a legally binding climate change agreement, signed by 196 parties at the UN Climate Change Conference in 2015, which commits to limiting the global temperature increase to 1.5°C (United Nations 2023). As part of the strategy to meet this target, the EU has proposed the European Green Deal, part of which includes a revision of the EU legislation on Packaging and Packaging Waste. This revision aims towards inhibiting packaging waste through reducing the quantity of waste, preventing packaging deemed unnecessary and increasing reusable packaging. Crucially, this proposal also introduces mandating recyclable packaging, with all primary drug packaging required to be recyclable on a large-scale from 2035 (European Commission Directorate-General for Environment 2022).

As a result, great emphasis has been put on manufacturers, both of blisters and of blister components, in the pharmaceutical industry to work towards the aforementioned zero-waste strategy in order to move towards creating a more sustainable blister pack which reduces packaging waste and eventually will allow for fully recyclable blisters (Song *et al.* 2015).

There is growing awareness in the literature of the regulatory pressures driving sustainability, particularly within the EU and global ESG frameworks. However, these discussions often treat legislation as a broad external driver without fully analysing how companies interpret or respond to these evolving requirements. The potential conflict between long-term regulatory goals and the short-term operational realities of pharmaceutical manufacturing is underexplored. Little attention is paid to how regulatory ambiguity, perceived risk, or lack of transitional guidance may delay sustainable packaging innovation. This points to a gap in understanding how regulation is internalised and operationalised within the sector.

2.3.2 Sustainable Packaging

Sustainable packaging must meet various criteria to be considered truly sustainable, including the utilisation of renewable or recycled raw materials, clean manufacturing practices, which use only the materials and energy necessary, and recoverability of materials to be used in a closed-loop cycle (Yip 2009; Breton *et al.* 2022). This is considered by many to be a highly idealistic view as much change would be required to achieve all these criteria and such innovation is not yet robust enough to be used in a large commercial scale (Breton *et al.* 2022).

The literature offers a wide range of sustainable packaging alternatives, from recyclable polymers to biodegradable materials. However, the focus is predominantly on material properties and theoretical benefits, with little literature available detailing how these alternatives perform in real-world production environments. Operational challenges such as tooling compatibility, validation timelines, supplier readiness, and internal buy-in are rarely addressed. This disconnect between material science and manufacturing reality reveals a critical knowledge gap: we know what is possible in theory, but not what is practical for real-world usage. As such, it is clear that further investigation is needed into the extent to which sustainable packaging initiatives are being trialled or implemented at the site level.

2.3.2.1 Packaging Optimisation

One potential method of increasing blister sustainability is waste reduction through reducing the blister volume, space between tablets or thickness of the forming or lidding material. Although the waste produced will not be disposed of using a sustainable method, the amount of waste being generated will be lessened and thereby the environmental impact.

One study by Falconnier-Williams *et al.* (2024) assessed the amount of waste that could be saved in Germany by reducing space in between blisters and the size of the pocket in which the tablet

sits (Falconnier-Williams *et al.* 2024). This study was completed by calculating the amount of waste produced from the packaging material of the 45 most prescribed oral solid dosage forms in Germany and evaluating the volume of waste that could be reduced by positioning the cavities to have 2mm between each blister (which is the technical minimum). The main findings of this research were that annually, the 45 most prescribed medications alone lead to the production of 3868 tons of waste. It was also found that the blister cavity is on average four times larger than the tablet itself and that 69% of blister packaging was used for the space in between cavities. The authors showed that by optimising the blister layout, 37% of primary packaging material can be saved. This study is relevant as by simply optimising the blister layout on the packaging, the potential exists to reduce the volume of blister waste by over a third and bring about cost savings for pharmaceutical manufacturing sites. Nonetheless, there are limitations present in this study, as this study focuses on one country, rather than taking a holistic approach and including the blister waste data in Europe, for example.

Furthermore, a study was conducted by Huawei Pharma Foil Packaging (2018), which assessed the effects of switching from 25µm aluminium foil as a lidding material to 20µm aluminium foil in blisters. This study found that this switch resulted in an increase of 7040 in the number of blisters being produced, in addition to the 20% reduction in aluminium used in its production. No differences were observed in the seal strength and heat resistance between the two foils (HWPF 2018). This study highlights the importance of assessing the materials being used to ensure that only the material required is being consumed and highlights that manufacturers should assess their components to ensure no material is wasted through the use of components which are excessively thick in order to increase sustainability and reduce their own material costs. This study also provided data that was easily translatable into industrial practices – in addition to the information on waste reduction through the reduced foil thickness, the thinner foil facilitated an increased production output which is an advantage that manufacturing sites can directly benefit from and would therefore be more likely to adopt. As such, the results of this study can be considered more directly beneficial to manufacturing sites than that of Falconnier-Williams *et al.* (2024), as while that study provided a waste reduction strategy from a blister design perspective, the redesign of a blister may be a lengthy process with regulatory impacts. For sites manufacturing blisters, studies similar to that conducted by Huawei Pharma Foil Packaging (2018) can be used to inform decisions on components used and provide evidence to support adopting a more environmentally friendly option such as a thinner foil.

2.3.2.2 Separation of Blister Packaging for Recycling

Nonetheless, even when the volume of waste is reduced in this manner, there is still the issue of the disposal method of the blister materials, where incineration or landfill are the options. The materials used in current blister packaging (PVC and aluminium foil) can be recovered and

recycled once separated, yet this is by recycling companies due to the complexity associated with material separation (Yousef *et al.* 2018).

The separation of aluminium and plastic has been explored using multiple techniques by various researchers. This is due to the previously mentioned benefits of being able to sustainably separate the two for recycling, which are twofold; firstly, the environmental impacts of incinerating or landfilling blister packaging are avoided and secondly, the aluminium and plastic recovered can be recirculated into making further blister packaging. This is especially significant for aluminium as reduced aluminium recycling gives rise to increased need for primary aluminium, a process which has a high energy demand compared to aluminium recycling whose energy consumption is low (Frees 2008). However, recycling in itself is not equivalent to sustainability. Aside from the complexity associated with separating aluminium and plastic, there is also a negative environmental impact associated with the separation of the two.

Given the current available techniques, the process of separating blister components is associated with a high energy demand and uses harmful solvents (Pedrosa de Oliveira *et al.* 2021). One of the techniques that was developed for blister component separation is a mechanical technique known as cryo-comminution, which facilitated excellent recovery of both plastic and aluminium through separating the blister into conducting (aluminium) and non-conducting components (plastic) using a drum electrostatic separator as shown in Fig. 3 (Gente *et al.* 2003). However, this technique has a high energy requirement and does not purify either component, so further treatment is required before either are able to be recycled, as both aluminium was observed in the separated plastic, and plastic was seen in the separated aluminium. As such, this technique alone is not a feasible solution for blister pack recycling.

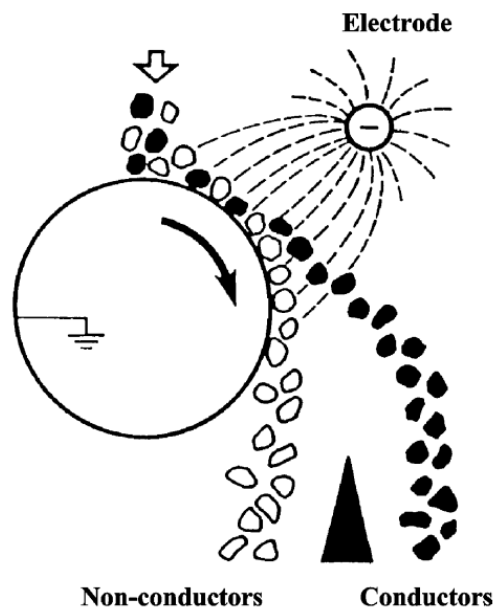


Figure 3: Drum electrostatic separator separating non-conducting plastic from conducting aluminium in blister packaging (Gente *et al.* 2003).

One study conducted by Agarwal *et al.* (2020) trialled a separation technique called electro-hydraulic fragmentation, which was a novel technique for blister packaging recycling that used high voltage shockwaves to break down a solid material (Gente *et al.* 2003). This technique had the potential to overcome the energy demand issues associated with the study from Gente *et al.* (2003) in cryo-communication. This study found that up to 88% of aluminium could be recovered from the blisters used, with the energy consumption associated with this separation being half that required for primary aluminium production (Agarwal *et al.* 2020). In this study, the authors have suggested that on a production scale, the amount of energy required for this separation would be even less, however as this experiment was only conducted at a laboratory scale, further research would be required to confirm this. As with other studies, this study by Agarwal *et al.* (2020), while providing valuable information on a potential technique for blister separation, showed a clear gap on industry scale knowledge that is available. This study was conducted at a laboratory scale with no data gathered or future plans to include an industry scale experiment to show how the technique would perform in a blister manufacturing waste disposal environment.

Chemical separation has also been investigated in two separate studies by Wang *et al.* (2015), using hydrochloric acid and sodium hydroxide to separate the aluminium and plastic, again yielding excellent recovery of both aluminium and plastic (Wang *et al.* 2015a; Wang *et al.* 2015b). However, the chemicals used in these techniques cause harm to the environment through ending up in the waste runoff and eventually in bodies of water which has a detrimental effect on animals and plants (Yousef *et al.* 2018). A similar hydrometallurgical process was assessed in 2024 by Shukla, Chernyaev and Lundström (2024) using phosphoric acid and hydrogen peroxide which produced approximately 100% aluminium yield in 4 hours, using the method shown in Fig. 4. However, this study did not cover the full extraction process, focusing on the potential feasibility for this mechanism, showing a further requirement for full investigation of the reaction mechanism, without which the full extent of the potential for use of this technique in industry cannot be known. Furthermore, despite the high yield, the authors conceded that there is an environmental impact associated with the hydrogen peroxide that cannot be overlooked and that other oxidants should be studied such as Fe^{3+} , which could potentially lessen the detrimental effect that this technique has (Shukla *et al.* 2024).

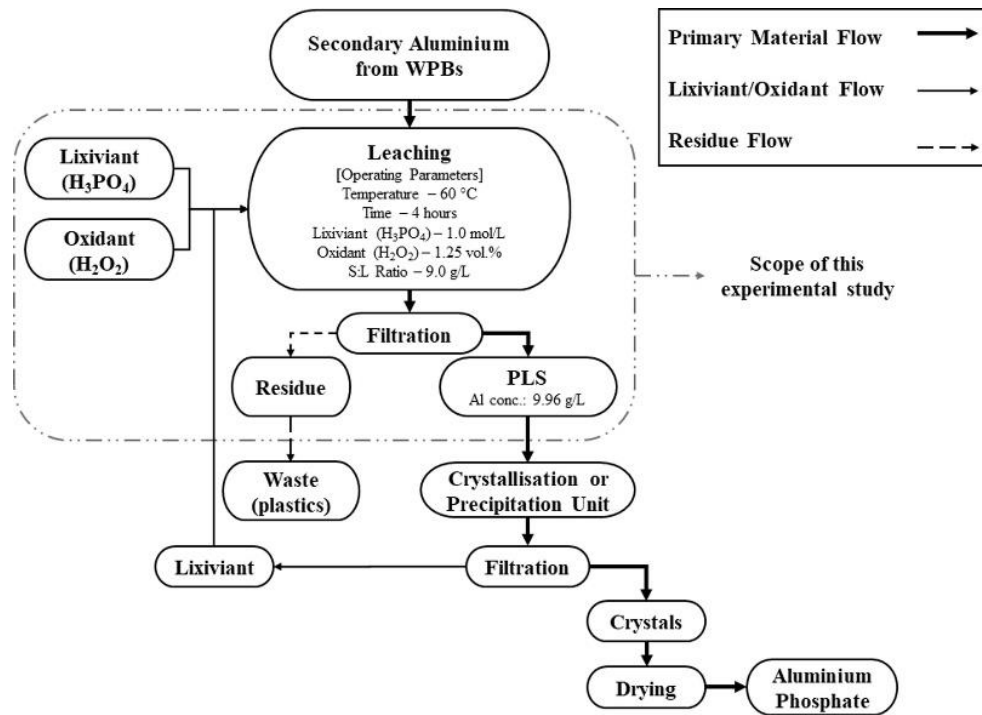


Figure 4: Technique used to extract aluminium for recycling from blister packaging (Shukla *et al.* 2024).

Yousef *et al.* (2018) also explored a chemical separation process, assessing switchable hydrophilicity solvent and ultrasonic treatment for layer separation in waste blisters (Yousef *et al.* 2018). This process, which lasted 300 minutes until full blister separation was complete, was shown to be extremely efficient, with an overall material recovery rate of 98%, with other benefits including low energy cost, unlike that seen in the study of Gente *et al.* (2003) and solvent reusability as seen in the studies by Wang *et al.* (2015) and Shukla *et al.* (2024). In addition to this, the authors gave a proposed actionable plan for implementation of their technique on an industrial scale. This plan includes a pretreatment stage to decontaminate the blisters before separation and extrusion in order to recover as much material as possible. While this study requires waste treatment plants to have the facilities and equipment to implement the identified method, the authors in this study provided recommendations for how a sustainable solution could be achieved on an industrial scale, which was not done in the other literature that was reviewed.

2.3.3 Feasibility of Green Blister Recycling

From the current research, it can be seen that the potential for blister separation and recycling has not yet been realised. Despite scientific efforts, all methods for separation of aluminium and plastic have environmental drawbacks which limit the success of these techniques as viable options for implementing recyclable blisters on a large scale. The cruciality of developing a sustainable blister recycling option is highlighted with the implementation of blister recycling schemes that have been seen across some major pharmacies. In 2020, Superdrug commenced a blister pack recycling scheme in their stores as a response to the lack of recyclability options for

blisters through local bin collection authorities, with Boots following suit with a pilot trial launched in 2023 (Bayer 2021; Lovell 2024). Although these developments are positive as they reduce the amount of blister waste going to landfill or incineration, since there are no blister separation techniques that can be deemed fully sustainable, these blister recycling schemes still lead to excessive energy consumption and adverse environmental impacts.

Emerging studies on eco-friendly separation techniques, such as lactic acid-based delamination or eutectic solvents, highlight strong recyclability potential. However, these technologies are often discussed without reference to cost, industrial throughput, solvent recovery, or pharmaceutical compliance. Additionally, their compatibility with existing waste management infrastructure is usually not evidenced in the literature available. The lack of evidence around real-world deployment and site-level decision-making means these promising approaches remain largely academic. A clearer picture is needed of how pharmaceutical companies perceive these technologies and whether they are actively exploring them as viable options.

Nonetheless, that is not to say that sustainable blister recycling is not possible, or indeed that other options are not available to facilitate environmentally friendly pharmaceutical blister manufacturing. In the next section of this literature review, the innovation that paves the way for the future of blister packaging sustainability will be discussed, with opportunities for improvement in blister manufacturing sustainability highlighted.

2.4 FUTURE OF SUSTAINABILITY IN BLISTER PRODUCTION

2.4.1 Environmentally Conscious Blister Separation Techniques

From the research that has been done to date, it is clear there is much appetite for innovation within blister packaging in order to produce a truly sustainable solution. As discussed in the previous section, in order to bring about recycling of blisters in a sustainable manner, the separation technique used to segregate the plastic and aluminium blister components must have minimal adverse environmental impact. One recent study by Nieminen *et al.* (2020) investigated the use of a deep eutectic solvent and lactic acid as green solvents for aluminium and plastic separation in blister waste, to address the gaps left by currently available blister separation techniques as detailed in section 2.3.2.2. Deep eutectic solvents are non-toxic and inflammable, giving them status as an environmentally friendly option, especially due to their excellent properties as a solvent. These solvents consist of two main components, which in this study are lactic acid and choline chloride (Nieminen *et al.* 2020).

This study also explored the use of lactic acid, which is largely used in the medical industry and is biodegradable as a solvent in its own right for blister separation. The results of this study showed that when using pure lactic acid, separation of PVC and aluminium could be achieved

with <5% mass loss as shown in Fig. 5 (Nieminen *et al.* 2020). Overall, the lactic acid showed the most success as a green solvent for blister separation in this study, achieving 95% aluminium purity, with the deep eutectic solvent successfully separating the components but corroding the aluminium.

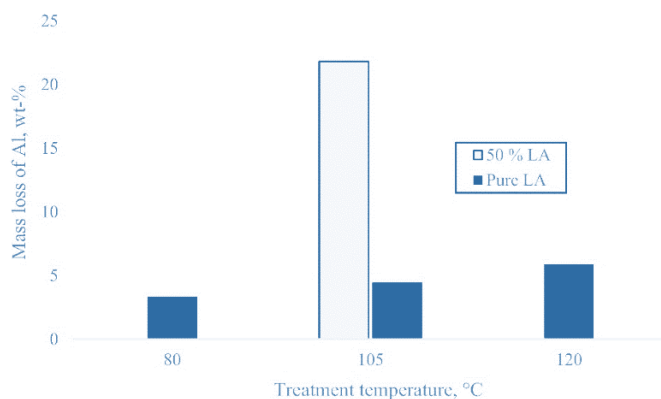


Figure 5: Mass loss of aluminium when using lactic acid as a solvent for blister separation at various temperatures (Nieminen *et al.* 2020).

Overall, lactic acid was found to be an excellent candidate for an environmentally friendly solvent for blister separation for recycling. Not only was separation of aluminium and PVC achieved, with the materials subsequently available to use for recycling due to their high purity level, the solvent can be reused to treat multiple batches of waste blisters. This has a positive environmental and cost-saving impact, further enhancing this solvent's potential. The authors noted that although there are some constraints with the deep eutectic solvent as a blister separation solvent, it should not be disregarded, but further investigated to assess if the aluminium corrosion can be reduced under different conditions.

This study should be noted as an excellent example of a potential solution for a current problem, as both solvents are considered to be environmentally friendly and successfully separated PVC and aluminium. With great success seen from the use of lactic acid as an environmentally friendly solvent, this can be considered a possible sustainable solution to the blister separation issue, the adoption of which should be explored by recycling facilities to reduce the environmental impact of blister waste and implement blister recycling as a widespread initiative (Nieminen *et al.* 2020).

While this study highlights one of the potential emerging techniques for separating blister components, it is primarily evaluated from a technical standpoint rather than a regulatory or operational one. There is little analysis of how these methods align with pharmaceutical safety standards, or whether they can be implemented without risking contamination or disrupting quality assurance processes. This oversight limits their real-world relevance and leaves a gap in understanding how viable these techniques are in practice and how the scale-up of these techniques would work in an industrial setting. The field would benefit from greater exploration of how such methods are perceived and assessed within industry settings.

2.4.2 Alternative Blister Component Materials

In 2021, the company Klockner Pentaplast developed the first certified recyclable PET blister film, the kpNext™ R1, which can be recycled in the RIC 1 stream (Klockner Pentaplast 2021). This type of forming material is yet to be commonly adopted across large manufacturing facilities, with PVC continuing to dominate within the industry. This may be attributed to the time associated with changing primary packaging materials from PVC to the kpNext™ R1. This can include feasibility studies, stability studies and qualification. Additionally, this still leaves the issue of lidding material to be used with this forming material, as blister component separation remains a concern for the true impact of an environmentally friendly alternative to be seen.

More recently, Bayer announced a mono-layer PET blister pack for its pain relief tablet, Aleve shown in Fig. 6 below. In a partnership with packaging company Liveo Research, they produced a ‘One-Material Blister’, which has a base film and lidding film, both made from PET (Bayer 2024; Business Wire 2024). This blister has been certified as fully recyclable by the Tray Circularity Evaluation Programme, spearheaded by PETcore Europe, and has been shown to reduce the carbon footprint of the blister pack by 38% (Packaging Europe 2024). This type of packaging is the first of its kind and its recognition as a recyclable blister is hugely promising for the implementation of similar blister packaging innovations in the pharmaceutical industry as it reduces the need for material separation at the disposal stage of the blister life cycle.



Figure 6: 'One-Material Blister' with PET forming and lidding material for Aleve tablet by Bayer and Liveo Research (Business Wire 2024).

Although alternative materials such as PET, PP, and bio-based polymers are frequently discussed, the literature does not fully assess their performance under pharmaceutical packaging requirements—such as moisture resistance, seal integrity, and machinability. Case studies are scarce, and most assessments do not include feedback from manufacturers who have trialed these materials. Additionally, the organisational and behavioural factors that influence material selection, such as cost sensitivity, regulatory conservatism, or supply chain dependency, are often ignored. Indeed, a study case among manufacturers in Malaysia found that manufacturers believe

that sustainable product design and development does not have a positive impact on cost performance or social performance (Abdul-Rashid *et al.* 2017). This points to a gap in understanding not just the materials themselves, but the decision-making dynamics that affect their adoption.

For the pharmaceutical industry, there are great benefits to be seen from adopting the current innovations mentioned previously as by reducing the volume of waste produced and facilitating recyclability of current blister material, the volume of blister waste going to incineration and landfill is greatly reduced. However, the recyclability of current materials is not an option that will be easily implemented due to the volume of blister waste currently generated and the time it would take to separate all this material. As such, future progress will depend on options for fully recyclable components to avoid the necessity to separate blisters for recycling, such as the kpNext™ R1 and the One-Material Blister, in order to move towards a more carbon neutral state within the pharmaceutical industry (Klockner Pentaplast 2021; Bayer 2024).

2.5 LITERATURE REVIEW CONCLUSION

This chapter has explored the key themes surrounding sustainability in pharmaceutical blister packaging, including its materials, waste management practices, regulatory influences, and emerging technological solutions. Due to the amount of blister waste generated, there is a requirement within the pharmaceutical industry for increased sustainability options to offset the environmental impact as well as the cost of waste disposal for pharmaceutical companies. However, there are multiple factors which make implementation of sustainable practices unappealing, including cost, time and regulatory factors. While the literature offers a strong foundation in material innovation and environmental theory, it remains largely disconnected from the operational realities of pharmaceutical manufacturing. Many proposed solutions, such as green recycling techniques or alternative blister materials, are still in the experimental phase and have not been critically evaluated for scalability, GMP compatibility, or cost-effectiveness.

In addition to this, regulatory frameworks are often discussed as long-term targets, but little is known about how they are interpreted at site level or how companies navigate the trade-off between compliance, performance, and sustainability. The literature tends to treat sustainability as a technical problem to be solved through material substitution, overlooking the behavioural, logistical, and organisational barriers that hinder progress. There is a notable absence of studies that capture perspectives from packaging SMEs, site-level decision makers, or global operations teams tasked with implementing change.

Furthermore, the accessibility of truly sustainable blister disposal methods is a huge limitation as eco-friendly blister separation is not currently an available option on a large scale for blister

recycling, despite previous efforts. This highlights the need for sustainable packaging components for blister manufacturers. Current innovations have shown a strong potential for increasing the feasibility of blister recycling, by reducing the negative environmental impact currently associated with blister separation or by negating the requirement for blister separation at all. As such, more resources should be directed by pharmaceutical packaging businesses towards increasing the number of options that blister manufacturers can avail of which allow for sustainable manufacturing of blisters. These solutions must be cost-effective, yet reliable, in order for the widespread adoption of these components to take place and for the positive impact to be seen on the environment as a result.

2.6 GAP ANALYSIS

The gaps identified across these domains highlight the need for a study that moves beyond lab-scale experimentation and captures real-world operational insight. This research responds to that need by examining blister packaging sustainability through the lens of blister packaging industry experts, with Table 1 detailing how the present study addresses these gaps. By gathering data across multiple global pharmaceutical sites, it aims to quantify blister waste, assess disposal practices, evaluate the adoption of sustainable packaging alternatives, and explore both the barriers and enablers of change. In doing so, it bridges the divide between academic proposals and industrial practice, providing practical knowledge to support sustainability transitions in pharmaceutical packaging.

| Literature Gap Identified | Research Element Addressing Gap |
|--|--|
| Lack of site-level blister waste data | This study collects site-specific waste data through a survey of global blister production sites. |
| Limited research on disposal practices in operational settings | The survey includes questions on regional disposal methods to highlight current practices at site level. |
| Disconnect between material innovation and GMP-compliant implementation | By gathering input from professionals working in GMP-compliant environments, this study explores real-world implementation challenges. |
| Minimal insight into regulatory and market influences on packaging decisions | The research investigates how regulatory pressures and customer demands shape material choices. |
| Underrepresentation of industry voices and SME perspectives | Subject matter experts (SMEs) from various functions are surveyed to capture their experiences and views. |

| Literature Gap Identified | Research Element Addressing Gap |
|---|--|
| Lack of analysis on barriers to adoption of sustainable materials | The survey includes both closed and open-ended questions to examine perceived barriers to sustainability adoption. |
| Few studies provide actionable industry-specific recommendations | The study aims to generate practical recommendations informed by both quantitative data and SME insights. |

Table 1: Summary of literature gaps and how the present study addresses these gaps.

2.7 CONCEPTUAL FRAMEWORK

Building on the literature reviewed, this study adopts a conceptual framework that connects the key themes explored, including material complexity, disposal methods, regulatory influence, sustainability initiatives, and data transparency, to the central research question regarding how sustainability in blister packaging can be improved across global pharmaceutical manufacturing sites.

The literature clearly identifies multi-material blister formats as a core sustainability challenge due to their incompatibility with most recycling infrastructures. This issue is compounded by inconsistent disposal practices, which are shaped not only by local waste capabilities but also by the high proportion of blister manufacturers which remain using the historically high performing PVC/aluminium blister format. Despite growing regulatory pressure to adopt more environmentally friendly packaging, the adoption of sustainable alternatives remains limited. Furthermore, the review highlights a recurring theme of poor data visibility at a manufacturing site level – most of the literature reviewed is at a laboratory scale level, which makes it difficult for manufacturing sites to make informed decisions on sustainability for their future based on similar scale operations as the data is not readily available.

This framework integrates five interrelated concepts, which are as follows:

1. Material composition and design complexity
2. Waste disposal practices and infrastructure
3. Sustainability initiative implementation and gaps
4. Regulatory and market pressures
5. Waste data visibility and operational decision-making

These elements reflect both technical and organisational barriers to sustainability which are all interlinked, as shown in Fig.7 below, and collectively shape how sustainability is adopted (or avoided) within blister packaging operations. For example, regulatory pressures may encourage the adoption of recyclable materials, but if these alternatives fail to meet performance

expectations or lack validation, implementation stalls. Similarly, without robust waste data, even willing sites may struggle to identify improvement opportunities or benchmark success.

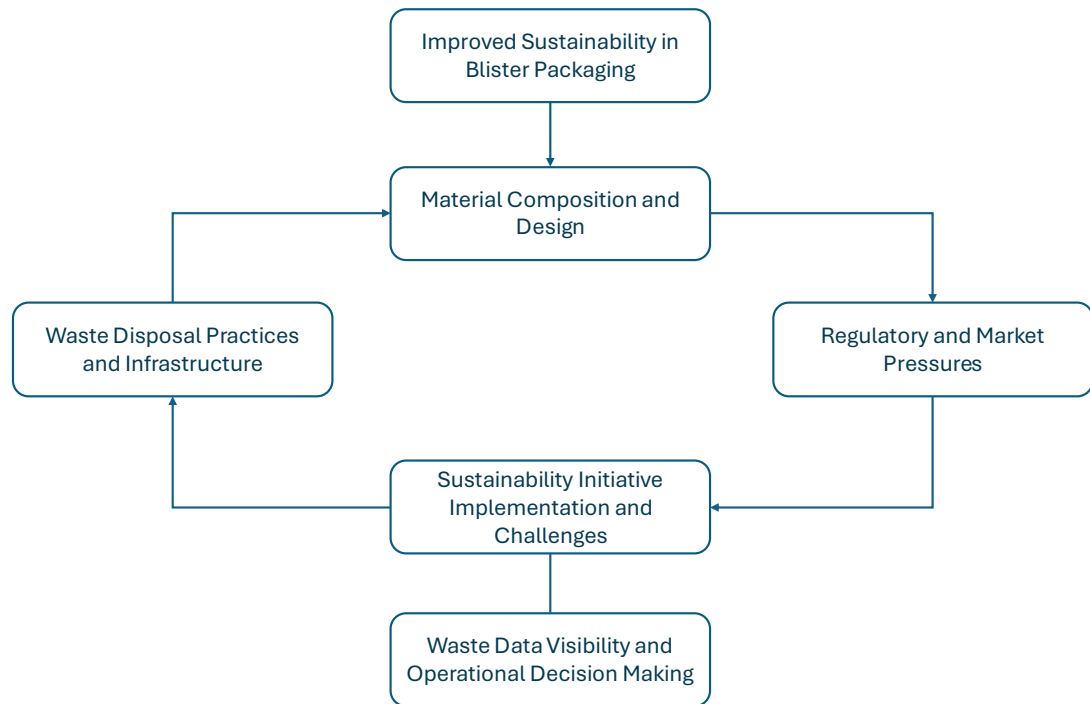


Figure 7: Flow diagram showing the interconnected concepts underlying this study.

The framework also supports theory development by highlighting where current academic research has not extended to with current literature. While sustainability literature often assumes that material innovation will naturally lead to adoption, this study investigates a more complex reality where performance risk, regulatory ambiguity, and data gaps have the potential to hinder real-world progress. In this way, the framework not only guides data collection and analysis but also enables reflection on how sustainability in blister packaging can be advanced through operational, regulatory, and material innovations.

3 RESEARCH METHODOLOGY

3.1 INTRODUCTION

In order to learn more about the topic of interest for this research project, it was proposed to use primary data gathering to collect information from subject matter experts in the pharmaceutical packaging industry, structured using Saunders’ Research Onion. This data gathering method enabled deeper understanding into the volume and components involved in blister waste produced, and what is preventing more sustainable packaging solutions from being brought into common practice.

3.2 SAUNDERS’ RESEARCH ONION

Saunders’ research onion was used in this dissertation to fully examine the different aspects of the research methodology of this study. This tool, coined by Saunders *et al.* (2023), allows each individual aspect of research methodology to be examined before moving onto the next step. These components are as follows: philosophy, approach to theory development, methodological choice, strategy, time horizon and procedures and techniques (Saunders *et al.* 2023). The following sections will detail each layer of the research onion and how each aspect of the research methodology was selected using this tool.

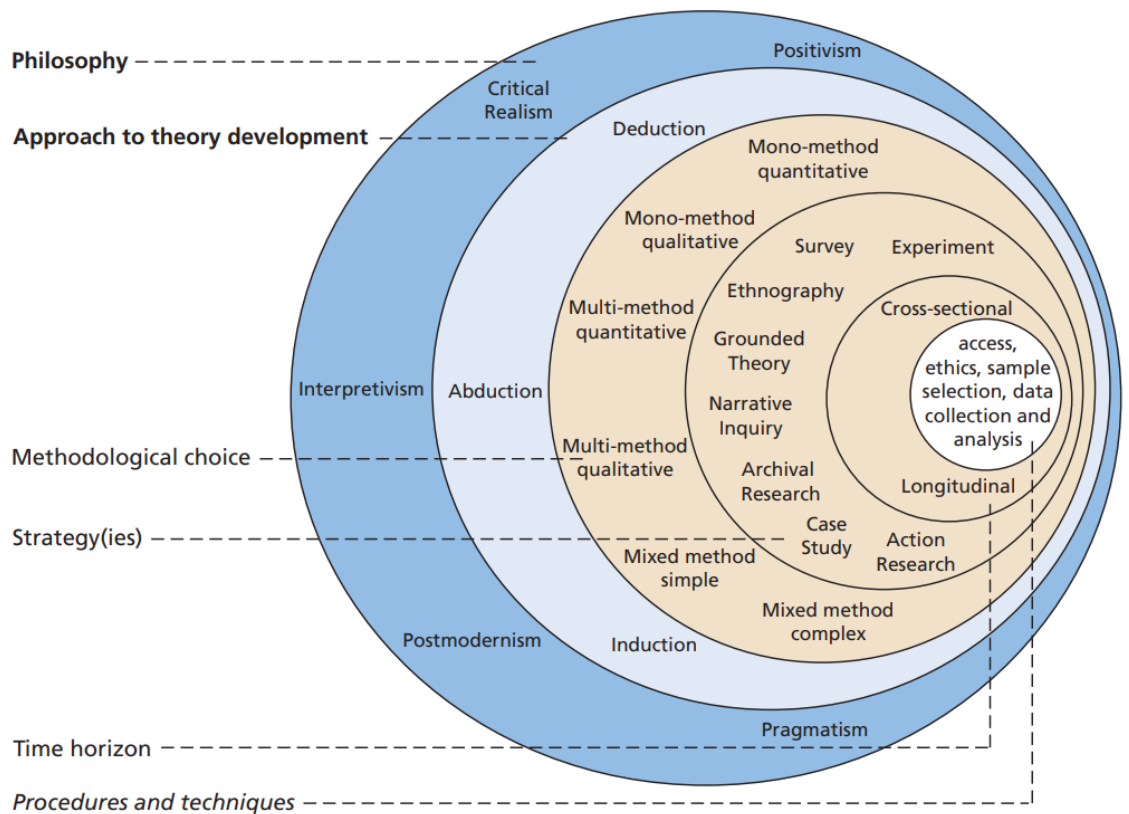


Figure 8: Saunders' Research Onion (Saunders *et al.* 2023).

3.2.1 Research Philosophy

The research philosophy refers to the set of beliefs upon which the research is founded. As per Saunders' Research Onion, the main research philosophies are pragmatism, postmodernism, interpretivism, critical realism and positivism (Saunders *et al.* 2023). Of these, the most applicable research philosophy to the present study was deemed to be pragmatism. Pragmatism was selected as the research philosophy to be used in this study as it has a focus on providing solutions to real-world problems. It does this by focusing on the research question and using the problem presented in this question to conduct research that aims to offer recommendations that allow steps to be made towards overcoming the relevant issue (Creswell and Creswell 2018). Differing to other research philosophies such as positivism, which believes there is one single reality, pragmatism believes that multiple perspectives can all be valid and allows for different opinions to be taken into account to inform the final recommendations of the research (Kaushik and Walsh 2019).

Pragmatism was applicable to this study as this research presents a clear problem that it seeks to provide future recommendations towards alleviating – what is preventing sustainable blister manufacturing and how can the blister packaging industry move towards a more sustainable production process? Pragmatism allows further insight into the perspectives and experiences of packaging subject matter experts at blister production sites and the analysis of differing viewpoints. The opinions provided by the participants were likely to vary due to different operational requirements, local regulatory restrictions and products being manufactured at these various global sites, and pragmatism is suited to this as it does not force the research towards arriving at one true conclusion, but instead acknowledges that different perspectives can be used towards ensuring that the most suitable solution is derived (Saunders *et al.* 2023).

Furthermore, the main goal of pragmatism is to ensure that there is a real-world application of the findings of the research that is being carried out (Kaushik and Walsh 2019). This aligned with the primary aims of this research which are to provide actionable recommendations to pharmaceutical blister manufacturing sites and blister component manufacturers for how to move towards reducing waste within the industry. For these reasons, pragmatism was chosen as the most suitable research philosophy to be used for this study.

3.2.2 Theory Development

The next layer of the research onion is theory development, which has three primary approaches: deduction, induction and abduction. The first two theories, deduction and induction, have always been recognised as the main types of reasoning when conducting research (Okoli 2022). Deduction is used in research that starts with a hypothesis to be tested to allow a conclusion which either confirms the theory or proves it to be incorrect. Induction involves the development of a theory based on the data which is gathered and observations made as part of the research carried

out (McAuliffe 2015). The third type of reasoning, abduction, was identified and developed by Charles S. Peirce in 1903 (Peirce 1903). Abduction differs from deduction and induction as, rather than using a hypothesis to work towards collecting data or collecting data in order to work towards a hypothesis, it uses the context of the situation, pre-existing data and information gathered throughout the course of the research to understand the issue at hand. The nature of this approach is that it begins with the observation of a situation and tries to use all the tools at hand to understand why this situation has occurred (Saunders *et al.* 2023).

In the case of this research project, abduction was the most appropriate type of reasoning to use as it functions to work towards an understanding of what is preventing sustainability in the pharmaceutical blister packaging industry from being fully adopted with a view to providing recommendations. Abduction allowed for the current understanding of barriers sustainability in blister packaging to be taken into account, while also utilising the viewpoints of SMEs in the blister packaging industry to further inform the research. Further to this, Peirce, the founder of pragmatism, has stated that abduction lays the foundation for a pragmatic research philosophy: ‘If you carefully consider the question of pragmatism you will see that it is nothing else than the question of the logic of abduction’ (Peirce 1931; Aliseda 2005). For these reasons, abduction was deemed the most applicable theory development approach for this study.

3.2.3 Methodological Choice

As per Saunders’ Research Onion, the options for methodological choice are mono-method quantitative, mono-method qualitative, multi-method quantitative, mixed-method simple and mixed-method complex (Saunders *et al.* 2023). This research chose to utilise mixed-method simple, as this study gathers both quantitative and qualitative data through the completion of a survey with both closed- and open-ended questions (Kajamaa *et al.* 2020). This mixed-method research is considered to be parallel data collection and analysis as the quantitative and qualitative data is gathered at the same time in the survey (Saunders *et al.* 2006). The selection of mixed-method research also aligned with the decision to use pragmatism as the research philosophy as there is a consensus within academia that shows that pragmatism is extremely well-suited to the requirements of mixed methods research, as pragmatism places an emphasis on using whatever the most appropriate methodological choice is to answer the research question, including mixed-methods (Kaushik and Walsh 2019).

There was a requirement for both quantitative and qualitative data to be collected as the closed-ended questions (quantitative data) in the survey allows for statistical analysis of the responses and permits the direct comparison of the responses to assess trends across participants’ responses. This ensured that objective, measurable data is obtained, for example understanding the quantity of sites affected by specific challenges such as regulatory constraints or cost of materials. Open-

ended questions (qualitative data) throughout the survey allowed for a further understanding into the context of the answers from the experts' perspective. These allowed for more detail to be provided into the perceptions and concerns that underpin the answers to the closed-end questions. Obtaining this data is crucial to understanding the barriers to blister sustainability at manufacturing sites. As such, the mixed method approach was most suitable for this research as the quantitative data allowed for numerical analysis of waste and blister sustainability, and the qualitative data ensured an understanding of how well or poorly blister production sites have adopted these options and the factors preventing blister packaging from moving to an entirely sustainable state.

3.2.4 Data Collection Methods

The decision to use a survey as the strategy (the next layer of the research onion) for this study was taken as it is a useful research strategy when there is a requirement to contact a large group of people in a short amount of time, where interviewing them individually would be too time consuming. Furthermore, the survey is an ideal strategy to use where the individuals are widely dispersed and cannot be brought together due to geographical and time zone constraints (Kuphanga 2024).

As such, the strategy for this research was to use an online Microsoft Forms survey, due to internal compatibility with existing company software and for data security purposes. This survey was distributed to packaging experts at each of the 17 blister producing sites in the global network of the pharmaceutical company being assessed. This questionnaire had a total of 24 questions, assessing different themes which collectively cover the research objectives set out for this study which are further detailed in section 3.2.5.2.

3.2.5 Time Horizon

The time horizon for this study was deemed to be cross-sectional, as it is a short-term study collecting data at a fixed time point with a clearly defined timeframe for collection of data from survey participants (Melnikovas 2018).

3.2.6 Research Design

The final layer of Saunders' research onion is procedures and techniques, which encompasses using primary data, selection of sample groups, participant profile & recruitment, developing & testing survey content and data collection & analysis.

3.2.6.1 Participant Profile and Recruitment

The participants for this study were industry professionals with expertise in blister packaging operations within the selected pharmaceutical company. They represented a cross-section of roles

critical to the production, management, and innovation of blister packaging. These individuals had the following characteristics in common:

- Direct involvement in packaging design, production & waste management processes.
- Knowledge of regulatory, operational and technical aspects of blister packaging.
- Experience in driving innovation, managing product lifecycles and implementing sustainability initiatives.
- Understanding of sustainability barriers and ability to generate recommendations for improvement based on their experience.

These participants were selected as collectively they represented a range of functional roles within blister packaging in the pharmaceutical industry, including packaging design, procurement, quality control, and sustainability initiatives. This ensured diverse perspectives on the challenges and opportunities in blister packaging and facilitated input from all relevant subject matter experts on the survey to be sent out. Furthermore, their roles aligned directly with the study's aims of understanding waste generation, barriers to sustainability, and identifying actionable improvements. The distribution of participants by role was as follows:

- Packaging Technologists: 8
- Packaging Engineers: 7
- Packaging Managers: 5
- Technical Leads: 3
- Product and Technology Managers: 2
- Quality Lead: 1
- Value Engineering Specialist: 1
- Procurement Manager: 1
- PLM (Product Lifecycle Management) Lead: 1
- R&D Packaging Senior Scientist: 1

This broad representation allowed the study to reflect both day-to-day manufacturing considerations and higher-level strategic and technical decision-making processes, providing a well-rounded perspective on the barriers and opportunities for sustainable blister packaging across global sites. The global distribution of these participants was as follows:

- Asia-Pacific: 6 sites (China (Suzhou), China (Tianjin), Indonesia, Malaysia, Sri Lanka, Taiwan), 8 participants total.
- Europe: 3 sites (Ireland, Italy, Spain), 8 participants total.
- Latin America: 3 sites (Argentina, Brazil, Panama), 6 participants total.

- Middle East/Africa: 3 sites (Cape Town, Kenya, Pakistan), 6 participants total.
- North America: 2 sites (Canada, USA), 2 participants total.

The participants were recruited through multiple avenues. Firstly, the global packaging manager was contacted with a request for one blister packaging SME for each blister production site in the global network. Each individual on this list was contacted with some background information on the study in the form of a Participant Information Leaflet (PIL) as seen in Appendix 1. The contacts were also asked for permission to send the survey link to them and if they had any further contacts at their site that would have blister packaging knowledge and would be willing to participate. These further SMEs were subsequently contacted and asked if they would complete the survey also. In addition to this, a post was put on the ‘Global Packaging Team’ and ‘Sustainability Packaging Data’ Teams sites for the company to ask for experts at blister packaging sites to participate in the survey. After a week, a follow up Teams message was sent to all participants who had not yet completed the survey to increase response rates as much as possible.

3.2.6.2 *Sample Size*

In order to ensure that the margin of error in the data obtained from this research is as low as possible, the sample size must be calculated to ensure that the sample is representative of the population. One formula that can be used to calculate the sample size is Cochran’s formula, which is as follows:

$$n_0 = \frac{Z^2 \cdot p \cdot q}{e^2}$$

Where n = sample size, Z = Z score (1.96 for a 95% confidence interval), p = the estimated proportion of the population (here assumed to be 0.5), q = 1-p and e = margin of error (0.05 for 5% which is being used here) (Nanjundeswaraswamy and Divakara 2021).

The overall population for this study was estimated to be 34, with an average of 2 packaging SMEs at each of the 17 blister manufacturing sites. As such, the sample size must be adjusted due to the small population size. For this, the following formula is used to adjust n₀, where N = population size (Nanjundeswaraswamy and Divakara 2021):

$$n = \frac{n_0}{\left[1 + \left\{\frac{n_0 - 1}{N}\right\}\right]}$$

Using these formulas together, it was found that a minimum of 31 survey responses is required to achieve a 95% confidence interval with a 5% margin of error. For this study, 30 participants were successfully recruited. This was a small deficit in participants, being one participant short of the minimum required for a 95% confidence interval, however the study still includes a diverse range

of global perspectives across a diverse group of SMEs, with the conclusions drawn from this study remaining meaningful.

3.2.6.3 Survey Development and Testing

This survey was designed to ensure alignment with the research objectives and collected the relevant data to answer the research question ‘What are the key challenges and opportunities for improving sustainability in blister packaging production within the pharmaceutical industry, and how can waste reduction and environmentally friendly practices be effectively implemented while ensuring quality and compliance is maintained?’.

This survey was developed to directly address the key gaps identified in the literature review, including the lack of site-level data on blister waste generation, limited understanding of practical barriers to sustainable packaging adoption, and minimal insight into how regulatory and market pressures influence decision-making. Each question was designed to ensure relevance to real-world operations across global pharmaceutical sites, obtaining both quantitative and qualitative insights from industry experts. This alignment with literature gaps supports the survey’s validity and ensures the data collected provides meaningful contributions to the literature on blister packaging sustainability in industry.

There were 24 questions in total in the survey (detailed fully in Appendix 1), covered in 7 sections which are as follows:

- Section 1 - Research Aim and Participant Consent: This section outlines the overall aims of the study and has a tick box section for participants to consent to their responses being used in the present dissertation.
- Section 2 - General Information: This section aims to gather information on the survey respondents to understand their packaging background and experience as well as to verify the site’s location and size.
- Section 3 - Blister Packaging Components: This section contains questions on the materials used at their packaging site in addition to waste quantity and disposal techniques.
- Section 4 - Barriers to Sustainable Blister Packaging: This section investigates the obstacles preventing the widespread adoption of sustainable blister packaging solutions.
- Section 5 - Regulatory and Market Constraints: This section explores the influence of regulatory requirements and market demands on packaging sustainability.
- Section 6 - Sustainability Initiatives and Future Outlook: This section looks to understand what attempts have been made to implement sustainable initiatives at blister packaging sites.

- Section 7 - Open Ended Questions: This final section allows further expansion on any deeper insights on sustainability in pharmaceutical blister packaging manufacturing.

This survey was developed on Microsoft Forms, as this aligns with the company's pre-existing use of Microsoft software. A pilot test was conducted with a colleague within the company to ensure that the survey was functioning and to review the survey for any potential errors. This pilot test resulted in the correction of spelling mistakes and removal of a duplicate question, as well as showing that the survey is functional and results accessible by the data collector.

Subsequently to this, the survey was distributed on Microsoft Forms through sending an email invite to complete the link to all participants who had agreed to take part.

3.2.6.4 Data Collection and Analysis

Data was collected in the form of survey responses through Microsoft Forms and exported after the data collection deadline to a Microsoft Excel spreadsheet. Microsoft Excel was used to complete statistical analyses such as mean/standard deviation, pivot tables, Cochran's Q, Kendall's W, and Chi-Square test. These tests were used to provide an indication of the spread of data and agreement among participants on the answers provided. This data was then presented using visual media created in Microsoft Excel such as pie charts and bar charts to support the interpretation and discussion of the data obtained. Thematic word analysis of the open questions was also conducted by creating a word cloud using FreeWordCloudGenerator.com to visualise this data (FreeWordCloudGenerator.com 2025).

For survey questions addressing respondents' experiences or opinions, all 30 survey responses were included in the statistical analysis. For site-specific questions, a single response was randomly selected from each site at the outset of the analysis to ensure consistency across all such questions. This resulted in a total of 17 responses, representing each site, being used for all site-specific analyses.

All data collected from this research was digital data in the form of survey responses and data analysis files. This digital data was stored on a password protected device with cloud backup present on company-provided OneDrive, which is also password protected. All data related to this research was retained throughout the duration of the research and will continue to be retained for two years after in the event of any academic review requiring the research data. After this time, the data will be erased from the device and all cloud backups deleted.

To manage data protection issues, all GDPR regulations were adhered to in all data collection. This includes the obtaining of informed consent from all participants (informed consent was obtained as a tick box question within the survey after a paragraph summarising and explaining the purpose of the survey) as well as the full anonymisation of all survey responses. The

anonymisation of all survey responses included the omission of participant names, company name and specific location of relevant sites. Furthermore, the data was only accessible to the researcher as it is stored on the secure company OneDrive, with raw data being shared with the supervisor only.

3.3 ETHICAL CONSIDERATIONS

One of the possible ethical implications facing the conduction of this research included the issue of data privacy and confidentiality of information collected in the survey. This is because the data being collected from employees at multiple global sites was of a sensitive nature and care had to be taken to ensure that this information cannot be traced to the respective site or indeed the company which is being studied for this research. To address this issue, all participants were informed that their survey responses will only be used for the purpose of this research and that all data will be anonymised to ensure the employee and site cannot be identified. All participants were required to check off a tick box question at the start of the survey providing consent and verifying they understand the purpose of the research. Further to this, the company remained unnamed so that the information collected cannot be attributed to same.

3.4 RELIABILITY AND VALIDITY OF PARTICIPANT RESPONSES

This study was designed to ensure the reliability of the data as much as possible by designing clear, structured survey questions that aligned closely with the study's objectives. The use of closed and ranking questions reduced ambiguity and encouraged consistent interpretation across respondents. However, as the data collection relies on self-reported responses, it is important to acknowledge that variability in individual understanding of a given topic, role-specific knowledge, and site-specific ways of working may introduce a degree of inconsistency in the responses obtained. That being said, the inclusion of a wide range of participants from a variety of roles and regions served to balance these differences and improve the overall consistency of the dataset.

Further to this, the validity of the responses was supported through the strategic sampling of subject matter experts directly involved in blister packaging activities, including technical, quality, procurement, and sustainability functions. This ensured that responses were based on professional experience and operational relevance to provide meaningful results. Nonetheless, the potential for bias is still present, as participants may have stated information based on their own perception of industry operations or due to a lack of holistic visibility of their site's ways of working. As such, open-ended questions were included to capture individual perspectives and support the trends seen from the closed questions in the survey, thereby adding to the validity of the findings from this study as a whole.

4 FINDINGS AND ANALYSIS

The primary research aimed to investigate five key objectives related to sustainability in pharmaceutical blister packaging. These were as follows:

- To quantify the current volume of blister packaging waste generated by all blister production sites in one global pharmaceutical company.
- To assess how waste is disposed across these sites to examine the environmental impact of pharmaceutical blister waste at these sites.
- To assess current sustainability practices used in the blister production sites, including recycling, waste reduction initiatives, and disposal practices.
- To investigate challenges faced by these sites in adopting sustainable blister packaging materials and technologies.
- To develop compliant recommendations for improving sustainability in blister packaging.

The findings presented in this chapter are structured around these objectives and draw on both quantitative trends and qualitative insights collected from subject matter experts across a global network of pharmaceutical sites.

4.1 SURVEY RESPONDENT AND SITE PROFILES

In the first section of the survey, data was gathered about the background of each of the participants and the site at which they worked. This included information about their job titles and years of experience in their roles, in addition to information about the blister manufacturing sites in scope for this survey. This data was gathered to verify and validate the suitability of all survey respondents.

The results showed that the majority of the survey participants worked as packaging technologists or packaging engineers, with some packaging managers, technical leads and product & technology managers, among other titles shown in Fig. 9. Furthermore, it was seen that there was a wide range of experience in pharmaceutical packaging among the participants as seen in Fig. 10, with eight participants having over 16 years of experience.

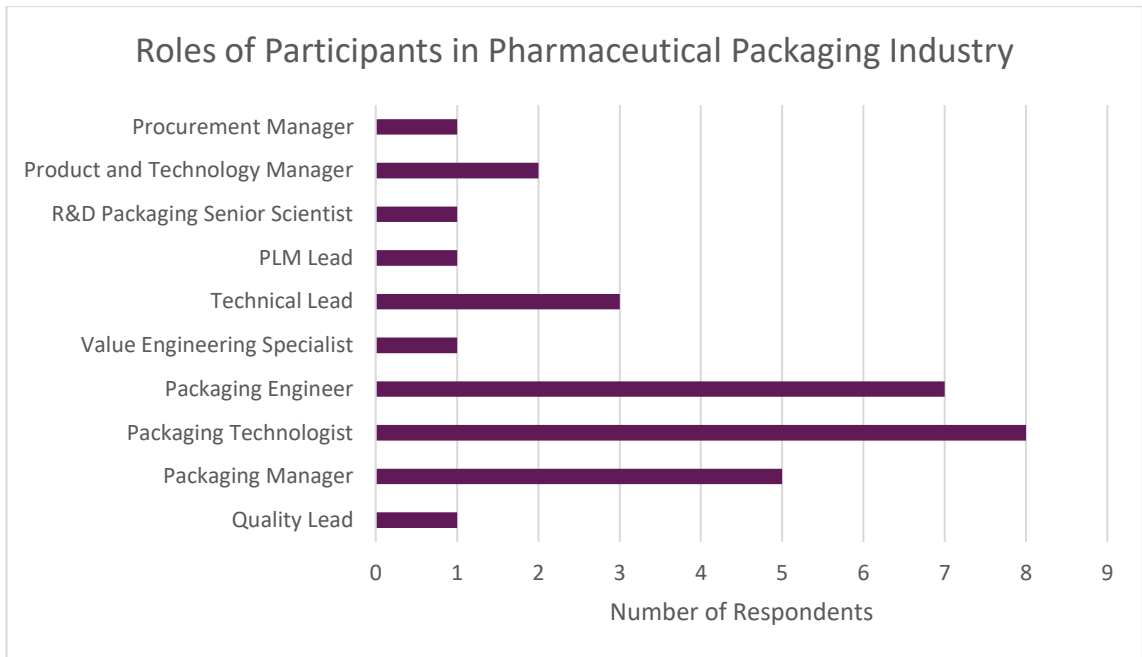


Figure 9: Clustered bar chart showing job titles of survey participants.

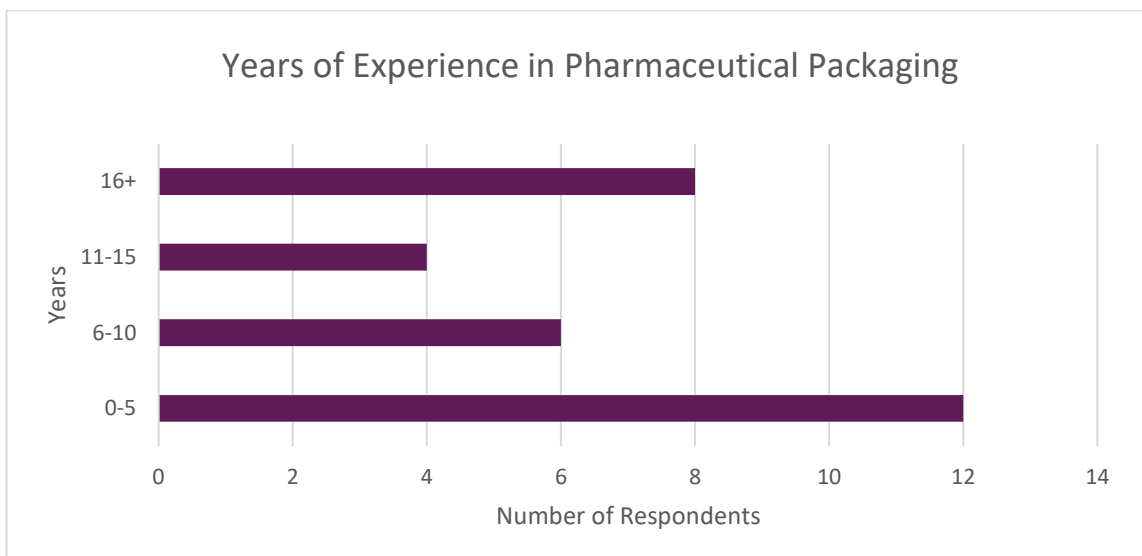


Figure 10: Clustered bar chart indicating participants' years of experience in pharmaceutical packaging.

With regard to the 17 blister packaging sites being surveyed, the vast majority of sites packed pain relief products, with 15 out of 17 sites primarily packing pain relief products in blisters, one site packing digestive health products and one further site packing respiratory products (Fig. 11). The location of these sites varies widely with a relatively even spread, as seen in Fig. 12, with sites in Asia, Africa, Europe, the Middle East and the Americas. Furthermore, the sites ranged from medium to large, with most sites having 101-500 employees, which is visually represented in Fig. 13 below. No sites which partook in the survey were considered to be small (under 100 employees).

Primary Product Type Packed in Blisters on Site

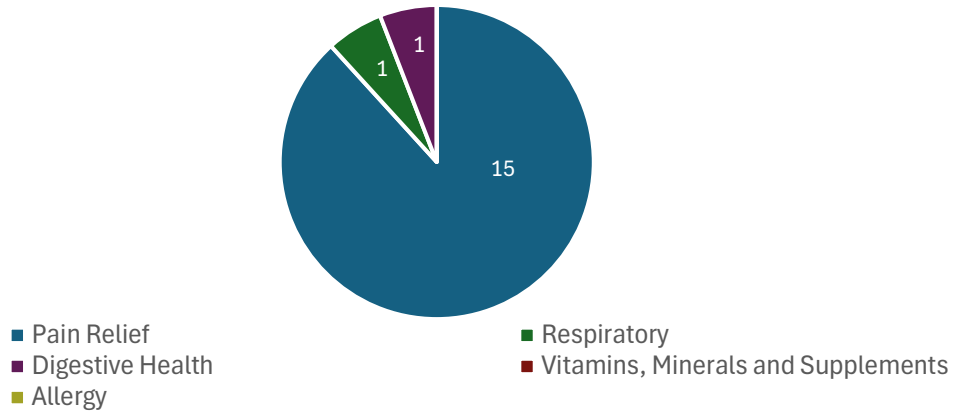


Figure 11: Pie chart showing primary product type packaged in blisters at each site.

Site Location

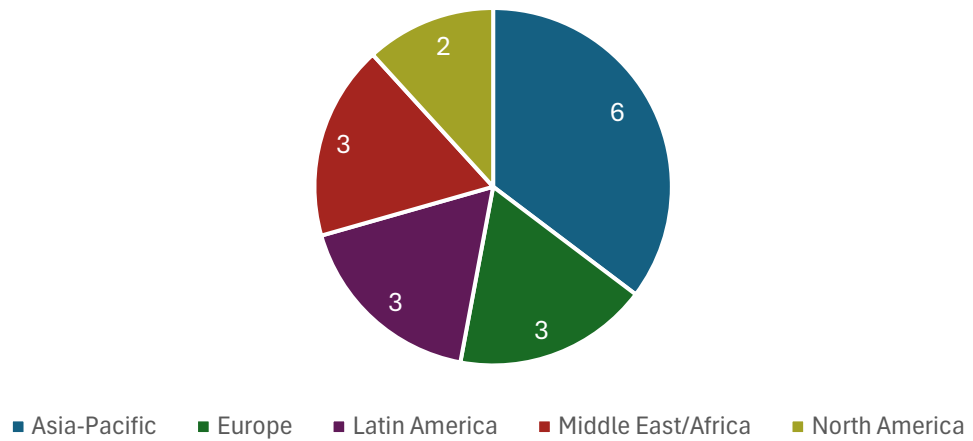


Figure 12: Pie chart showing global locations of sites which had participated in the survey.

Employees at Site

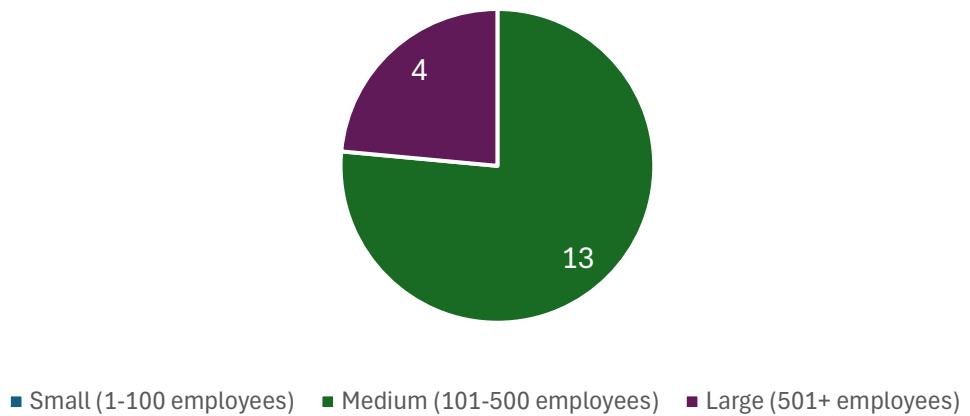


Figure 13: Pie chart showing employee numbers at all sites included in this study.

4.2 BLISTER PACKAGING MATERIALS AND WASTE DISPOSAL

4.2.1 Blister Packaging Materials Used by Site

The most commonly used blister packaging materials at each site were assessed, with results showing that of the 17 sites, all of them used PVC in blister packaging and 15 used aluminium. These results align with the materials used in traditional blister packaging methods, with PVC used as forming material and aluminium foil functioning as a lidding material (Pilchik 2000a).

Further to this, PVDC was used in the majority of sites, with 14 sites reporting the use of PVDC in their blister packaging process. PVDC is a synthetic polymer that can be used as a layer in multilayered forming films or as a coating for PVC films. This functions to increase the barrier properties of the forming film, while also providing thermal stability as its properties remain consistent in different temperature conditions (CloudFilm 2024). As such, PVDC is likely used in conjunction with the PVC to form a robust forming material at the sites at which it is used.

The other materials used by a minority of sites include PET (used in Asia-Pacific and Europe sites), HDPE (used in Latin American site only) and PCTFE (used in North American site only), which are used either as an additional layer with PVC to enhance the forming layer's barrier properties or as a standalone forming layer (Packaging Europe 2022; Perlen Packaging 2025).

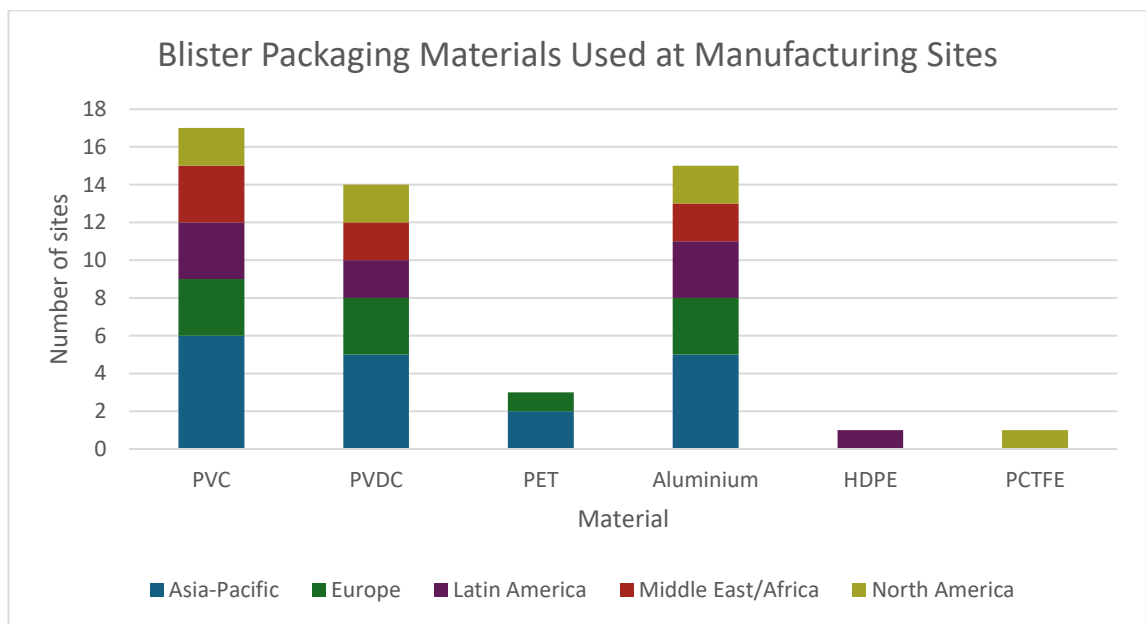


Figure 14: Bar chart showing materials used in blister packaging at all sites grouped by region.

4.2.2 Blister Waste Production

In terms of overall site waste production attributed to blisters, it was found that the majority of sites attributed 10% or less of their total site waste to blister packaging waste, with eight sites selecting this option (Fig. 15). Three sites found that 11-25% of their site's waste was due to blister packaging and two sites stated that over half of the site's waste was produced as a result

of blister packaging. Of the 17 sites, four did not know what percentage of their waste was attributable to blister packaging.

Regionally, a great deal of variation was seen across the Asia-Pacific sites in terms of percentage waste reported, while all the remaining sites stated that their waste was either in the 0-10% bracket or that they were unsure of their waste percentage. Of note, neither of the North American sites were able to provide a waste percentage range, with both sites stating “Unsure”.

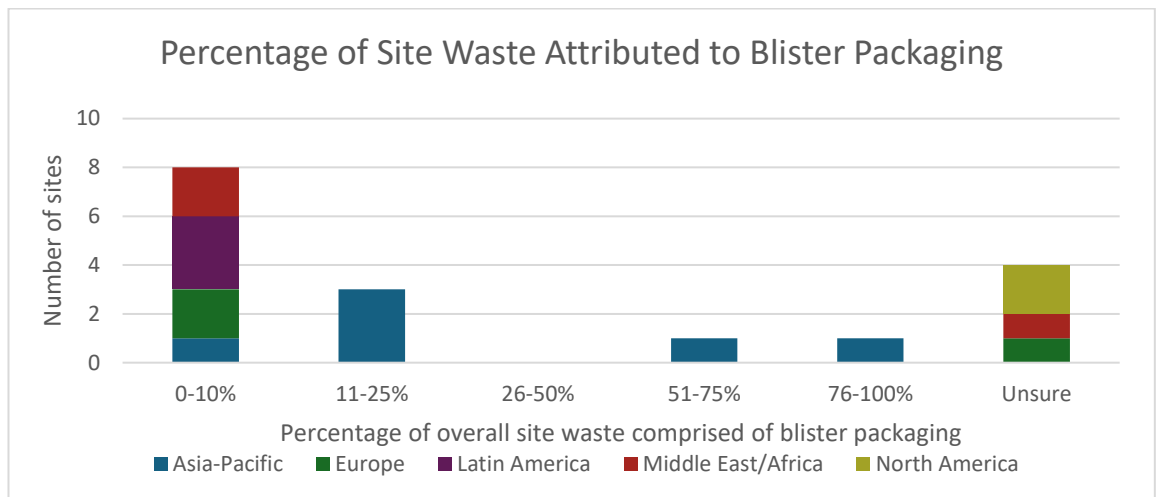


Figure 15: Bar chart showing blister packaging waste as a percentage of total sites' waste, grouped by region.

On an annual scale, the blister packaging waste produced for each site was found to be extremely variable, with a range of 90-148,000kg of blister waste being produced annually across 11 of the sites. This large variation can be attributed to a difference in blister volumes being produced across the sites – for example, the Irish site is the largest blister manufacturing site within the company and also had the largest volume of blister waste, reporting 148,000kg of blister waste annually.



Figure 16: Scatter chart showing the annual blister packaging waste by site.

The responses to this question revealed that six sites (35.3% of all blister manufacturing sites in the global network) did not have the data on blister waste readily available. This lack of data is concerning as it indicates an inability to accurately quantify the waste produced. Without precise data, these sites cannot fully understand the extent of their waste generation and its potential negative environmental impacts.

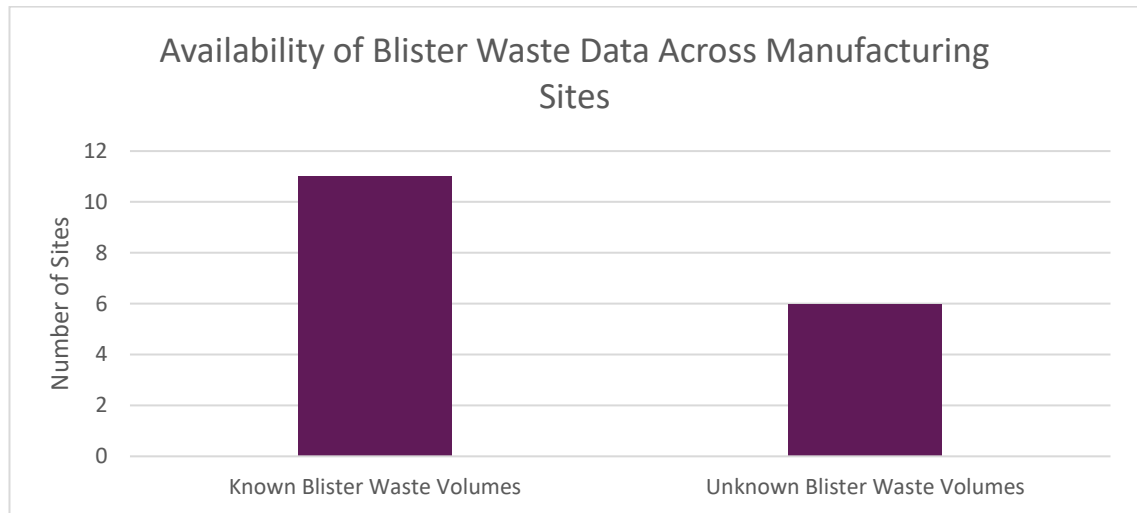


Figure 17: Proportion of sites with known vs unknown blister waste volumes.

4.2.3 Blister Waste Disposal Methods

After confirming the blister packaging waste quantities both annually and as a proportion of the sites' total waste, the blister waste disposal methods were investigated and results shown in Fig. 18. Cochran's Q non-parametric statistical test was carried out in Excel to evaluate whether the proportion of votes for each disposal method were significantly different from one another (Lewis-Beck *et al.* 2004; Aslam 2023). This statistical test indicated significant differences among the disposal methods, $Q(4)=15.3, p<0.01$. A post-hoc Dunn test found that significantly more sites used incineration (one site) than those who used waste disposal companies (two sites) and those who were unsure of their waste disposal method. Incineration emerged as the most common disposal method across all sites.

This preference for incineration suggests that many manufacturing sites may find it to be a more accessible or cost-effective solution for managing blister waste. However, the reliance on incineration also raises concerns about the environmental impact, as incineration can contribute to air pollution and greenhouse gas emissions. Furthermore, the presence of a site which was not sure of its waste disposal method highlights an overall need for awareness surrounding waste disposal as it is impossible to implement sustainable solutions when the blister lifecycle is not fully understood.

Regionally, a relatively even spread is seen, with many regions utilising multiple waste disposal methods. As seen in Fig. 18, sites in Latin America, Middle East/Africa and North America

dispose of blister waste using a combination of recycling, incineration and landfill. Asia-Pacific sites utilise these methods while also using waste disposal companies, along with European sites which use waste disposal companies along with incineration. Only one site (located in Europe) was unsure as to their waste disposal methods.

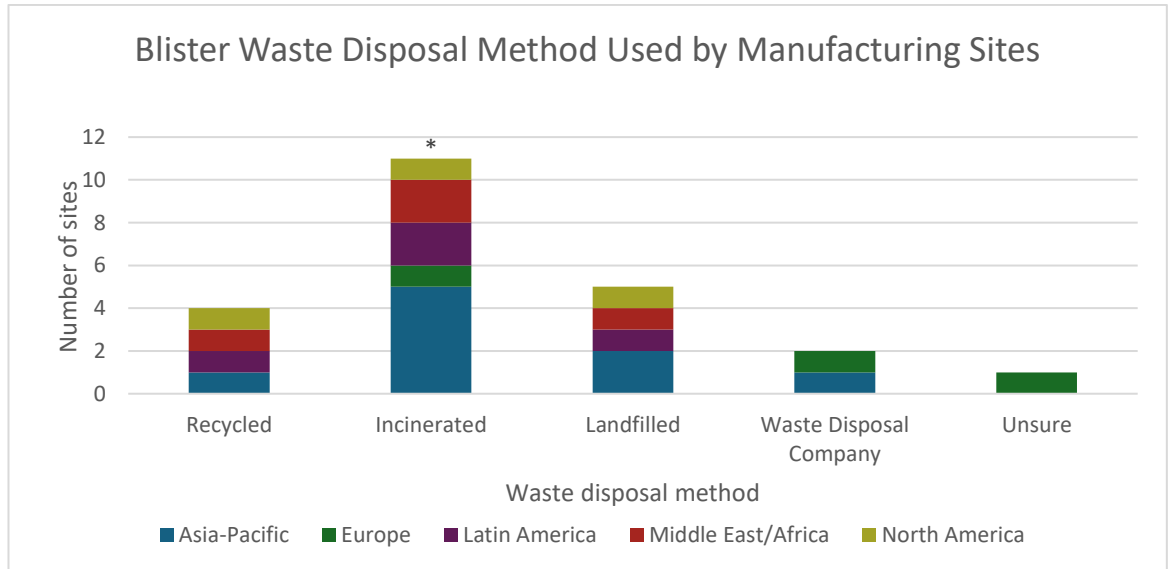


Figure 18: Blister waste disposal methods used across all sites, grouped by region, * $p < 0.01$.

4.3 BARRIERS TO SUSTAINABLE PACKAGING

4.3.1 Primary Factors Driving Blister Packaging Material Choice

The survey participants were asked to rank the primary factors impacting the use of current blister packaging materials by importance to assess which factors influence packaging material component selection. These factors were as follows: cost, regulatory compliance, market availability, packaging performance and sustainability concerns. Table 1 below shows the results, with a score of 1 indicating the least important factor and 5 corresponding to the most important factor. These results are also visually represented in Fig. 19.

The mean ranks reveal that packaging performance is the most important factor for the respondents, with a mean rank of 3.93, indicating that it is consistently ranked as the most important factor. Regulatory compliance follows as the second most important factor with a mean rank of 3.40. Cost and market availability are also prioritised, with mean ranks of 3.20 and 2.57, respectively, and sustainability is ranked at the lowest importance with a mean rank of 1.87.

A Kendall's W statistical test was carried out in Excel to measure the agreement across all rankings (Field 2005). The W value obtained from this score was 0.25, with 0 indicating no agreement and 1 indicating full agreement across all respondents, with a p-value of 0.00000384. The significant result ($p < 0.001$) suggests that there is a consensus among the respondents, albeit weak, regarding the ranking of the factors, despite the low W value. A Nemenyi post-hoc test was

carried out (with a critical difference of 1.113), which found that packaging performance is rated significantly higher than market availability (difference of 1.367) and sustainability (difference of 2.067) (Demsar 2006). Regulatory compliance is also rated significantly higher than sustainability (difference of 1.533), and cost is rated significantly higher than sustainability (difference of 1.333). These findings highlight the lower prioritisation of sustainability compared to other factors. This highlights that the respondents do share some common views on the importance of the factors, particularly the low ranking of sustainability.

The results shown in Table 1 and Fig. 19 below indicate that sustainability concerns are not a primary driver in the selection of blister packaging materials among the surveyed respondents. The significantly lower ranking of sustainability compared to packaging performance, regulatory compliance, and cost suggests that environmental considerations are often secondary to other factors such as product safety, regulatory adherence, and cost-effectiveness.

This finding is critical as it highlights a gap in the prioritisation of sustainable practices within the industry. Despite the growing awareness of environmental issues, sustainability is not yet a key factor in decision-making for blister packaging materials. This underscores the need for increased emphasis on sustainable packaging solutions and the development of industry standards that prioritise environmental impact alongside performance and compliance.

| Respondent ID | Packaging performance | Regulatory compliance | Cost | Market availability | Sustainability |
|---------------|-----------------------|-----------------------|------|---------------------|----------------|
| 1 | 5 | 2 | 3 | 4 | 1 |
| 2 | 2 | 5 | 4 | 3 | 1 |
| 3 | 4 | 2 | 5 | 3 | 1 |
| 4 | 4 | 5 | 3 | 1 | 2 |
| 5 | 3 | 1 | 2 | 4 | 5 |
| 6 | 3 | 5 | 2 | 4 | 1 |
| 7 | 4 | 5 | 3 | 2 | 1 |
| 8 | 4 | 2 | 5 | 3 | 1 |
| 9 | 2 | 5 | 3 | 4 | 1 |
| 10 | 2 | 1 | 4 | 5 | 3 |
| 11 | 4 | 3 | 5 | 2 | 1 |
| 12 | 4 | 5 | 2 | 1 | 3 |
| 13 | 4 | 2 | 5 | 3 | 1 |
| 14 | 5 | 3 | 4 | 2 | 1 |
| 15 | 3 | 1 | 4 | 2 | 5 |
| 16 | 5 | 2 | 1 | 3 | 4 |
| 17 | 5 | 4 | 3 | 2 | 1 |
| 18 | 5 | 4 | 2 | 1 | 3 |
| 19 | 5 | 4 | 3 | 1 | 2 |
| 20 | 5 | 1 | 4 | 3 | 2 |
| 21 | 5 | 3 | 4 | 2 | 1 |
| 22 | 2 | 4 | 5 | 3 | 1 |
| 23 | 4 | 5 | 2 | 3 | 1 |

| Respondent ID | Packaging performance | Regulatory compliance | Cost | Market availability | Sustainability |
|---------------|-----------------------|-----------------------|------|---------------------|----------------|
| 24 | 4 | 5 | 2 | 1 | 2 |
| 25 | 5 | 2 | 3 | 1 | 4 |
| 26 | 3 | 4 | 2 | 5 | 1 |
| 27 | 5 | 4 | 3 | 2 | 1 |
| 28 | 4 | 5 | 3 | 1 | 2 |
| 29 | 4 | 3 | 2 | 5 | 1 |
| 30 | 4 | 5 | 3 | 1 | 2 |

Table 2: Ranking of primary factors influencing blister packaging material selection, with corresponding colour grading (1 = least important, 5 = most important).

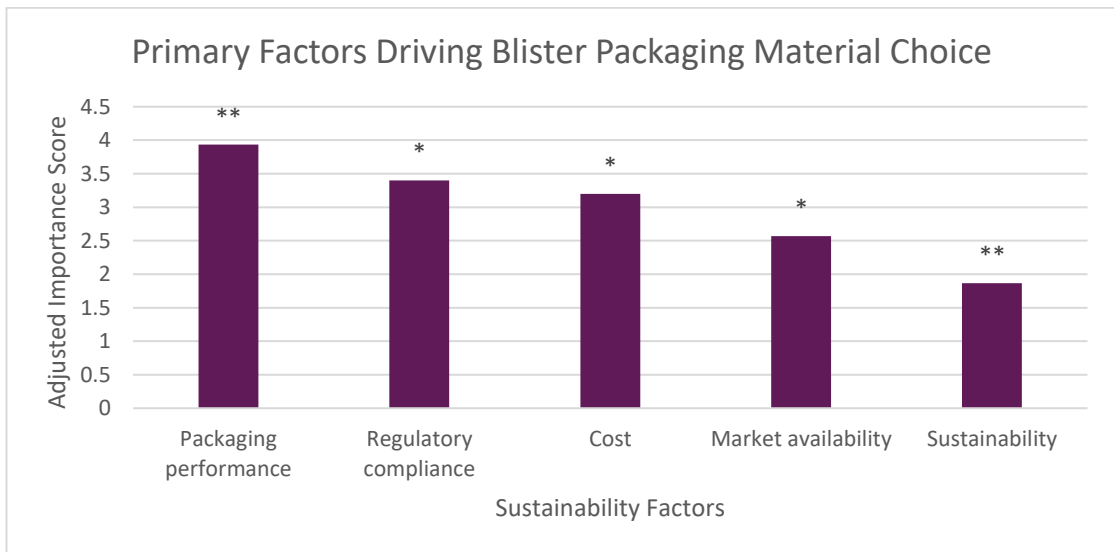


Figure 19: Bar chart showing mean importance score assigned to each primary factor where higher score indicates greater importance, * $p < 0.05$ from one other factor, ** $p < 0.05$ from multiple other factors (based on Nemenyi post hoc test).

4.3.2 Challenges to Sustainable Blister Material Adoption

The participants were asked to select what they believed were the biggest challenges to adopting sustainable blister packaging materials at their site from the following list: high cost of sustainable materials, lack of suitable alternatives, performance concerns, supply chain issues, low market demand and regulatory barriers. The results are shown in bar chart form in Fig. 20 below. The consensus from these responses was that packaging performance was the biggest challenge associated with the adoption of sustainable blister materials, with 90% of respondents selecting this factor as a challenge, followed by lack of suitable alternatives (63% of respondents selected) and high cost of sustainable materials (56% of respondents selected). Supply chain issues and low market demand were the two least selected challenges at 6% and 3% selection respectively, suggesting that these factors were not considered to be significant barriers to the use of sustainable materials.

A Cochran's Q test was run to assess whether there are significant differences in the proportion of participants selecting each challenge (Lewis-Beck *et al.* 2004; Aslam 2023). This statistical test resulted in a Q value of 78.83 ($p < 0.001$), indicating that some factors were selected

significantly more than others. A post-hoc Dunn test showed that cost is perceived as a significantly greater challenge than low market demand ($p = 0.0049426$). The lack of suitable alternatives is seen as a significantly greater challenge compared to both supply chain issues ($p = 0.0128212$) and low market demand ($p = 0.0006093$). Performance concerns are identified as significantly more challenging than supply chain issues ($p = 0.0000011$), low market demand ($p = 0.00000011$), and regulatory barriers ($p = 0.0000165$). These findings highlight that SMEs in the blister packaging manufacturing industry have found performance concerns, lack of suitable alternatives, and cost to be the most significant barriers to adopting sustainable blister materials.

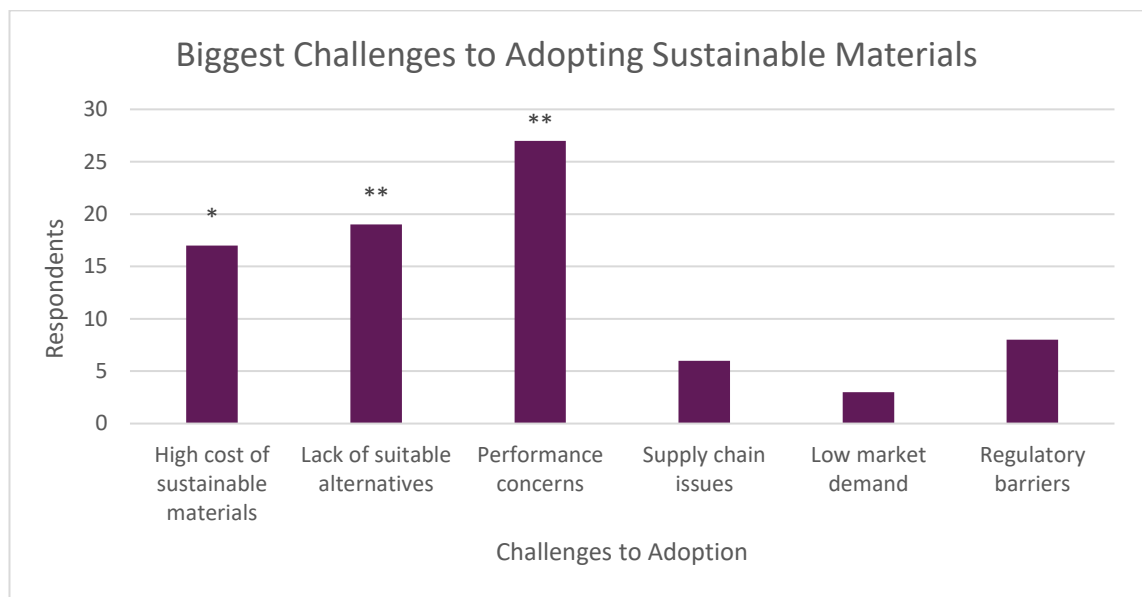


Figure 20: Bar chart showing main challenges for sustainable material adoption as selected by participants, * $p < 0.05$ from one other factor, ** $p < 0.05$ from multiple other factors (based on Dunn post-hoc test).

4.4 IMPLEMENTATION OF SUSTAINABILITY INITIATIVES AT BLISTER MANUFACTURING SITES

All blister manufacturing sites were asked as part of this survey if the site had tested or implemented any sustainable packaging alternatives for blister packs. It was found that of the 17 sites, seven of them had not explored testing or implementing sustainable alternate packaging in blister packaging at their site, as shown in Fig. 21. Four sites were each either currently testing sustainable alternatives or had assessed the possibility of sustainable solutions but had not implemented due to issues. Two sites stated that they had successfully implemented sustainable packaging alternatives. No significant difference was found between the proportion of sites selecting any of the statuses.

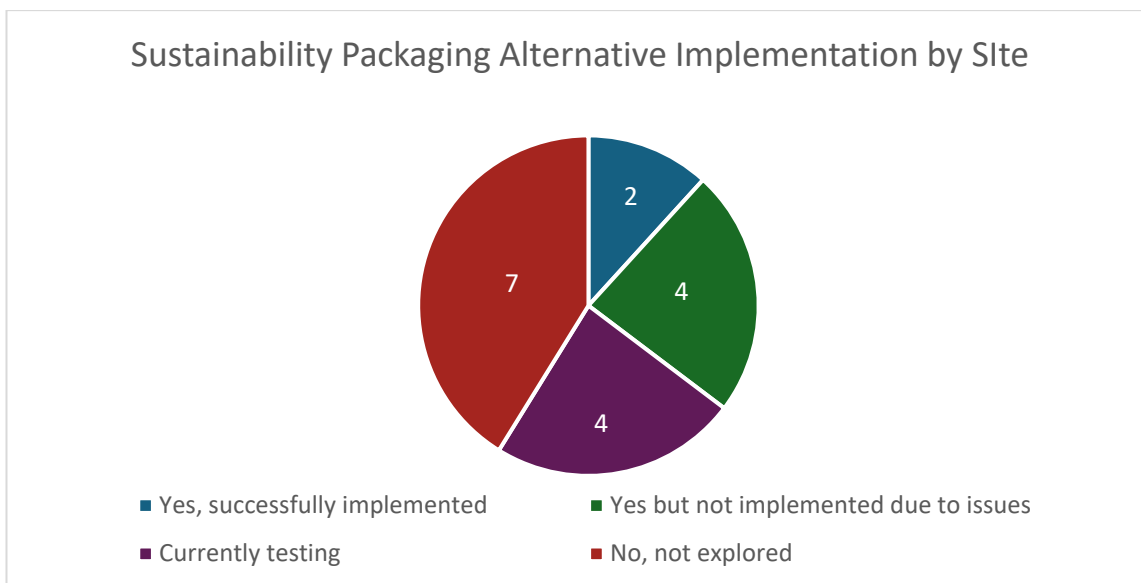


Figure 21: Pie chart showing proportion of sites who have trialled/implemented sustainable blister packaging alternatives compared to those who have not.

The participants were asked a follow up question asking if they answered yes, what was the outcome of their testing and if no, why the site had not tested/implemented sustainable alternatives. The survey responses reveal a mixed consensus on the implementation of sustainable alternative materials for blister packaging across various pharmaceutical sites. Several sites are actively pursuing trials and projects to identify viable sustainable materials, such as the trials at the Spanish site to identify suitable materials set for 2025 and ongoing PET/PET trials at the Irish site.

However, many sites face significant challenges, primarily related to cost and material performance. For example, one site reported that “the performance of the material, PET, is not satisfactory against the current blistering machine”, highlighting issues with micro holes causing blister sealing integrity failure. Another site mentioned encountering “many issues with sealability at low production cycles and temperature-related issues” when testing HDPE materials. One further site highlighted the “high impact on cost of goods” as a major barrier. Additionally, some sites rely on above-site global resources for identifying materials, but no sustainable alternatives have been identified yet.

Despite these challenges, there is a clear focus on minimising plastic use to enhance sustainability, which also offers marketing advantages and potential cost reductions. One site which had successfully implemented sustainable alternatives mentioned, “Sustainable packaging alternatives have been mainly focused on minimising plastic use in order to enhance sustainability, and it also offers marketing advantages and as well as potentially reducing material costs”.

4.5 REGULATORY BARRIERS TO IMPLEMENTATION OF SUSTAINABLE BLISTER PACKAGING

When asked to what extent regulatory requirements limit the adoption of sustainable blister packaging in the pharmaceutical industry, the majority of participants found that these requirements are somewhat limiting, with 43.33% of participants selecting this option. 23.33% of participants found that regulatory requirements are a major barrier and a further 23.33% found that there is little to no impact seen from regulatory requirements. The remaining 10% of participants were unsure as to the impact that regulatory requirements have on blister material selection. These results are shown visually in Fig. 22.

A Chi Square Goodness of Fit test was completed, with a result of 0.07855316 suggesting that there is no significant deviation from what might be expected by chance among the responses, indicating a relatively balanced distribution of opinions (Riffenburgh 2012).

Overall, while some sites view regulatory requirements as a major barrier, the majority find them somewhat limiting, and a fair proportion report little to no impact. This highlights the diverse experiences and challenges faced by different sites in navigating regulatory landscapes for sustainable blister packaging materials. Furthermore, the finding that some SMEs were unsure as to the influence of regulatory requirements on blister material selection shows a requirement for more readily available information and comprehensive guidance for understanding regulations and how these impact blister packaging, especially regarding sustainability in this area.

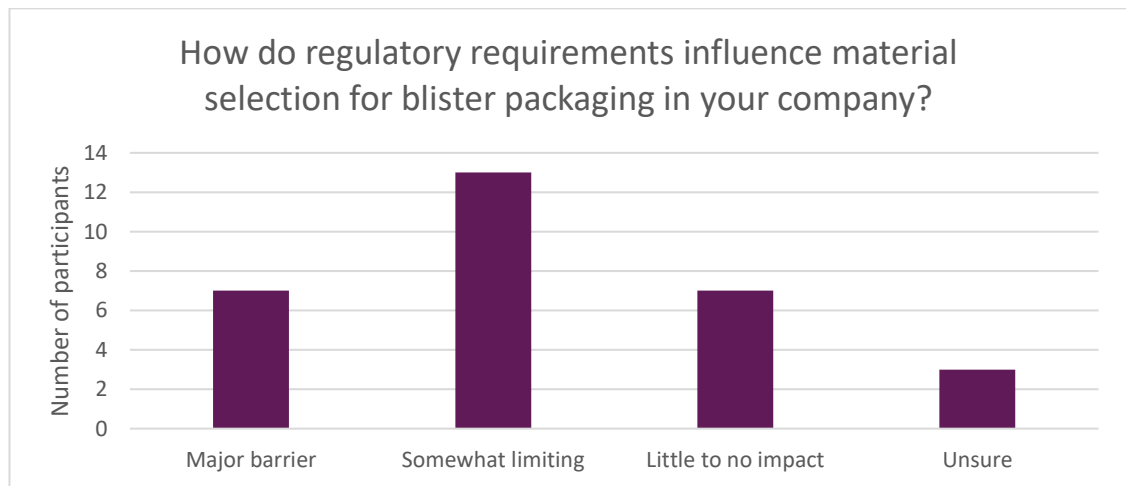


Figure 22: Bar chart showing participants' view on influence of regulatory requirements on blister material selection.

Participants were then asked as to whether they believed that the current regulations support or hinder the adoption of sustainable packaging in the pharmaceutical industry. The results of this question are shown in Table 2 below.

The Chi Square Goodness of Fit test result of 0.040427682 suggests that there is a statistically significant variation in responses, indicating a diverse range of opinions on the impact of current regulations on sustainable blister packaging implementation.

To further assess significance, a pairwise binomial test was conducted, but no significance was found. This indicates that while there are varied opinions, none of the individual pairwise comparisons between the categories showed a statistically significant difference. As such, while the majority of participants feel that regulations somewhat support the adoption of sustainable packaging, a notable number find them somewhat hindering. This variation in responses further shows the complexity of regulatory requirements and the impact these have on sustainability initiatives within the pharmaceutical industry.

| <i>Do you believe that current regulations support or hinder the adoption of sustainable packaging in the pharmaceutical industry?</i> | <i>Participant Count</i> |
|--|--------------------------|
| <i>Strongly support</i> | 3 |
| <i>Somewhat support</i> | 10 |
| <i>Neither support nor hinder</i> | 7 |
| <i>Somewhat hinder</i> | 9 |
| <i>Strongly hinder</i> | 1 |

Table 3: Survey participants' opinion on whether the current regulations support or hinder the adoption of sustainable blister packaging.

4.6 MARKET DEMAND AND SUSTAINABLE BLISTER PACKAGING SOLUTIONS

Demand from customers and from the markets which take the blister packed product can impact a site's decisions on adopting sustainable packaging solutions. If there is a market requirement for a recyclable blister, for example, the site will often prioritise this type of packaging in order to meet the market demand. Participants in this survey were asked to assess the influence of customer demand on decisions being taken on adopting sustainable packaging solutions.

The majority of participants (17 participants) indicated that customer demand influences their decisions "somewhat", while nine participants reported that it influences their decisions "a great deal". This highlights the importance of market requirements and customer demand in driving the adoption of sustainable packaging solutions. However, a small number of participants (two for each) reported that customer demand has very little or no impact on their decisions, indicating that other factors may be more influential for these participants. These results are represented visually in Fig. 23.

The Chi Square Goodness of Fit test result of 0.000140236 indicates a statistically significant variation in responses ($p < 0.05$) (Riffenburgh 2012). This suggests that customer demand plays a considerable role in influencing decisions for many participants. As a post-hoc test, a pairwise

Binomial test with Bonferroni adjustments was completed, finding that the proportion of participants stating that customer demand “somewhat” affects their decisions was significantly greater than those stating that it affected their decisions “very little” or “not at all” ($p < 0.05$ for both).

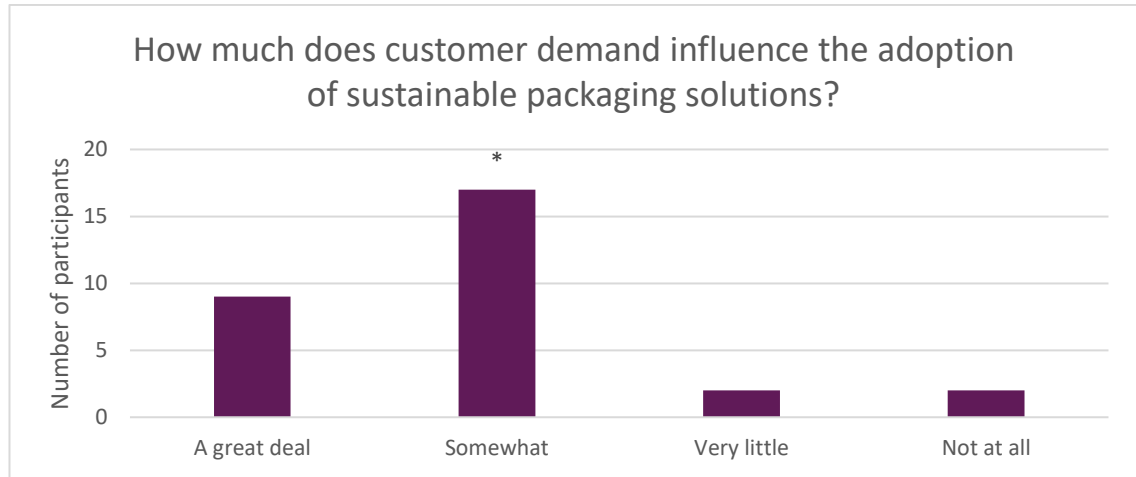


Figure 23: Bar chart showing participants' view on influence of customer demands on sustainable packaging adoption, $*p < 0.05$ (based on post-hoc Binomial test).

4.7 WASTE REDUCTION IN BLISTER PACKAGING

Survey participants were assessed as to the sustainability initiatives implemented at each site with the goal of reducing waste production. These initiatives were not limited exclusively to recyclable materials, but also included material reduction, improved packaging designs and reuse/recycling programs. The results showed that the vast majority of sites had implemented at least one waste reduction initiative, with just one site stating they had not implemented any waste reduction strategies. The distribution of initiatives selected by each of the sites are shown in Fig. 24 below, with material reduction and improved packaging designs being the most common waste reduction strategies. This may be attributed to the ease in implementing these types of initiatives in comparison to attempting to qualify an entirely new forming/lidding material.



Figure 24: Bar chart showing sustainability initiatives implemented at 17 blister manufacturing sites.

4.8 FUTURE OF SUSTAINABILITY IN BLISTER PACKAGING

Participants were asked as to what they believed was the most promising solution for reducing blister packaging waste in the pharmaceutical industry, with a view to improving the sustainability of blisters in the future. The results, shown in Fig. 25, showed that the majority of respondents (14 respondents) believed that increased recyclability of blisters is the most promising solution for reducing blister waste, followed by redesigning blister packaging (7 respondents) and biodegradable materials (5 respondents), with implementing takeback programs being selected the least (4 respondents). Increased recyclability was likely the most selected option due to the large amount of recyclable blister materials that are currently being developed by blister component manufacturers, which show great promise as a future solution (Klockner Pentaplast 2021; Bayer 2024).

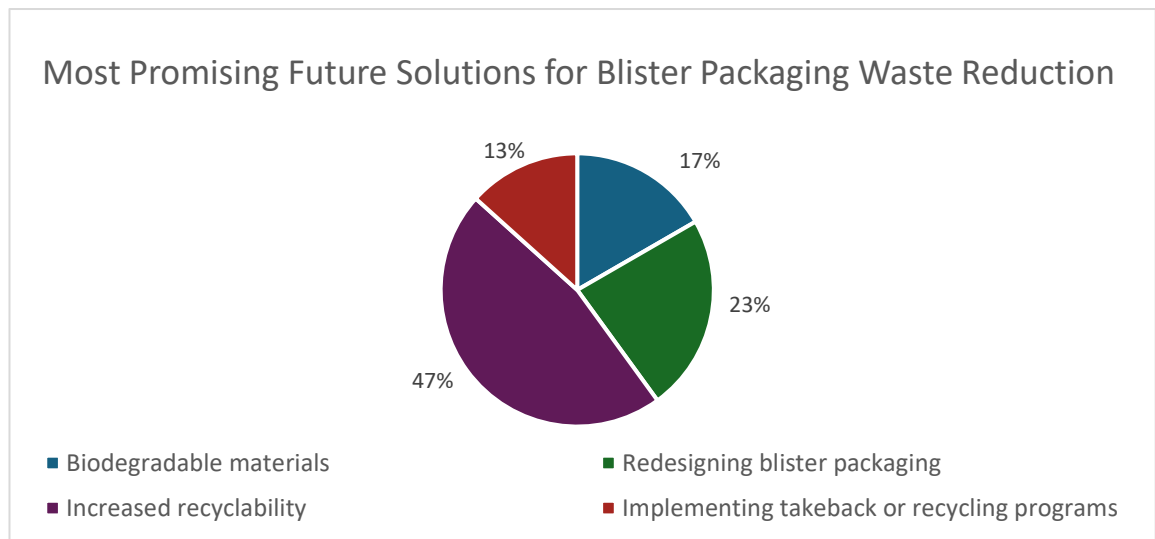


Figure 25: Pie chart showing proportion of respondents' opinions as to the most promising solution for reducing blister packaging waste.

Participants' outlook as to the future of sustainability in blister packaging was examined by asking them what their view on the future of adoption of sustainable blister solutions was. Overall, most participants had a somewhat optimistic outlook as to the future of sustainability in blister packaging, with 21 participants selecting this option. A further 6 participants had a very optimistic outlook, with fewer participants adopting a neutral or pessimistic stance (2 and 1 respondents respectively).

These results indicate a positive outlook shared by the majority of blister packaging SMEs, with a belief that the blister packaging industry will adopt sustainable solutions in the future, despite challenges that can prevent this process from running smoothly. This outlook can be attributed to a variety of factors including advances in sustainable blister components in recent years (Klockner Pentaplast 2021; Bayer 2024), along with an emphasis on sustainability from governmental agencies such as the European Commission (European Commission Directorate-General for

Environment 2022). These recent developments in sustainability point towards a necessity for adoption of sustainability in blister packaging and may account for the shared positive stance from the survey participants.

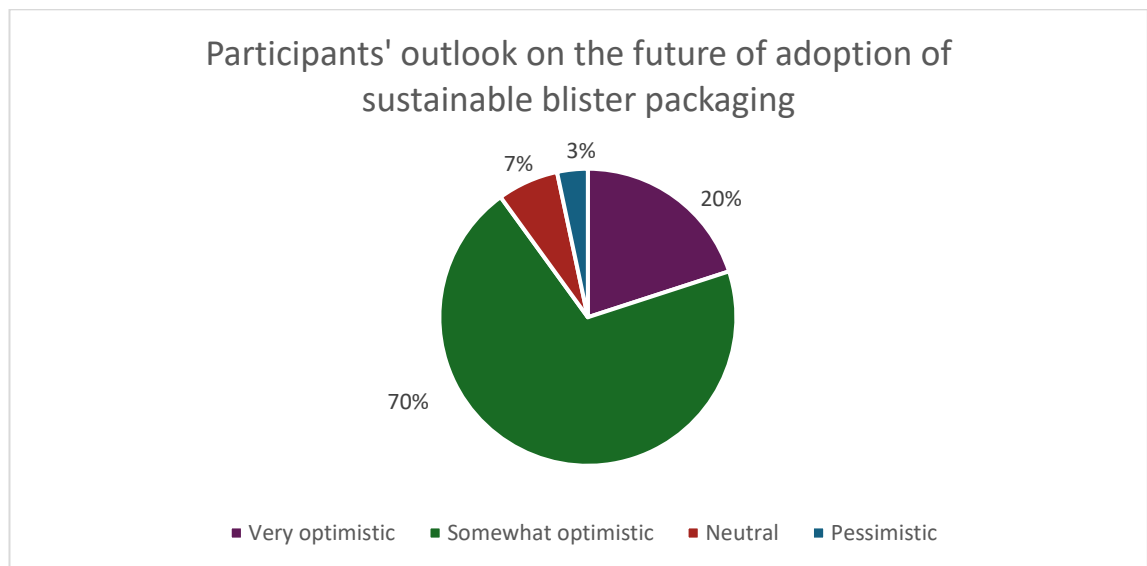


Figure 26: Pie chart showing proportion of respondents' outlook of adoption of sustainable blister packaging in the future of the pharmaceutical industry.

4.9 OPEN QUESTIONS

For the final survey questions, the participants were asked open-ended questions to allow them to further elaborate on any additional views and opinions they may have had regarding sustainable blister packaging. In this section, they were firstly asked what the single biggest barrier preventing the pharmaceutical industry from adopting more sustainable blister packaging solutions is, in their opinion. The most common words present in the participants' responses to this question are shown in the word cloud in Fig. 27 below, which was generated using www.freewordcloudgenerator.com (FreeWordCloudGenerator.com 2025).

The responses to this question highlighted several key barriers preventing the pharmaceutical industry from adopting more sustainable blister packaging solutions, with the performance of sustainable materials often noted as a barrier for implementation of these materials, along with compatibility with existing machinery and processes. One participant stated, "the balance of sustainable material characteristics in terms of machine compatibility and product protection is a bottleneck for sustainable material to be implemented," while another responded with "availability of sustainable materials that provide the same barriers and perform at the same cycle rates" as the biggest barrier.

Further to this, cost and availability of materials was seen as a recurring answer throughout the responses. Multiple participants made the point that sustainable materials are often more expensive and harder to source. One respondent noted, "overall costs which are coming from

material unavailability and missed performance” can be a large barrier to sustainable material implementation, while another mentioned, “the cost of material, as well as sourcing”.

Finally, regulatory challenges were also seen as a significant barrier. One participant stated, “the regulation is very hard to change”, and another highlighted that “in my opinion, the primary barrier preventing the pharmaceutical industry from adopting more sustainable blister packaging materials is the stringent regulatory requirements that prioritise patient safety and product integrity”.

The agreement of multiple participants across different sites in different companies as to the primary barriers to sustainable blister implementation highlights the universal nature of these issues in the industry. These barriers underscore the complexity of transitioning to a more environmentally friendly standard in the blister packaging industry and must be addressed in order to facilitate adoption of sustainable solutions in this industry.



Figure 27: Word cloud showing participants' most used words when asked for single biggest barrier preventing the pharmaceutical industry from adopting sustainable solutions (FreeWordCloudGenerator.com 2025).

Finally, participants were asked what changes would need to occur for sustainable packaging solutions to become mainstream in the pharmaceutical industry, in their opinion. Again, the most common words present in the participants’ responses to this question are shown in the word cloud in Fig. 28 below, which was generated using www.freewordcloudgenerator.com (FreeWordCloudGenerator.com 2025).

The open-ended responses from participants highlight three key changes needed for sustainable packaging solutions to become mainstream in the pharmaceutical industry. First, technological advancements are crucial, with improved sustainable materials that are compatible with existing machinery and provide adequate protection. One respondent stated, “better technology in sustainable materials to be able to have a successful performance at machine trials”, with another

responding that there is a requirement to “standardise formats and reduce line speeds from a technical perspective. Infrastructure/machinery needs to be in place to allow recycling”.

Additionally, regulatory reforms are essential, including simplifying requirements and incentivising the use of sustainable packaging. One participant elaborated on this point stating “The regulatory initiatives would definitely act as a catalyst in adoption of recycled/recyclable packaging material initiatives, by reducing the taxes and customs on the sustainable solutions which will motivate the pharma packagers to adopt sustainable packaging solutions. As a progressive increase in demand, more and more suppliers will start providing sustainable packaging solutions for pharma packagers. This will also help the packagers to sell the product at lesser cost which will attract more customers ensuring sustainable growth in recycled/recyclable pharma packaging.” This answer highlights the potential for regulatory changes to go hand in hand with increased accessibility to sustainable blister components at a lower cost, a sentiment echoed by another respondent who said “several regulatory changes and adoptions are needed to balance environmental goals with the industry's strict safety and quality requirement. If regulatory authorities decrease or reduce the taxes on sustainable solutions it will motivate the suppliers to sell the product at cheapest cost and it will also attract more customers ensuring sustainable growth in pharma packaging.”

Overall, the key changes that were identified as being a priority to aid the widespread adoption of sustainability in the blister manufacturing industry were identified as technological improvements, a shift in regulatory requirements and a reduction in cost. As such, an emphasis should be placed on addressing these areas in order to help overcome current barriers and drive progress towards sustainable solutions becoming standard practice in blister packaging.



Figure 28: Word cloud showing participants' most used words when asked what changes are required to achieve sustainable packaging solutions becoming mainstream in the blister packaging industry (FreeWordCloudGenerator.com 2025).

4.10 SUMMARY OF FINDINGS IN RELATION TO RESEARCH OBJECTIVES

The findings of the primary research, when assessed against the current literature as reviewed in Chapter 2, provide a deeper and more practical understanding of sustainability in pharmaceutical blister packaging. In addressing the first research objective, quantifying blister packaging waste, existing studies have broadly acknowledged blister formats as a major contributor to pharmaceutical packaging waste but have failed to present real-world site-specific data (Karliner *et al.* 2019; Unitaid 2023). This gap was reflected in the primary data, where many participants were only able to estimate waste contributions, and a large proportion could not quantify their blister waste at all. While most sites indicated that blister waste made up between 0-25% of total packaging waste, the lack of precise measurement systems highlights a broader industry challenge in tracking packaging waste accurately.

Regarding the second objective, the literature consistently identifies incineration and landfill as the dominant disposal methods, citing the difficulty of recycling multi-material blisters (Pedrosa de Oliveira *et al.* 2021). The primary research confirmed this, with incineration reported as the most commonly used disposal route, and few sites engaging in any form of recycling. The persistence of these unsustainable methods across global sites reflects the operational limitations as well as the issues regarding overall blister recycling infrastructure previously described in the literature and reinforces concerns about the industry's reliance on unsustainable disposal practices (Nieminen *et al.* 2020).

In relation to the third objective, evaluating the extent of sustainability initiatives, the literature offers a range of material innovations and process improvements but suggests limited adoption within the pharmaceutical industry (Falconnier-Williams *et al.* 2024). This was mirrored in the survey findings, where only a small number of sites reported successful implementation of sustainable blister alternatives. Most others had either encountered issues during trials or had not explored alternatives at all. Common initiatives tended to focus on low-risk improvements such as reducing plastic use or optimising packaging design. These findings suggest that while awareness and intent may exist, widespread transformation is still in its early stages.

When exploring the fourth objective—identifying barriers to the adoption of sustainable materials—there was strong alignment between literature and primary research. Both point to high costs, performance concerns, and lack of suitable alternatives as primary challenges (Abdul-Rashid *et al.* 2017). With mixed results on the perception of the extent to which regulatory constraints limit blister packaging material selection, the literature recognises that policy developments such as the EU Green Deal are placing long-term pressure on the industry to transition towards recyclable and environmentally sustainable packaging formats (European Commission Directorate-General for Environment 2022). However, there remains a lack of

clarity on how these ambitious legislative goals will be operationalised in practice and a sense of uncertainty of the impact of these regulations on blister packaging operations.

Finally, in addressing the fifth objective, gathering expert insight to inform practical recommendations, the literature often proposes theoretical solutions such as techniques for separation of aluminium and plastic, yet lacks manufacturing data to assess their feasibility (Yousef *et al.* 2018; Nieminen *et al.* 2020). The survey helped to bridge this gap by collecting views from SMEs in various roles and regions, offering insight into what is realistically achievable. The majority of participants viewed increased recyclability as the most promising pathway, followed by packaging redesign and material reduction. While there was a general sense of optimism about future improvements, many respondents acknowledged that meaningful progress would require a reduction of the cost currently associated with environmentally friendly materials, clearer regulatory direction, and stronger cross-functional collaboration. These real-world insights provide valuable context to the academic discussion and form the foundation for the recommendations outlined in the next chapter.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 KEY FINDINGS AND IMPLICATIONS

5.1.1 Lack of Sustainability Prioritisation in Blister Packaging

One of the primary findings of this study was that while sustainability was recognised as an industry priority to some extent, it was consistently viewed as a secondary consideration with other factors such as performance, cost and market availability being ranked higher on the scale of importance by the majority of SMEs surveyed. This finding was extremely insightful into the industry mindset as environmental concerns are currently extremely topical within the blister manufacturing industry. This can be seen through component suppliers striving to develop a more sustainable alternative (Klockner Pentaplast 2021; Bayer 2024), and governments implementing requirements for sustainability (European Commission Directorate-General for Environment 2022). Yet, despite this urgency around implementing sustainability, the blister manufacturing decision makers are prioritising other factors, with sustainability being consistently ranked the lowest out of the five factors detailed in section 4.3.1. This suggests a fundamental misalignment between sustainability goals and operational decision-making, where short-term cost and market concerns override long-term environmental benefits.

This lack of industry commitment to sustainability is further reflected by the answers seen in section 4.4 which asks if the sites have implemented or trialled sustainable materials, which found that of the 17 sites, seven had not explored the testing and implementation of sustainable materials at all. Just two of the sites had successfully implemented sustainable materials, with other sites citing cost of materials, performance issues such as micro holes and lack of suitable materials as factors preventing successful implementation of sustainable packaging alternatives.

This finding directly addresses Objective 3, which aimed to assess current sustainability practices, and Objective 4, which sought to investigate barriers to the adoption of sustainable materials. The low prioritisation of sustainability despite environmental pressures reveals an industry mindset that favours cost, performance, and availability over environmental impact. The implication is that internal attitudes within manufacturing decision-making processes remain a significant barrier to progress, and any future strategies must include cultural and behavioural change, not just technical solutions.

5.1.2 Performance Concerns as a Perceived Barrier

According to the survey participants, performance concerns were seen as the single most prominent barrier to the adoption of sustainable blister materials, with one participant stating that “the balance of sustainable material characteristics in terms of machine compatibility and product protection is a bottleneck for sustainable material to be implemented”. Although there is a

foundation for stating this, with some sites who conducted trials seeing failures in blister weld testing as a result of holes in the material, successful trials of PP monolayer blisters have been seen at one of the sites in the network, proving the feasibility of such an option.

This aversion to implementing sustainable materials, with 41% of sites not having trialled or implemented sustainable materials indicates that the reluctance to transition is not purely technical but also cultural, and that manufacturing sites may be prioritising stability over innovation. The pharmaceutical industry operates on high-risk aversion, particularly in packaging, due to regulatory scrutiny and product integrity concerns. However, this aversion may be an overestimation of risk rather than an evidence-based assessment, as successful trials of alternative materials have already been conducted, both at sites within the company being surveyed and from component manufacturers. The successful development and launch of materials such as the Bayer PET monoblister shows that sustainable materials which meet performance and regulatory criteria do exist and can be used for blister manufacturing (Bayer 2024). As such, sites within this network should prioritise the conducting of trials in order to further explore the possibility of implementing sustainable materials with a long-term view to the environmental benefits and without preconceptions about performance impacting their willingness to fully investigate the feasibility of sustainable alternatives.

This finding contributes to Objective 4 of investigating challenges to the adoption of sustainable solutions by highlighting performance-related concerns as a key deterrent to adopting sustainable blister materials. While the literature and site experiences show that alternative materials, such as PP monoblister, can perform adequately, fear of production issues such as weld failures limits trialling and adoption. The implication is that risk aversion is not always based on evidence, and this mindset could delay meaningful innovation unless mitigated by shared case studies between sites and collaborative trials between the supplier and manufacturing site.

5.1.3 Implications of Regulatory Requirements

In response to the question in section 4.5 which asks the participants to what extent do regulatory requirements affect blister material selection and whether they hinder or support the adoption of sustainable packaging, the mixed response indicates a lack of certainty and understanding of the regulatory impact that is present. Specifically, the mixed response on whether regulations hinder, or support sustainability suggests a lack of clarity in how sustainability requirements intersect with pharmaceutical compliance frameworks.

While the EU Green Deal and other sustainability policies set clear long-term targets, many surveyed sites viewed regulations as an obstacle rather than a facilitator. This could indicate an implementation gap, where regulations provide a vision, for example, the Paris Agreement or the requirement for drug primary packaging to be recyclable on a large-scale from 2035, but the

mechanisms required for industry compliance (e.g. guidance on material transitions) are lacking (European Commission Directorate-General for Environment 2022). This is a critical gap which severely impacts the ability of blister packaging manufacturers to fully understand and comply with regulatory requirements, especially with a hard deadline such as this to adhere to the requirements.

One large scale consumer healthcare company Haleon said that while welcoming the new guidelines, they had “serious concerns” about the timelines, stating that there was “no technically recyclable solution commercially available at scale that ensures the quality, safety and efficacy” and expressing a desire for the EU to “help fund innovation to speed up the development of new solutions” (Ridley 2023). As such, it is clear that industry-wide collaboration between regulatory bodies, manufacturers, and packaging suppliers could help bridge this gap, ensuring that sustainability is not just a compliance burden but a structured pathway to innovation with positive impacts on both the pharmaceutical industry and the environment.

This finding addresses Objective 4 (barriers to adoption) and Objective 5 (developing recommendations) by illustrating the uncertainty and mixed perceptions around regulatory impacts. The confusion regarding whether regulations are supportive or restrictive suggests a communication and implementation gap that hinders progress. As a result, without clearer, harmonised regulatory guidance, in addition to a potential requirement for financial or technical support, manufacturers will continue to struggle to interpret and meet sustainability requirements, which are increasingly becoming a priority.

5.1.4 Blister Waste Data Inaccessibility as a Barrier to Data-Driven Decisions

The final critical finding from this study was that over 35% of surveyed sites lacked clear data on their blister waste production volumes. As such, these sites were unable to quantify their annual blister waste production as seen in section 4.2.2, which is highly concerning as this indicates a lack of understanding of the environmental impact of their waste production. Without accurate data, it is impossible to trend blister waste production or quantify the impact of sustainability initiatives which may be implemented at their site or to track progress.

This gap reflects a broader failure to integrate sustainability metrics into operational key performance indicators (KPIs). As part of the overall performance metrics for the site, manufacturing sites such as these track cost efficiency, adherence to production plans and overall equipment effectiveness (OEE). In order to fully understand the sites’ blister waste production and how this increases or decreases over time, waste production should be included as an additional factor to be continually monitored, and waste reduction targets should be embedded into performance assessments for all sites.

This finding aligns with Objective 1, which focused on quantifying blister packaging waste, and Objective 5, which seeks to offer recommendations. This finding also strongly links to Objective 2 because without quantifiable data on blister waste, it becomes impossible to evaluate how materials are disposed of or what their environmental impact is. The widespread inability of sites to report accurate waste data points to a systemic issue in monitoring and accountability. Without clear baselines, sites cannot measure improvement or justify investment in sustainability initiatives. The implication is that digital waste tracking systems should become standard to support more strategic and evidence-based decision-making in blister sustainability.

5.2 RECOMMENDATIONS FOR BLISTER PACKAGING INDUSTRY

5.2.1 Manufacturer-Supplier Collaboration on Blister Material Development

The first recommendation that is being made to manufacturers in the blister packaging industry as an outcome of this study is to engage and invest in cross-functional collaboration with material suppliers during the trialling and implementation process of sustainable materials. In this way, instead of defaulting back to conventional material such as PVC/PVDC due to minor performance concerns seen during sustainable material trials, manufacturers should work closely with packaging suppliers to refine sustainable materials that meet stringent stability and barrier requirements. During feasibility trials which assess sustainable blister material implementation, both sustainability and cost-saving potential should be evaluated, for example, optimising material thickness to reduce waste while maintaining integrity.

Feedback on the overall material performance and areas for improvement during trials should then be provided to the supplier with recommendations for how to improve the material runnability. By working with packaging material suppliers and providing recommendations and feedback based on trial results, both the manufacturer and supplier benefit as the manufacturer has an increased likelihood of resolving any performance issues that may be seen, and the supplier is able to use the feedback to create a more robust packaging material.

5.2.2 Regulatory Body Engagement for Clear Guidelines

Further to engaging with blister component suppliers in the development of sustainable components, another recommendation for blister manufacturers is to engage with regulatory bodies to strengthen and clarify regulatory guidelines in relation to packaging requirements and sustainability. By actively collaborating with regulators governing large regions such as the European Commission or local regulatory bodies such as the HPRA, blister manufacturing companies can provide input on shaping packaging sustainability guidelines that are both ambitious and realistic. These guidelines could include structured transition plans for packaging material approvals, reducing the uncertainty that currently slows adoption and easing the concerns that major blister production companies, such as Haleon, have (Ridley 2023). As such, the

implementation of a clearer regulatory framework for transition to sustainable materials through collaboration with regulatory bodies provides clarity to blister packaging companies and assurance to regulatory authorities that the sustainability requirements will be met.

5.2.3 Sustainability in Site Metrics

One key finding from this study was the lack of readily available data regarding blister waste production for the sites, with over 35% of sites being unable to provide blister waste data. As stated in section 5.1.4, blister waste data inaccessibility can be a barrier to making data driven decisions, as it is impossible to make fully informed decisions on sustainable materials and the success of sustainability initiatives without understanding the full extent of waste produced. Due to this, the recommendation to blister manufacturing sites in the pharmaceutical industry is to implement a form of continuous waste monitoring system. By utilising modern solutions to improve waste monitoring, such as digital waste tracking systems, sites could increase data-driven decisions to enhance overall blister sustainability at a site level.

An example of such a system is the TraceWaste waste management solution by Avery Weigh-Tronix, which allows waste to be recorded and tracked over time by site, equipment and product (Avery Weigh-Tronix 2021). Through implementing a modern system such as TraceWaste, sites can have greater visibility on their waste production data and work towards quantifying their waste production to understand the effectiveness of their sustainability initiatives and adherence to sustainability targets.

5.2.4 Sustainability as a Competitive Advantage

The results of this study show that many sites and blister packaging SMEs view sustainability as a hindrance, ranking it as the least important factor when selecting blister materials with mixed views as to the future of adoption of sustainable blister packaging. This mindset of sustainability being an inconvenience rather than an advantage that can put a company in front of its competitors can be harmful to the adoption of sustainable materials. This is because companies may be more likely to focus on other initiatives rather than sustainability if they don't believe it is of sufficient benefit to them and if they are not required by regulations to immediately move to sustainable materials. Companies should transition from viewing sustainability as a regulatory hurdle to seeing it as a market differentiator. Early adopters of sustainable packaging could gain a first-mover advantage, securing partnerships with retailers and healthcare providers that prioritise environmental responsibility.

As such, where sustainability has been adopted in a company it should be encouraged and learnings shared within its network. In the present study, two of the 17 sites were seen to have successfully implemented a form of sustainable packaging alternative for blister packaging, with the remaining 15 sites either currently trialling sustainable alternatives, had previously

unsuccessfully trialled alternatives or not explored sustainable alternatives. This provides a vital opportunity for sharing of learnings on what sustainable alternatives were successfully implemented at these sites and how, as well as any challenges that were met and how these were overcome. This knowledge sharing creates a culture of innovation and allows the company as a whole to progress towards sustainability together and reap the rewards as one.

Industry leaders should also invest in consumer education, raising awareness of the benefits of sustainable pharmaceutical packaging to create additional demand for this type of packaging on the consumer's end. The desire for consumer education by experts in the pharmaceutical industry was expressed by multiple survey participants, with one participant stating that "the single biggest barrier in adoption of sustainability initiatives is lack of awareness in the public". Another participant pointed out that "technology & consumer education should go hand-in-hand to ensure smooth implementation and product adoption in the market.". As such, by focusing on changing business mindset to viewing sustainability as an advantage and marketing to customers to educate them on the benefits of sustainable packaging, sustainability can be implemented using a proactive approach which benefits the pharmaceutical company and environment.

5.3 RESEARCH ALIGNMENT WITH AIMS AND OBJECTIVES

This research set out to explore the sustainability challenges and opportunities associated with pharmaceutical blister packaging, responding to growing regulatory, environmental, and industry pressures to improve packaging practices. As outlined in Chapter 1, the significance of the study lay in its potential to address a major knowledge gap: while the environmental impact of blister packaging is widely acknowledged, there has been limited investigation into the opportunities and challenges faced by global blister manufacturing sites in adopting sustainable packaging solutions.

The findings of this study demonstrate that the present research has provided a novel insight into the mindset of industry experts as to the current state of blister waste and the implementation of sustainable solutions. It provides a global, multi-site insight into the volume of blister waste, the disposal methods in use, the current level of sustainability adoption, and the barriers encountered, which were all detailed as the research objectives in Section 1.5. These insights were then used to provide meaningful and actionable recommendations for researchers, manufacturers and suppliers, which was the final objective of this research.

Furthermore, this research has captured the perspectives of 30 subject matter experts from 17 globally distributed sites, offering a valuable view into operational decision-making and the factors influencing this decision making that is often absent from academic literature. The alignment between the literature gaps, research objectives, and survey design affirms the relevance and necessity of the study. Ultimately, the research contributes actionable knowledge

to both academia and industry and facilitates further progress to be made in the transition toward more sustainable pharmaceutical packaging systems.

5.4 STUDY LIMITATIONS

While this study was conducted in accordance with established academic standards and methodologies, there are inherent limitations present in the research design and executions which should be acknowledged as follows:

1. The research in this study focused on the perspectives and data from sites and experts within a single pharmaceutical company's network, which, while providing a global perspective, may not fully capture industry-wide trends. This is because different companies may have different approaches to adopting sustainability in blister packaging which were not captured as part of this study.
2. The sample size required to reach a 95% confidence interval was calculated to be 31, based on an overall population of 34, however 30 responses were received. Despite this number not reaching the required sample size, enough responses were received to draw meaningful conclusions. Nonetheless, the sample size not being reached is an overall limitation to this study and should be noted when interpreting the results.
3. The lack of data from some sites on blister waste production limited the ability to make precise waste volume comparisons and to draw exact conclusions on this subject.
4. As this study primarily relied on self-reported data from survey respondents, there is a potential for bias as some of the responses received may be based on individual perspectives rather than objective measurements.

5.5 FUTURE RESEARCH OPPORTUNITIES

There are many opportunities for meaningful research into sustainability in pharmaceutical blister packaging that is being carried out in the future, as this area is not well studied which makes it difficult to truly understand the major influences and drivers present. A clear opportunity for potential future research is to carry out a similar study to understand blister waste volumes and the perspective of blister packaging experts across a larger sample size and multiple blister manufacturing companies. This would reduce any potential bias present by only surveying individuals in one company and provide more data to build a comprehensive picture of sustainability in the blister packaging industry.

Further to this, more research should be carried out by blister component manufacturers into additional opportunities for development of sustainable materials. Since recyclable blisters have not been widely adopted by blister manufacturers, with PVC and aluminium still being the most commonly used materials, it is clear that there is a need for a more robust material at a cost-

effective price to encourage increased uptake by blister manufacturers. Component suppliers should liaise with manufacturers during this development stage and conduct research into the pitfalls and challenges faced to date with sustainable material trials in order to produce a viable sustainable material with potential for widespread adoption.

This study observed a small number of sites which reported successful implementation of sustainable blister packaging solutions, offering valuable insights that could support wider adoption across the network. These sites that have successfully implemented sustainable blister packaging solutions provide a valuable foundation for broader adoption across the network. It is recommended that these sites actively share technical learnings, supplier collaborations, and validated material solutions with other sites in the global network. By formalising the transfer of historically successful approaches to sustainability, organisations can build confidence within the company network and accelerate the rollout of sustainable packaging solutions more widely.

Finally, in order for blister manufacturing sites to fully understand the benefit of sustainable materials, it would be beneficial to carry out a cost-benefit analysis of sustainable material adoption. This could quantify long-term financial impacts beyond material costs, including regulatory benefits, waste reduction savings, and increased consumer uptake. By carrying out this type of research, blister manufacturing sites could more clearly see the comprehensive benefits associated with the use of sustainable materials. This in turn may encourage them to overcome challenges seen when trialling sustainable materials, rather than reverting to unsustainable materials, ultimately leading to increased adoption and realisation of these benefits.

5.6 CONCLUSION

This study has highlighted a fundamental disconnect between sustainability aspirations and operational realities in pharmaceutical blister packaging. While the industry acknowledges the need for sustainability, risk aversion brought about by performance concerns, regulatory ambiguity, and cost concerns continue to hinder large-scale adoption. Furthermore, the lack of prioritisation of data availability regarding sustainability and waste production highlights the disconnect between environmental concerns as a global priority and the focus on performance and cost within pharmaceutical corporations.

Nonetheless, the relative optimistic outlook held by the majority of participants in this study, along with the developments that continue to be made by component manufacturers, point towards a future where sustainability in pharmaceutical packaging is more widespread and the waste that is seen today significantly reduced. This industry is currently in a state where there are multiple opportunities for implementation of strategies to reduce detrimental environmental impact and improve the reputation that the pharmaceutical industry has as one of the main generators of waste globally (Belkhir and Elmeligi 2019; Karliner *et al.* 2019). However, in order

to do this, a huge shift is required in the approach taken towards sustainability of blister manufacturers worldwide.

Pharmaceutical companies must move beyond incremental changes and embrace a transformative approach to implement the changes required to see meaningful environmental impact, viewing sustainability as a core pillar of innovation rather than a compliance obligation. The future of pharmaceutical packaging sustainability will not be determined by regulations alone but by the industry's willingness to rethink its priorities and investment strategies. By leveraging regulatory engagement, data-driven decision-making, and development of sustainable materials in collaboration with component manufacturers, the pharmaceutical industry can position itself at the forefront of sustainable packaging innovation, not just for compliance, but for long-term business resilience and environmental responsibility.

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APPENDIX 1: PARTICIPANT INFORMATION LEAFLET

PARTICIPANT INFORMATION LEAFLET

TITLE OF THE STUDY:

Sustainability in Blister Packaging Production: Challenges and Opportunities for Waste Reduction in the Pharmaceutical Industry

I would like to invite you to take part in a research study. Before you decide, you need to understand why the research is being conducted and what it would involve for you. Please take time to read the following information carefully. Feel free to ask questions if anything is unclear or if you would like more information. Take as much time as you need to decide whether or not to participate.

WHO I AM AND WHAT THIS STUDY IS ABOUT

My name is Charlotte Black, and I am conducting this research as part of my Master's degree in Pharmaceutical Business and Technology at Griffith College Dublin. This study aims to explore the challenges and opportunities associated with sustainability in blister packaging production within the pharmaceutical industry, with a focus on waste reduction strategies and practices.

The goal of the research is to gather insights from subject matter experts across global manufacturing sites to generate recommendations for improving sustainability in blister packaging.

WHAT WOULD TAKING PART INVOLVE?

If you agree to participate, you will be asked to complete an online survey. The survey will take approximately 10-15 minutes and will include both multiple-choice and open-ended questions related to your professional experience and knowledge about blister packaging waste and sustainability practices.

Your participation will be completely anonymous, and no identifying information will be linked to your responses.

WHY HAVE YOU BEEN INVITED TO TAKE PART?

You have been invited to participate because of your professional expertise in the pharmaceutical packaging industry. Your role and insights are highly valuable in understanding current practices, challenges, and opportunities for improving sustainability in blister packaging production.

DO YOU HAVE TO TAKE PART?

Participation in this study is entirely voluntary. You have the right to:

- Decline to participate without any consequences.
- Refuse to answer any specific questions.
- Withdraw your consent and participation at any time without explanation.

If you decide to withdraw, please contact Charlotte at charlotte.black@student.griffith.ie at any stage.

WHAT ARE THE POSSIBLE RISKS AND BENEFITS OF TAKING PART?

Risks:

There are no foreseeable risks associated with participating in this study.

Benefits:

Your participation will contribute to a deeper understanding of sustainability in blister packaging and help develop practical recommendations for improving waste management practices in the pharmaceutical industry.

WILL TAKING PART BE CONFIDENTIAL?

Yes, all information provided will be treated as confidential. Your responses will be anonymised, and no personal or identifying information will be linked to the data. The data will be used solely for research purposes.

Confidentiality may only be breached in exceptional circumstances, such as if there is a strong belief of harm or danger to you or others.

HOW WILL INFORMATION YOU PROVIDE BE STORED AND PROTECTED?

Data collected will be securely stored in a password-protected file on my Haleon computer's OneDrive. Only I, as the researcher, will have access to the raw data.

All survey data will be retained until after my degree is conferred. An anonymised transcript of survey results may be retained for up to 2 years post-degree for quality assurance purposes, after which all data will be permanently deleted.

WHAT WILL HAPPEN TO THE RESULTS OF THE STUDY?

The results of this study will be used solely for my Master's dissertation. The final report will be submitted Griffith College Dublin where it may be stored in the library or an online repository. The data may also be used for academic presentations or publications.

WHO SHOULD YOU CONTACT FOR FURTHER INFORMATION?

If you have any questions about this study, please contact Charlotte Black at charlotte.black@student.griffith.ie

THANK YOU FOR YOUR TIME AND PARTICIPATION!

APPENDIX 2: ONLINE SURVEY DISTRIBUTED TO GLOBAL PACKAGING EXPERTS



Section 1

Research Aim and Participant Consent

1. Thank you for participating in this research study.

This study aims to explore sustainability practices in blister packaging production across our global network, focusing on identifying opportunities to reduce waste and implement more environmentally friendly solutions. Your input is invaluable in understanding the challenges and opportunities faced in the industry, particularly in areas such as material selection, production processes, and waste management practices.

The findings from this research will help generate actionable recommendations to support sustainable practices while maintaining operational efficiency and compliance with industry standards. Participation is entirely voluntary, and your responses will be anonymized to ensure confidentiality. We appreciate your time and insights in contributing to this important research. *

Note: if you do not consent you may exit the survey now. No data will be recorded.

- I consent to participate in this study and agree to my responses being used for research purposes.
- I do not consent

General Information

2. What is your role in the pharmaceutical packaging industry? *

Enter your answer

3. How many years of experience do you have in pharmaceutical packaging? *

0-5 years

6-10 years

11-15 years

16+ years

4. What type of products do you primarily pack in blisters at your site? (if other, please specify) *

Vitamins, Minerals and Supplements

Respiratory Products

Pain Relief Products

Digestive Health Products

Other

5. Which region is your site located in? *

North America

Europe

Asia-Pacific

Latin America

Middle East/Africa

6. How many employees work at your site? *

Small (1-100 employees)

Medium (101-500 employees)

Large (501+ employees)

Blister Packaging Materials and Components

These questions focus on the materials and components used in blister packaging and their environmental impact.

7. What materials are commonly used in blister packaging in your company? (if other, please specify) *

- PVC (polyvinyl chloride)
- PVDC (polyvinylidene chloride)
- PET (polyethylene terephthalate)
- Aluminium
- Other

8. What percentage of your company's packaging waste comes from blister packaging? *

- 0-10%
- 11-25%
- 26-50%
- 51-75%
- 76-100%
- Unsure

9. How much blister packaging waste does your company generate on average per production cycle (in kg)? *
(An estimate can be provided if the exact figure is unknown)

Enter your answer

10. How much blister packaging waste does your company generate on average annually (in kg)? *
(An estimate can be provided if the exact figure is unknown)

Enter your answer

11. How are blister packaging materials disposed of in your company? (if other, please specify) *

- Recycled
- Sent to landfill
- Incinerated
- Other

Barriers to Sustainable Blister Packaging

This section investigates the obstacles preventing the widespread adoption of sustainable blister packaging solutions.

12. What are the primary factors driving the use of current blister packaging materials? (Use the arrows to rank the following from 1 = most important to 5 = least important) *

| |
|---|
| Cost |
| Regulatory compliance |
| Market availability |
| Packaging performance (e.g. moisture barrier, durability) |
| Sustainability concerns |

13. What are the biggest challenges to adopting sustainable blister packaging materials in your site? (Select all that apply) *

- High cost of sustainable materials
- Regulatory barriers
- Lack of suitable alternatives
- Performance concerns (e.g., durability, protection of product)
- Customer/market demand is low
- Supply chain issues
- Other

14. Has your site tested or implemented any sustainable packaging alternatives for blister packs? *

- Yes, successfully implemented
- Yes, but not implemented due to issues (e.g., cost, performance)
- No, not explored
- Other

15. If you answered yes to Q14, what was the outcome of the testing/implementation of sustainable packaging alternatives? If you answered no, why has your site not tested/implemented any sustainable alternatives? *

Enter your answer

Regulatory and Market Constraints

This section explores the influence of regulatory requirements and market demands on packaging sustainability.

16. How do regulatory requirements (e.g., FDA, EMA) influence material selection for blister packaging in your company? *

- Regulatory requirements are a major barrier
- Regulatory requirements are somewhat limiting
- Regulatory requirements have little to no impact
- Unsure

17. Do you believe that current regulations support or hinder the adoption of sustainable packaging in the pharmaceutical industry? *

- Strongly support
- Somewhat support
- Neither support nor hinder
- Somewhat hinder
- Strongly hinder

18. How much does customer demand influence your company's decisions on adopting sustainable packaging solutions? *

- A great deal
- Somewhat
- Very little
- Not at all

Sustainability Initiatives and Future Outlook

This section looks to the future of sustainable blister packaging.

19. What sustainability initiatives has your company implemented relating to packaging waste reduction? (Select all that apply) *

- Material reduction (e.g., using less plastic)
- Use of recyclable materials
- Improved packaging designs (e.g., minimizing waste)
- Reuse/recycling programs for packaging
- None
- Other

20. What do you believe is the most promising solution for reducing blister packaging waste in the pharmaceutical industry? *

- Switching to biodegradable materials
- Redesigning blister packaging to use less material
- Increasing recyclability of materials
- Implementing take-back or recycling programs
- Other

21. What is your outlook on the future of the adoption of sustainable blister packaging in the pharmaceutical industry over the next 5-10 years? *

- Very optimistic (widespread adoption likely)
- Somewhat optimistic (adoption will increase, but challenges remain)
- Neutral (adoption will remain the same)
- Pessimistic (significant barriers will prevent adoption)

Open Ended Questions

This final section allows you to expand on any thoughts you may have on sustainability in pharmaceutical blister packaging manufacturing.

22. In your opinion, what is the single biggest barrier preventing the pharmaceutical industry from adopting more sustainable blister packaging solutions? *

Enter your answer

23. What changes (e.g., technological, regulatory, market) would need to occur for sustainable packaging solutions to become mainstream in the pharmaceutical industry? *

Enter your answer

24. Please share any additional comments or insights regarding blister packaging waste and sustainability in the pharmaceutical industry. *

Enter your answer