ASSESSING SUSTAINABILITY FOR PACKAGING: ENVIRONMENTAL CHALLENGES AND RESPONSIBILITIES OF PACKAGING DESIGN

By: Kevin Leggett

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Abstract:

Packaging is a unique industry and often not top of mind to everyday people. However, it plays an important role influencing consumers with every purchasing decision in addition to having major impacts on the environment and climate change. In this study the use of assessment tools was examined to identify environmental impacts of packaging and how sustainable packaging design provided solutions to those impacts. Several research questions were identified and addressed regarding media influence, specific environmental impact indicators, existing assessment tools such as life cycle assessments, and a policy evaluation for producer responsibility. An extensive literature review was conducted regarding the four research topics to provide findings on flexible packaging, one of more visible packaging types to everyday consumers that represent environmental challenges. A fifteen-question online survey was sent to twenty experts in the packaging field to gain their insights on the four major topics. The results of the survey and analysis were compared to the literature review findings to answer the overall research question. Media influence does occur amongst consumers as well as the expert decision makers on the issue of packaging impacts especially regarding recyclability. Assessment tools for packaging were effective at addressing the harmful environmental and climate impacts of packaging. These tools helped to highlight sustainable packaging development and design solutions, in addition to better communicate these findings to the public. Finally, the responsibility of packaging impacts was debated, however Extended Producer Responsibility programs were implemented in several states in the US where the success of that tactic is not yet determined. Addressing these research problems on packaging will help consumers understand a piece of the environmental equation that affects their everyday lives that is not communicated fully enough to the public.

Executive Summary:

Media attention has typically fixated on improper waste management practices of packaging by consumers as the root cause of environmental harms and recycling as the primary solution. This feedback loop of negative information and confusion has shaped consumer perception of packaging as solely responsible for environmental harm. With a focus earlier in the design phase, the primary decision makers have access to several available assessment tools to effectively choose materials or containers that mitigate environmental burdens at various life cycle stages before reaching consumers. Life cycle assessments along with others such as carbon footprint analysis, and supplier scorecards can evaluate environmental impacts from packaging while ensuring packaging is designed sustainably to address food waste, safety, and a circular economy. Finally, policies and laws around the world addressing packaging impacts is being debated in the US with the emergence of policies such as Extended Producer Responsibility for packaging to hold producers accountable for material burdens over consumers. A review of existing literature and case studies identified and evaluated the assessment tools and resulted in several findings on packaging impacts and benefits. The methodology utilized to test four critical research questions was a fifteen-question online survey sent to packaging professionals and experts to gain their insights into four main research categories: media influences, environmental impacts of packaging, assessment tools, and consumer/producer responsibility for packaging. The main findings of the literature review and survey indicated packaging professionals align on most of the existing knowledge behind these research questions. Those who manage the designs of packaging have a deep knowledge base of the benefits and barriers to sustainable packaging and the diverse set of tools to assess them. Packaging professionals were equally influenced by media perception as everyday consumers but have a level of insider knowledge that steer their

decisions to create and promote sustainable packaging. The best available assessment tool, not without flaws and limitations, was still considered the life cycle assessment as it is able to assess environmental impacts of new and existing packaging from design to disposal phases. However, LCAs were considered better optimized when paired with the other tools such as the targeted carbon footprint analysis or a scorecard approach that evaluated the entire supply chain of a producer. Another main finding to promote sustainable packaging design was the integration of supply chains in businesses large and small. There were also differing opinions on whether consumers or producers should be held responsible for packaging's impacts on the environment. Packaging professionals felt that a shared responsibility approach should be considered between consumers and producers and that the industry should have a seat at the table in creating EPR programs in the US. The primary limitations of the study included time and resources to conduct a specific comparison of these assessment tools through a common packaging item. Ultimately this study challenged the status quo of media influence regarding packaging and recycling and LCA usage as the primary assessment tool. Insights were gained from subject matter experts in this unique field to better understand packaging's impacts and solutions to environmental and climate challenges faced today. The hypothesis was affirmed that packaging engineers and professionals have several effective tools available to identify and interpret the environmental and climate challenges that packaging presents.

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Abbreviations and Acronyms:

Abbreviations	Meaning
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
GWP	Global Warming Potential
EPR	Extended Producer Responsibility
EU	European Union
EPA	Environmental Protection Agency
LDPE	Low Density Polyethylene
LLDPE	Linear Low-Density Polyethylene
HDPE	High Density Polyethylene
PET	Polyethylene terephthalate (Polyester)
PLA	Polylactic Acid
Polyamide	PA6 (Nylon)
EVOH	Ethylene Vinyl Alcohol
COMPASS	Comparative Packaging Assessment
PIQUET	Packaging Impact Quick Evaluation Tool
GHG	Greenhouse Gas
CF	Carbon Footprint
Kg	Kilogram
Eq	Equivalent
MJ	Mega Joules
KPI	Key Performance Indicators
CO2	Carbon Dioxide
NOx	Nitrogen Oxide
SO2	Sulfur Dioxide
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
AL	Aluminum
MOPP	Monoaxially Oriented Polypropylene
MPET	Metalized Polyester
SPC	Sustainable Packaging Coalition
IRB	Institutional Review Board
FPA	Flexible Packaging Association
CPG	Consumer Packaged Goods
SPA	Sustainable Packaging Alliance

1.0 Introduction:

Companies around the world and across all sectors are embracing the concept of sustainability. Even those industries seen as major contributors to climate change and environmental harm are incorporating the language and practices of sustainability into their corporate strategies (Kiygi-Calli, 2019). The growing volume of packaging needed to deliver products and meet the demands of consumers has significant consequences on the environment and climate change. In the larger picture of climate change, there are obvious indicators – visible smog from factories or the melting of arctic shelves. Packaging is also a visible and commonly observed problem plaguing the environment – with mounds of plastic waste piled in the oceans – where the harms are typically identified at the end-of-life or disposal stage (Hamilton et al., 2019). However, some of the more damaging contributions of packaging occur much earlier in its development**.**

One of these commonly observed packaging types is called ‘Flexible’ packaging, which offers greater conveniences to contain, transport, store, and sell products to consumers (Morris, 2017). This packaging type makes up bags, wrappers, pouches, and lidding each offering unique properties and protections for the product inside (Bukowski & Richmond, 2018). It is often constructed using multiple layers of material to provide enhanced protection and usability features for the optimal product and consumer experience (Maust, 2021). Consumers have begun to embrace the practices of reducing excessive packaging through recycling, and composting, and even supporting in some cases the absence of packaging altogether (Feber & Granskog, 2020). Though concepts like recycling have gained in popularity there is a dissatisfaction with the complexity and feeling of pointlessness when it comes to items collected being brought back to use. In the US, there currently is no closed loop system for flexible packaging due to the

complex nature of its construction (Swinehart, 2014). The combination of paper, foil, and plastic laminated into one film make recyclability a major challenge for this aspect of the packaging industry (Anthony, 2021). Separation of these materials is required to adequately recycle them, and that process is expensive and cumbersome (Hagerman, 2021). When flexible packaging is not accepted into recycling, it's typically tossed into the general waste stream or littered into the ground contributing to damaging environmental factors. However, the end-of-life stage only tells part of the story. The primary media attention and coverage on where packaging waste ends up, often ignores the other impacts from the original source, the manufacturers (Feber et al., 2021).

Many companies and academic researchers have relied on tracking these impact indicators at different stages of development through an assessment tool called Life Cycle Assessments (LCA). LCAs enable the user to apply inputs such as energy usage at various stages of a product/ packaging life cycle to determine the outputs in the form of the impact indicators such as global warming potential (GWP), ozone layer depletion, freshwater eutrophication, and others (Boz, 2020). These tools are also used to examine the potential impacts from adopting alternative packaging from renewable sources or with recyclable potential (Toniolo et al., 2013). LCAs are important first steps at gauging the impacts of packaging produced, however they present several limitations such as a short-term view of environmental impacts, varying assumptions, limited scopes, and lack of repeatability all depending on the user (Lingle, 2021). There are other assessment tools that are suitable to effectively target certain impacts and areas that promote sustainable packaging alternatives. Finally, some legislative and policy initiatives such as Extended Producer Responsibility (EPR) for packaging is emerging in the US, following a dramatic decrease in recycling programs since 2017 in other nations (Choi-Shagrin, 2021).

Objective: The purpose of this study is to analyze the effectiveness of assessment tools to address the environmental and climate impacts of packaging and implement sustainable packaging solutions. The influence of media sources will be examined to understand perceptions of packaging on consumers and producers. Life cycle assessments and other assessment tools will be explored to measure the effectiveness of impact identification, impact reduction strategies and other sustainable packaging solutions. Policy and legislative actions will be reviewed which were designed to address consumer and producer responsibility for packaging impacts. A survey of packaging industry professionals from various sectors and roles will be conducted to gain insights from these experts into four categories tied to the research questions below.

Hypothesis: The use of assessment tools is an effective method of identifying harmful environmental impacts from packaging and promoting the benefits of sustainable packaging design.

Research questions:

RQ1. How does the media drive and influence packaging perception? The expansive access of information and diversity of sources drive opinions and behaviors of people on several issues. Packaging industry decision makers are also consumers that can be influenced by different media and the validity of those sources. Understanding the media portrayal of packaging is important to understand how it affects the experts in decision making of sustainable design.

RQ2. What are the critical impacts of packaging on the environment and climate? There are several impacts that result from packaging's development and use in the world. With the increased volume of products and interconnected trade, packaging exacerbates impacts such as global warming potential and water pollution in addition to other

unforeseen impacts. The life cycle phases of flexible packaging will be examined to determine if recycling and end of life stages are more important than earlier stages.

RQ3. Which assessment tools are most effective at identifying and creating long term solutions to environmental impacts from packaging? Life cycle assessments are the most used tool but there are others that could effectively address the long-term impacts of packaging and not just a snapshot in time (Schwarz, 2017). Several tools including LCAs will be compared and examined for their metrics and findings across studies.

RQ4. Are consumers or producers responsible for packaging impacts? As EPR legislation gains momentum in the US, manufacturers are being driven to assume more of the financial responsibility of recycling waste packaging they produce. However, producers argue that consumers hold just as much decision-making power by what they're willing to buy in the form of sustainable packaging.

2.0 Literature Review:

An extensive review was conducted on the literature of packaging evaluating several assessment tools for environmental impacts and sustainable packaging design. The review looked at LCA studies that evaluated flexible packaging as the central variable. The review evaluated the principles and uses of other assessment tools for packaging and their tradeoffs in comparison to the LCA method as the most used tool. Lastly an emerging policy in the US on packaging waste and responsibility was examined.

2.1 Background:

2.1.1 Packaging Basics:

The study of Packaging is a unique field that is not always top of mind for consumers despite interacting with it daily. When people go to purchase an item at the store, packaging often drives the initial perceptions of many factors beyond the product such as the brand, its utility, the environment, and personal values (Feber & Granskog et al., 2020). From the eye-catching label on a bottle of wine to physical conveniences of microwave-in-the-bag vegetables, packaging is as much the selling point as the product itself. One of the main packaging types that is associated with environmental challenges and poor end of life outcomes is flexible packaging. Unlike rigid packaging such as plastic clamshells, trays, or bottles, as the name suggests, this type of packaging is most suitable for its flexibility to transport and store more products efficiently (Bukowski & Richmond, 2018). It also has a considerably smaller carbon footprint and material usage than rigid packaging (Swinehart, 2014). However, flexible packaging impacts are not insignificant and can be just as harmful from a climate and environmental standpoint. Flexible packaging typically takes the form of thin film material. At a glance most films appear

to be a single layer of material, but typically are constructed with multiple micro layers where each plays a specific role (Bukowski & Richmond, 2018). The multiple layers of materials create a major challenge for recycling sorting as the layers need to be separated (Swinehart, 2014).

Figure 1: Composition of multi-layer flexible packaging film construction:

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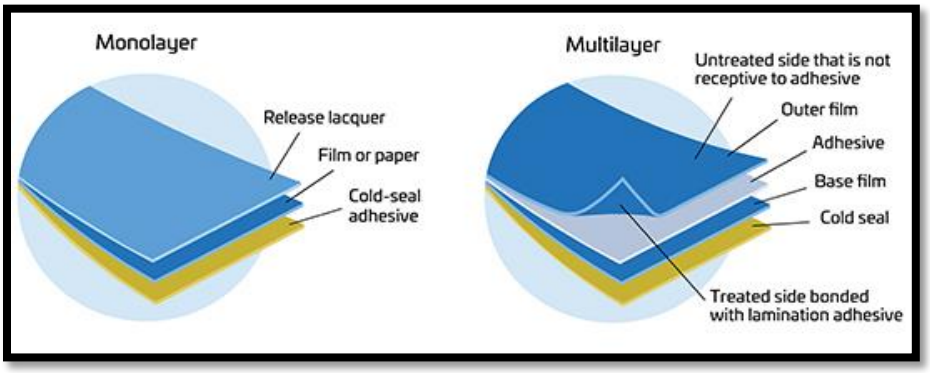


Source 1: CP Flexible Packaging. (n.d)

2.1.2 Sustainability:

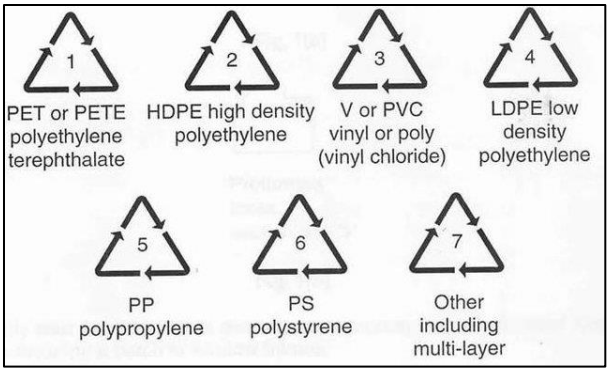
The concept of sustainability science emerged in the 1980s as scientists started to examine how humans meet their needs to survive while maintaining the functions and resources of the planet (Kates et al, 2001). The definition of sustainability has expanded across a wide span of industry sectors and into social framework of people's everyday lives. The EPA has defined sustainability as "conditions that ensure that human impact on the environment is sufficiently mitigated in pursuit of the protection of natural resources and of future generations' access to water, material, resources, and social and economic requirements" (EPA, 2022). With that foundation those in the packaging industry began to foster an understanding that packaging designs and development also needed to adhere to sustainable principles. The triple bottom line concept was identified as a framework for businesses to measure their impacts through social, environment, and financial lenses (Verghese et al., 2012). The book on *Packaging Sustainability*

by Verghese et al. (2012) noted the triple bottom line approach should be adopted for packaging design to balance with packaging performance. Encouraging a departure from business as usual, the book defines the sustainability framework for packaging design as “effective, efficient, cyclic, safe” (Verghese et al.’s, 2012).

2.1.3 Key Materials:

Despite dramatic push back in recent years, plastic remains the dominant material of choice for much of the packaging industry across all sectors and is set to continue growing at an accelerated rate (Bukowski & Richmond, 2018). Plastic polymer materials start out as pellets of resin that are extracted and formed into sheets of film through processes of co-extrusion and lamination (Tri-Cor, 2015). Each plastic type has specific properties for various applications and usages.

Figure 2: The 7 primary plastic polymers used in packaging that account for 70% of plastics produced (Posen et al., 2017).



Source (Valavanidis & Vlachogianni, 2014)

Two of those materials, Low Density Polyethylene (LDPE) and Linear Low-Density Polyethylene (LLDPE), are the most used for flexible film materials like grocery or trash bags. Bioplastics like Polylactic Acid (PLA) and bioethylene-based plastics are popular substitutes for the seven polymers that are utilized for their recyclability and renewable sourcing (Posen et al.,

2017). Other common film materials include Polyamide (PA6) or Nylon and EVOH (ethylene vinyl alcohol) (Pauer, 2020). As the flexible packaging industry has expanded, the use of multilayer film packaging has become a popular choice among manufacturers. Multilayer films combine various layers of films (ranging from three to seven films) coextruded into a single flexible film. Aluminum (AL) and metal-based foils are included as barrier layers to prevent sunlight and moisture vapor from penetrating the products themselves (Bayus, 2016).

2.2 Media influence and perception of packaging:

Improper waste management of packaging has been presented as the most harmful aspect of packaging by the general media. Sources from cable news channels and online articles from well-known news organizations like the New York Times have reported on the escalating climate crisis and environmental challenges with visuals like plastic mounds in the oceans (Corkery & Sengupta, 2021). Better recycling practices are an important aspect of reducing packaging impacts, however this has been covered as the primary action for consumers to solve this issue (Feber et al., 2021). Though mostly accurate, the media's influence on packaging in the minds of consumers has two main outcomes. First a feedback loop of information influences a view that is primarily focused on consumers properly recycling to address impacts from packaging. This influences the ideas and behavior of packaging professionals and decision makers to focus on making packaging recyclable as opposed to sustainable. Many of the primary plastics used for flexible films are sourced from petrochemicals in the raw material life cycle phase (EIA, 2021). The impacts from those raw materials occur several phases before recycling comes into play.

Second, the capability of sustainable packaging to bring down environmental impacts is not adequately conveyed to the public. Packaging plays a vital role as a contributor and solution to the environment despite the limited perspective of media reporting and information presented to the public on this topic. The recent Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment report briefly mentions the role packaging plays in reducing food waste (IPCC, 2022). But more sustainably designed packaging has the potential to offset other damaging factors such as GHG emissions, food insecurity, and other environmental contaminations outlined in section 2.4. Better communication of these other aspects is important to convey a full picture of packaging impacts and benefits to the public.

2.2.1 Media push for recycling

Alternative solutions are promoted heavily in the media through discussion of "green initiatives" or "eco-friendly" designs. However, these terms do not always convey the processes or feasibility to develop these alternate material sources. The pressure from media and regulators on producers to implement recyclable, green solutions, is brought onto packaging professionals in these businesses to deliver on these concepts (Felton, 2021). The effectiveness of alternate materials and packaging that is recyclable was among the more complicated discussions in the literature with differing results.

Bishop et al.'s (2021) study looked at the differences between production of two types of film raw materials, plant-based, recyclable PLA and a conventional petrochemical plastic. The results indicated that a host of environmental impacts were higher for PLA production, however proper recycling of the packaged product during the end-of-life stage improved overall environmental performance (Bishop et al., 2021). The reliance on proper recycling practices to offset impacts earlier in the process depended on recycling being at scale and a higher circularity

rate. In the US, recycling has yet to reach this level, so the impacts of production continue to cause harmful effects until there is a more consistent and efficient circular waste management system for these packaging types (Maust, 2021). Based on various waste treatment scenarios, Hou et al. (2018) found there were environmental benefits from the recycling process which can offset the impacts of virgin plastic production. Toniolo et al's (2013) study was unique as it compared innovative recyclable films to conventional non-recyclable films where both variables were upcycled from PET bottles that were treated for reuse. The results supported the idea that non-recyclable film material had significantly higher impacts among eighteen environmental indicators compared to the recyclable film (Toniolo, 2013). This scenario indicated that the processes of upcycling and recycling materials, a circular system, led to needed reductions in environmental impacts for packages generally sent to the landfill. Barlow, C. & Morgan, D. (2013) analyzed the impact of flexible films and bag packaging's "influence of packaging on levels of waste and energy consumption elsewhere in the system". The outcome of that study indicated that current conventional packaging is wasteful and inefficient, but alternatives can be just as harmful (Barlow, C. & Morgan, D., 2013).

2.2.2 Importance of Sustainable Packaging

The McKinsey Institute identified three critical elements that packaging sustainability addresses: packaging leakage into the environment, reducing greenhouse gas (GHG) emissions per packaging material across value chain, and circularity (Feber et al., 2021). The article stated that for "brand owners and retailers, the focus has been primarily around the circularity—dealing with recyclability and recycled content— but there is growing interest in carbon footprint and elimination of waste leakage" (Feber et al., 2021). Benchmarking was recommended as a better way to present the reality of specific packaging scenarios to consumers. The McKinsey Institute

study calculated recyclable beverage containers had a higher carbon footprint. Despite that, the study found that consumers expected aluminum and glass containers to have lower emissions based on perception of recyclability compared to plastic bottles. However plastic bottles had lower carbon footprints (both direct and indirect) compared to the AL cans which have energy intensive production processes (Feber et al., 2021).

The development of monolayer (single layer) film packaging has grown as a favored sustainable solution as the one layer, lacking the energy intensive barrier layer, created greater potential for recyclability (Swinehart, 2014). However, this led to a lack of preservation quality for food or reduced shelf life of other products that the multi layers of material offers (Swinehart, 2014). A shorter shelf life leads to greater food losses and insecurity. One of the most important functions that flexible packaging plays is the preservation of food. Flexible packaging can play a positive role in the fight against climate change through reducing food and product waste when these factors are considered in the early design phase (Voulvoulis et al., 2020).

2.3 Assessment Tool Evaluation and Findings:

As the sustainability movement has gained momentum due to the concerns of human and industrial impacts on the environment, assessment tools are used more and more to design packaging and products to reduce these challenges (Pauer et al., 2019). LCA's remain the most utilized tool to clearly point to damaging effects from packaging or products at different critical stages, however the variations in scope and boundaries hinder their ability to be used as drivers of decision making or provide conclusive research on alternative designs and materials for packaging (Shwarz, 2017). Various other tools were identified to evaluate sustainability of packaging outside of the general lifecycle process. These tools include carbon footprint analysis, material selection guides, scorecards, and eco design. These various environmental and

sustainability assessment tools both incorporate life cycle analysis in their frameworks and identify different long-term impacts that ultimately aid in the decision-making process of packaging design. The following section will examine the other existing assessment tools and approaches that can present other angles into packaging's impacts on the environment and climate change.

Table 1: Common assessment tools analyzing environmental and sustainability for packaging

Category	**Assessment Tools**	**Descriptions**	**Standards and References**
LCA	Life Cycle Assessment	The quantification of environmental impacts through a product or package life cycle (Boz, 2020).	ISO standards 14040 and 14044
	Life cycle Inventory (LCI)	US database that collects energy and material inputs to supports LCA studies.	NREL LCI Database (NRE, n.d)
	COMPASS	A cloud-based software that identifies impacts of packaging created by the Sustainable Packaging Coalition to bring together environmental performance and material selection for sustainable packaging design (Trayak, n.d).	Sustainable Packaging Coalition (Trayak, n.d)
	PIQET	Software that compares environmental impacts of various packaging options. Publicly funded by Australia's government and the data is accessible to businesses. (Horne and Fitzpatrick, 2006).	Sustainable Packaging Alliance (Australia)
Carbon Footprint	Carbon Footprint Analysis	Examines and measures the GHG emissions from the manufacturing of a product or package (Sanye-Mengual et al., 2014).	GHG Protocol, ISO-DIS 14067 (GHG Protocol, n.d). PAS 2050– Carbon footprint for goods and services. (Carbon Trust, 2017)
Design and Development	Material Selection Guides	A guide to the assessment of packaging materials. Some come in the form of complex matrices of materials or a collection of briefs on typical material alternatives. Utilized across different companies both small and large. (SPA, n.d; Parra, 2008)	These types of assessments are not standardized and come in several different forms depending on the user.
Design and Development	Eco Design	Approach meaning designing for the environment where environmental considerations are taken	EU directive 94/62/EC

		during the design phase of a product and packaging (Schwarz, 2017).	
Decision-Making	Scorecards	Each supplier receives a score to compare with others in various categories like space efficiency and utilization on pallets (Parra, 2008).	No standardized method.

Note: Categories from Schwarz' (2017) study was used to organize these tools.

2.3.1 Life Cycle Assessment

One of the primary assessment tools that resulted from environmental impacts tied to the boom of products and subsequent packaging is the Life Cycle Assessment. This methodology is one of the most popular tools used by companies and researchers to assess impact indicators generated from various stages of a product or package's journey to end users. Sand's (2020) article in *Packaging Digest* noted that LCAs can guide users in sustainable packaging design and material selection (Sand, 2020). LCAs are versatile methods for product and packaging assessment that can be examined from several different approaches.

The first version of LCA tools started in the food and beverage industry in the 1960s where manufacturers started examining production choices, specifically for raw material planning (Andrieu, 2021). With the introduction of sustainability as a concept, manufacturers were pushed to adopt LCAs to reduce their solid waste output. Later the International Standards Organization (ISO) standards 14040 and 14044 were established to prevent companies from misusing data from the tool to circumvent accountability for any environmental impacts (Andrieu, 2021).

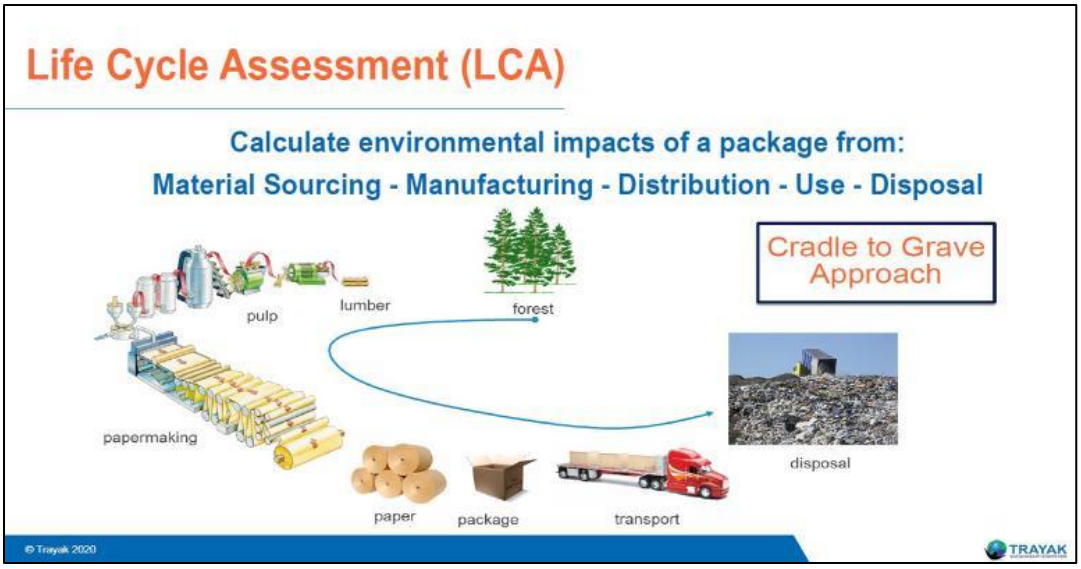
More packaging specific LCAs have been created to assist packaging professionals with evaluations of their designs (Sand, 2020). The Comparative Packaging Tool (COMPASS) and the Packaging Impact Quick Evaluation Tool (PIQUET) are streamlined lifecycle evaluation tools specifically for packaging design that were widely used by some researchers and companies in the review of the literature (Dobrot, 2014). LCAs notably identify and evaluate a

list of environmental indicators during the life cycle of a product or package (Farrelly et al, 2020). As a result of key inputs from raw material extraction to the energy intensive production processes, LCAs can calculate the overall manufacturing lifecycle that packaging contributes related to critical environmental and climate related impacts (Hartman, 2012).

Life cycle assessments examine various critical stages for packaging development where each contributes to varying levels of environmental impacts along the way to the consumer and beyond (Lingle, 2021). Various inputs and outputs occur throughout the process which have major contributions to the climate crisis facing the world today. The primary life cycle stages of flexible packaging development exanimated can vary depending on the boundaries drawn for the assessment (EcoEnclose, 2021). The different approaches of life cycle evaluations include the following:

1. **Cradle to grave**: a full evaluation from creation to disposal (Pauer et al., 2020).
2. **Cradle to factory gate:** examines the product/package from raw material extraction through production channels (Siracusa et al., 2014).
3. **Gate-to-gate:** approaches are partial LCA studies looking at specific impacts at a particular stage in the life cycle (Wassenaar, 2020).

Figure 3: Example of life cycle stages evaluated for a cradle to grave assessment



Source: (Lingle, 2021; Trayak, n.d)

Schwartz' (2017) study looked beyond the LCA process and developed a sustainability assessment framework that considered the "temporal changes and interrelations between the product and its system environment and vice versa". Without taking packaging and products' complex and interconnected journey into account, the true impacts cannot be identified and addressed (Schwarz, 2017). It concluded that LCAs should maximize the environmental and social performance of economic activities following Verghese et al.'s (2012) triple bottom line framework for driving sustainability in companies (Schwarz, 2017). Verghese et al. (2012) recommended expanding LCA metrics to include reductions in waste, more recycling, and water and energy consumption to improve life cycle efficiencies for packaging and the product.

2.3.2 Other Assessment Tool Breakdowns:

Scorecard: In 2006, Wal-Mart launched a sustainability scorecard system to evaluate its supplier's material usage and environmental impacts (Wal-Mart, 2006). This method transformed the way large retailers and manufacturers evaluated and held their network of

suppliers accountable. These scorecards are however company specific and are meant to align with “corporate sustainability goals/sustainable packaging policy” according to the Dordan Manufacturing’s methodology for assessing packaging sustainability (Slavin, 2013). Based on the targets a company sets, aggressive or not, the scorecard method follows their lead. Another limitation identified by Verghese et al. (2012) characterized the scorecard system as more ‘streamlined’ than a full LCA creating more limitations of impacts it addresses (See Appendix D for Scorecard example).

Material Selection Guides: This method varies and is not a standardized practice. Some entities utilize custom checklists or briefs on materials for packaging design (Liubkina-Yudovich, 2010). There are also online tools such as the one created by the SPA in Australia. Their material selector tool provides accessible material information covering descriptions and properties, applications, recycling rates and recyclability of certain materials (SPA, n.d; Parra, 2008). Liubkina-Yudovich, (2010) study evaluated quantitative (LCA) vs qualitative (material briefs) tools to aid packaging decision makers at a large manufacturer in creating sustainable designs. The study identified the variations in human experience and bias of a packaging engineer designing the packaging systems plays a major role in the choices made using the material selection brief. For instance, one packaging engineer's experience with a supplier can influence their decision to utilize a certain material from that vendor in the design phase (Liubkina-Yudovich, 2010). While another engineer may base their choice of avoiding sustainable design tools due to years of experience with a handwritten material list they’ve maintained over the years (Liubkina-Yudovich, 2010). Quantitative data from tools such as LCAs were found to be best tools to empirically test the impacts that specific materials and packaging have on the life cycle.

Eco Design: According to Schwarz (2017)**,** eco design makes up a collection of tools assessing sustainability in product development and considering its interactions with the environment. As one of the tools in the category of product design and development, this analysis method gauges product sustainability early in the development phase and is used to improve the existing product life cycle (Sanye-Mengual et al., 2014). Other environmental factors evaluated in the process are waste, resource consumption, and emissions. LCAs were used in some studies to confirm effects and impacts of the Eco Designs tool use (Sanye-Mengual et al., 2014; Sanye-Mengual & Lozano et al., 2014).

Carbon Footprint Analysis (CF): Addressing the social element of sustainability, several studies found in the literature utilize this type of analysis. In CF analysis, GHG emissions are put into CO2 equivalent. LCA tools were again used in tandem with CF analysis. Sanye-Mengual and Lozano et al. (2014) stated carbon footprint analysis was used more in the market to gauge emissions of specific products and set targets, whereas LCAs were utilized more in the literature and research. The standards in the GHG Protocol range from lifecycle approaches to individual products to an entire accounting of a corporate value chain finding the environmental impacts of emission (GHG Protocol, n.d). Sanye-Mengual and Lozano et al. (2014) identified several sustainable packaging designs in their study that utilize CF analysis to specify the emissions. Svannes' et al. (2013) study looked at the carbon foot of bananas across the product's value chain highlighting the role that the product itself plays on environmental.

Assessment tools can be used to close the information gap to consumers on packaging impacts and help communicate mitigation strategies. CF is more accessible to the public as "CF has been used as a tool to communicate the customer environmental performance not only about the product but also about the packaging" (Sanye-Mengual & Lozano et al., 2014). Certain tools

do not always effectively convey the full view of packaging impacts. For instance, the purpose of an LCA is to take in the entire life cycle of a product or package's environmental impact; however, the overall scope and boundaries drawn varies depending on the users' preferences and motivations (Farrelly et al., 2020).

2.4 Environmental Impacts and Main Findings:

2.4.1 Critical Environmental Impacts:

The primary goal throughout most of the LCAs conducted in these studies was to understand flexible packaging's influence on multiple environmental impact indicators identified throughout the studies. Table 2 presents the most common environmental indicators identified by LCAs tools.

Table 2: Environmental impact indicators identified from LCAs for packaging

Environmental Impacts	**Definitions**
Climate Change	Often presented as the 'climate change' indicator in studies measures the amount of energy absorbed by greenhouse gas emissions over a 100-year period (EPA, 2021).
Ozone Layer Depletion	This layer of the stratosphere is vulnerable to potential release of toxic contaminants from chemical products (Copernicus Services, n.d). The depletion and reduction of ozone particles faster than they can be replenished raises concerns of decreased filtration from UV sun rays (CAM, n.d).
Freshwater eutrophication:	When a body of water is enriched with minerals. This is caused by runoff from human sources like agricultural wastes and byproducts, and smog generated from combustion vehicles (USGS, n.d).
Fossil Resources	Reduction and reduction of fossil fuel resources.

Human Toxicity	Metric calculating the effect on human health and well-being from chemical leakage into the environment (Siracusa, 2014; Toniolo, 2013).
Respiratory Effects	Particulate matter; health effects of air pollution.
Water Consumption	Resource and energy usage of water
Embodied Energy	Energy required to manufacture the polymer (Bayus, 2016)
Energy Carriers	Energy or fuel brought to a system (Bishop et al., 2021)

The use of clear and tangible impact categories helps to communicate urgency to those decision makers and encourage more consideration in the early design phases of packaging. Izhar & May (2020) performed an LCA to evaluate the plastic packaging system for common bag raw materials such as LDPE finding high percentages of climate change (GWP) impacts, followed by acidification and particulate matter (Izhar & May, 2020). Multilayer films combining Polyamide (PA6-Nylon) and LDPE were examined in Siracusa et al.'s (2014) study which generated high fossil fuel primary energy consumption utilizing natural gas and crude oil. Finally, Morales-Mendez & Silva-Rodgriguez (2018) referenced a University of Hawaii study that noted breakdowns in plastics emit one of the most toxic GHG emissions, methane. In addition, the study indicated "metals of cadmium and lead contained in the pigments used in the manufacture of plastic bags… Sources of ozone layer depletion and air pollution". Based on those findings, the influence of raw material components contributes significantly to climate and environmental challenges which occur earlier in the design process. Further indicating factors can be missed when the focus is solely placed on recycling and end of life challenges.

LDPE and HDPE have some of the highest impacts during the production and processing phases even if the plastic packaging itself isn't immediately harmful to people (Morales-Mendez & Silva-Rodgriguez 2018). Although studies from the Flexible Packaging Association (FPA)

(Bukowski & Richmond, 2018) have highlighted flexible packaging's smaller carbon footprint compared to rigid packaging, most lifecycle assessments from more independent sources found that the production process of conventional flexible packaging contributes significantly to environmental impact categories like climate change (Swinehart, 2014). A comparison of plastic packaging materials to paper (kraft) packaging was done by Dahlgren et al. (2015), and plastic material production was found to be more impactful than paper production throughout the total life cycle of the product. The study noted flexible packaging Key Performance Indicators (KPI**s)** including global warming, acidification potential, eutrophication, and photochemical ozone layer depletion potentials were higher among the listed indicators for plastic material than paper alternatives during their manufacture (Dahlgren et al., 2015). The air emissions during the production phase of the two materials, included significant amounts of CO2, NOx, SO2, and aromatic hydrocarbons (Siracusa et al., 2014).

2.4.2 Impact Mitigation and Reduction Strategies:

Impact mitigation strategies employed to address these environmental factors were seen as the most effective compared to packaging designed to be recycled or have more circular end of life scenario because of LCAs. Pauer et al. (2020), Barlow & Morgan, (2013), and Siracusa et al. (2014) identified that packaging weight reduction offered a more effective way to decrease categories like climate change. All three studies also found reducing the usage of Polyamide (PA) in films would bring down impact categories in conventional multilayer films. Siracusa et al. (2014) suggests the contribution due to the packaging phase, in terms of environmental impact, can be reduced by adopting solutions oriented towards materials use and energy consumption optimization.

2.4.3 Package/Product Combination

Packaging experts have noted that the approach of examining the packaging, or the product individually misses fundamental impacts and paints a narrow picture of true environmental impacts (Swinehart, 2014). Pauer et al. (2020) conducted an LCA using a cradle to grave approach to examine six representative flexible films for packaging bacon blocks. The carbon footprint of the packaging was evaluated against the carbon footprint of the bacon and package together. The approach for evaluating environmental impacts in this study was different from many of the others looking at the whole product/ packaging system. The result was much higher environmental impact indicators for the combined system occurred whereas the impacts from the film packaging alone was lower (Pauer et al., 2020). With that finding, the recommendation was to light weight the materials that make up the film and to use less PA6 material instead of focusing on recyclability of the packaging material.

2.4.4 Integrated Supply Chain

One of the most common findings on implementing sustainable packaging practices was through a holistic assessment of the supply chain which goes beyond LCAs or any single tool looking at internal and external factors. Afif et al.'s (2021) study aimed to identify drivers of sustainable packaging. The study found collaborative interactions in the entire supply chain was the predominant driver. The effectiveness of integrating the supply chain also depends on the size of the firm (Afif et al, 2021). Supplier scorecards can be suitable tools to promote supply chain integration as they are designed to ensure vendors chosen at various levels in an organization comply with overall sustainability goals (Parra, 2008). Mattia et al.'s (2021) study noted that sustainable packaging would depend on the broader supply chain collaborating with

various stakeholders such as procurement, marketing, distribution, and others. The McKinsey Institute's methodology for linking sustainability elements focused on two supply chain related aspects to fix. First it focused on the indirect influence of carbon footprint where material weight and food waste impacted the shipping and distribution life cycle stage. The other aspect involved the potential for slow and sustained damage to packaging (Feber et al., 2021).

2.5 Policy and Legislation:

In the US, packaging laws and policies focused on sustainability and driving down environmental impacts are slim (Felton, 2021). However as renewable energy and emission reduction initiatives have emerged in localities, these policies and actions have risen to the state and federal level. The focus of packaging related policies is mostly aimed at drastically reducing single use plastics (Corkery & Sengupta, 2021). Specifically bans on plastic bags are growing as a common policy solution (Philippe, 2020). Verghese et al. (2012) noted that "Policies focusing on a single issue achieve limited environmental outcomes. More flexible approach enables strategies to be optimized on a case-by-case basis". Extended Producer Responsibility (EPR) for packaging is one major policy that has emerged to address the broader effects of packaging materials and designs chosen by producers. The Product Stewardship Institute (PSI) defines EPR for Packaging as providing sustainable funding for recycling by shifting the burden from governments and taxpayers to packaging producers and brand owners (PSI, 2020). The European Union along with other countries like Canada and Japan have implemented comprehensive packaging policies to manage waste including producer responsibility laws that have since boosted their recycling rates since the collapse of China's importation policies of the world's recyclables (Choi-Shagrin, 2021). The US has not implemented a broader national policy but EPR for packaging and product stewardship is being adopted by several states with a federal bill

pending a vote in Congress (Felton, 2021). The following section will examine the effectiveness of these policies to reduce environmental impacts and adopt sustainable packaging.

2.5.1 EPR Abroad:

The European Union has led the way in comprehensive directives that set rules and regulations on packaging development for manufacturers throughout the continent which include Directives 94/62/EC and Directive 2008/98/EC (Verghese et al., 2021). Directive 94/62/EC was first established in 1994 aiming to create a national standard of reducing packaging waste and promoting a circular market for packaging (European Commission, n.d). A 2018 amended Directive 2008/98/EC also focuses on protecting human health by reducing waste and environmental impacts such as resource use (European Commission, n.d). The EU directives incorporated EPR and product stewardship programs for all member nations as principal requirements (Verghese et al., 2012). Parra's (2008) study found the Directives push manufacturers to reduce leakage into the environment from raw material extraction through the transport and storage phases of the life cycle. Lee and Xu (2005) noted the EU set high targets for recovery and recyclability using whatever method best helped a producer reach them. At the time, reaching cost parity was a challenge due to the lack of scale and market for recycled content (Lee & Xu, 2005). However according to an assessment by Europen, member states still have uneven rates of recycling due to a lack of harmonization in minimum requirements for packaging EPR programs (Europen, 2021).

2.5.2 EPR in the US:

Significant legislative action has started to circulate amongst state governments to implement Extended Producer Responsibility for Packaging. The policy imposing a fee on those who manufacture waste items to cover their disposal has existed for specific everyday products in the US but for packaging it's a relatively new concept only recently implemented in a few states such as Maine and Oregon (Quinn, 2021). One of the reservations behind EPR laws is they could lead to increases in the price of goods if producers are incurring a greater fee on packaging (Gleason, 2021). Choi-Shagrin's (2021) article in the *New York Times* stated "One of the industries' main contentions was that the laws would lead to higher grocery prices for consumers. A study by the Oregon Department of Environmental Quality of Canadian E.P.R. programs found that consumer product prices had increased by only $0.0056 per item." With inflation on the rise, there is growing concern that EPR programs would affect groceries and other necessities kicking the costs onto consumers as a "regressive tax hike" (Gleason, 2021).

Another issue is the exemptions made for certain state specific industries. In the case of the Maine law, blueberry packaging, which is a major industry in that state, was exempt from the EPR program. There is concern exemptions like this might lead to other state exceptions (Felton, 2021). Another debate occurring with EPR is which entity manages requirements and financing of the programs. In Maine, industry stakeholders were excluded from the process with the state Department of Environmental Protection fully in charge (Felton, 2021). Oregon is taking a different approach by involving manufacturers on an advisory council to support the government run effort. Oregon will require producers to cover about 28 percent of the recycling costs and municipalities paying the remaining balance. This contrasts with Maine which requires producers to pay the entire fee (Choi-Shagrin, 2021).

3.0 Methodology:

An online survey, sent to packaging industry professionals who represent a cross section of those in different sectors, roles and experiences was conducted to test the hypothesis of the study. The aim of the survey was to provide an anonymous space for participants to convey their real-world experiences and insights on several questions that represented the overall study research questions including media influence of packaging perceptions, expert opinions on packaging impacts, assessments tools and their effectiveness, and producer/consumer responsibility. Several steps were taken to conduct this study and collect results.

First, an application was sent for approval to the Johns Hopkins Institutional Review Board (IRB) for human subject research. The process consisted of choosing a sample size of participants, a plan for recruiting, a submitted questionnaire, consent form, and explanation for minimizing risk to participants. Approval was granted by the IRB for exemption after a month.

Twenty participants were selected through Purposive Sampling which is a process of choosing participants based on their specific expertise and backgrounds for research (Robinson, 2014). Respondents were chosen from across industry sectors, experiences, roles, and departments with some in consulting and academic roles. They were reached by email and social media platform, LinkedIn. Each was asked to sign the approved consent form which was sent back before they accessed the survey. Participants accessed the survey through a web link provided to them. The survey was created and managed by Survey Monkey, an online survey creation platform. De-identification of the respondents was enabled through Survey Monkey and responses were stored there. This study contained fifteen total questions with an additional question for consent provided to participants as the first question in the survey. A series of open-ended and some closed-ended questions were asked. The questions were made up of multiple

choice, yes/no, ranked choices, and some short explanation responses. The first category of questions involved understanding the perception of media influence on consumers and their own personal information collection sources. The next category gained insights into respondents' expert opinions on environmental impacts from packaging and where they occur (i.e.: across materials, life cycles, and industries). After that, questions were asked about several assessment tools and their effectiveness. The participants identified the most valuable tools, and which was most effective at achieving sustainable packaging overall. Finally, two questions were asked regarding consumer and producer responsibility of packaging impacts.

Following completion of the survey, twelve respondents provided answers (60% participation rate). The results from respondents were analyzed for their insights on the four proposed research categories reflecting the four overall research questions. Connections were identified and recorded between findings in the literature review and the respondent answers. The nominal scale questions were examined first to analyze the numerical responses of certain questions such as number of respondents who gained information from scientific journals vs online articles. An ordinal scale analysis was done to analyze responses to questions that ranked answers from "somewhat valuable" to "extremely valuable". These measured the level of support for different responses (Question Pro, 2022). Finally, all open-ended responses to questions were recorded in separate documents along with the question to examine free thoughts and insights from the participants into the survey questions.

4.0 Results:

Following the end date of the survey, access was stopped, and results were reviewed. The main findings of the survey were separated into the four main research categories including: media influence/ information sources, packaging environmental impacts, assessment tools, and consumer/producer responsibility reflecting the overall research questions. The categories were chosen to evaluate and test the hypothesis. Table 3 presents the list of questions sent to participants.

Table 3 List of survey questions provided to participants

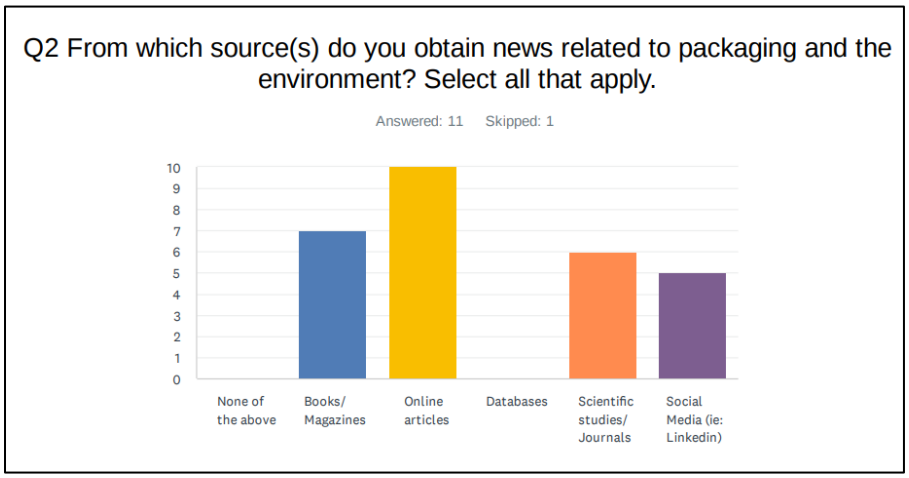
Category	Survey Question #	Survey Questions
Media Influence	2	From which source(s) do you obtain news related to packaging and the environment? Select all that apply.
	3	How accurate is the media perception of packaging impacts to the environment?
	4	What does the media get wrong about packaging's impact on climate change and the environment?
Environmental Impacts	5	Which industry creates the greatest environmental burdens?
	6	In your experience, at which stage of a packaging/product lifecycle has the highest environmental impacts on average?
	7	Which raw material used in bag packaging do you believe has the highest environmental and climate impacts through the early life cycle?
	8	Is production of monolayer flexible films (typically more recyclable) more energy intensive than multilayer films?
Assessment Tools	9	Are Life Cycle Assessments effective decision-making tools to aid companies to adopt sustainable packaging?
	10	Do Life Cycle Assessment outcomes typically favor sustainable packaging adoption?
	11	How valuable are environmental assessment tools (i.e.: LCAs, Carbon Footprint Analysis, Scorecards, or Material Selection Aids) to sustainable packaging adoption?
	12	How effective are material selection aids for choosing low impact materials to design flexible film packaging?
	13	Which sustainability assessment tools listed provide packaging engineers the best data to design and implement sustainable packaging while accounting for their overall environmental impact?

	14	Do you believe consumers adapt to what's presented to them such as technology or innovations in packaging. Or do consumers drive innovation and changes to conventional packaging? Should consumers be lead down one path?
Consumer/ Producer Responsibility	15	Should more states adopt the Extended Producer Responsibility legislation for packaging that places more financial responsibility to recycle on producers and municipalities over consumers?

Note: Question 1 asked participants for their consent to answer survey.

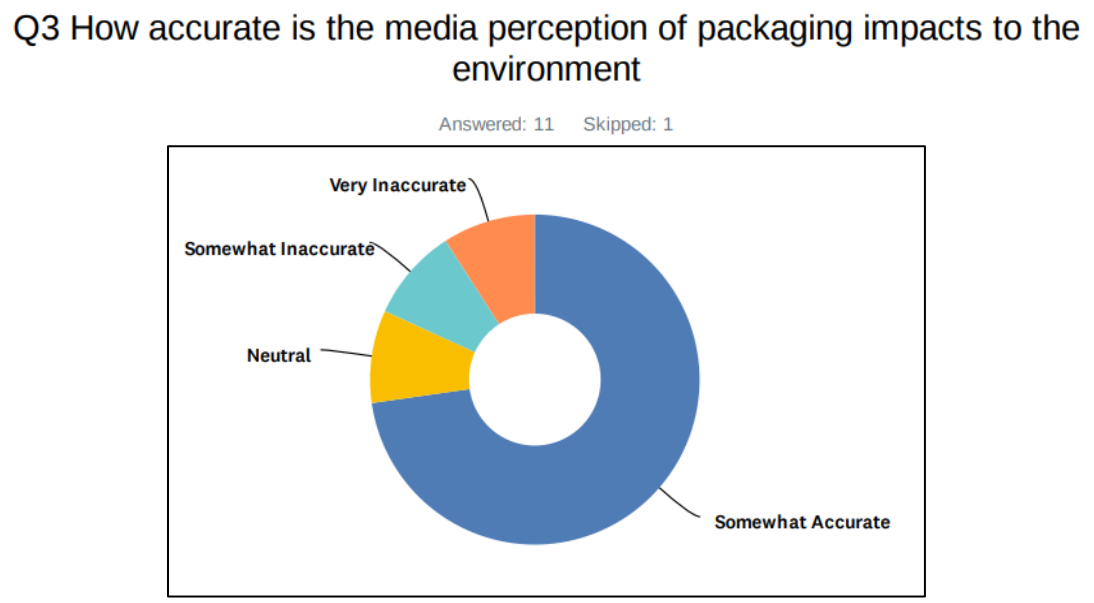
4.1 Media and Information:

Figure 4: Survey Question 2 -- From which source(s) do you obtain news



Most respondents obtained information from online articles (90%). The next were books and magazines (63.4%). The use of scientific studies as a source of information was almost as low as social media usage for information gathering. Alternate sources were identified by several respondents including: supplier/vendor data, discussions with global partners, and knowledge sharing from teams/ conferences.

Figure 5: Survey Question 3 -- Media accuracy of packaging perceptions

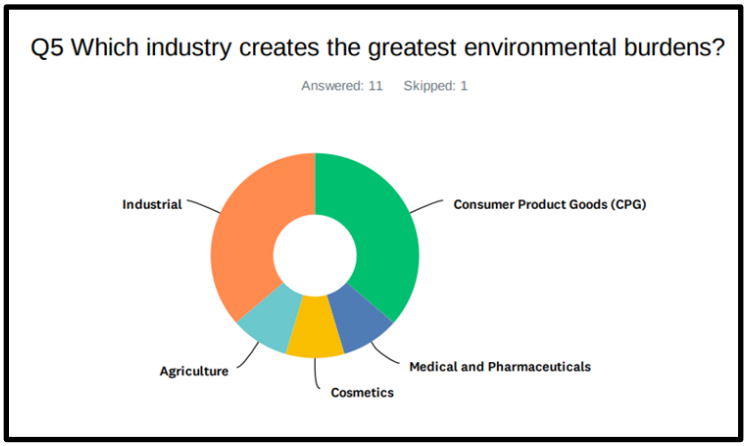


Most respondents found the media's interpretation of packaging's impacts to be somewhat accurate (73%). Only two out of the twelve found media portrayals to be inaccurate (17%).

Respondents were asked to provide open-ended insights into what the media gets wrong about the issue of packaging impacts on the environment. Appendix B for Survey Question 4 presents full list responses.

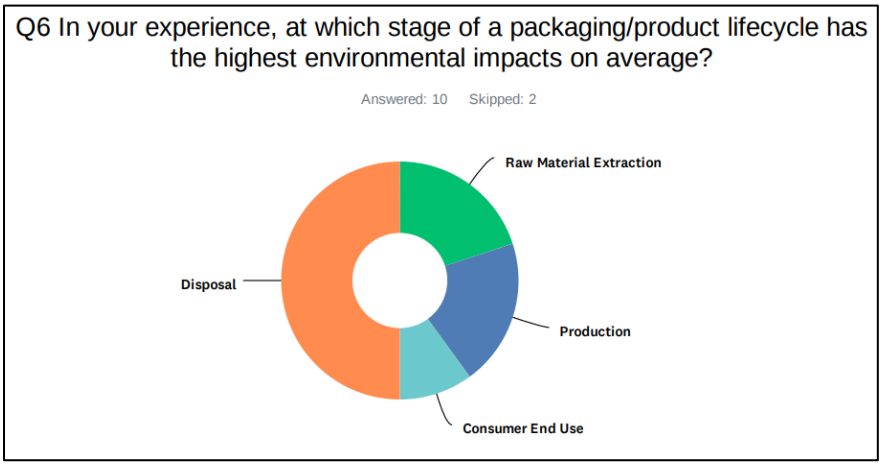
4.2 Expert Opinions on Environmental Impacts of Packaging:

Figure 6: Survey Question 5 -- Which industry creates the greatest environmental burdens?



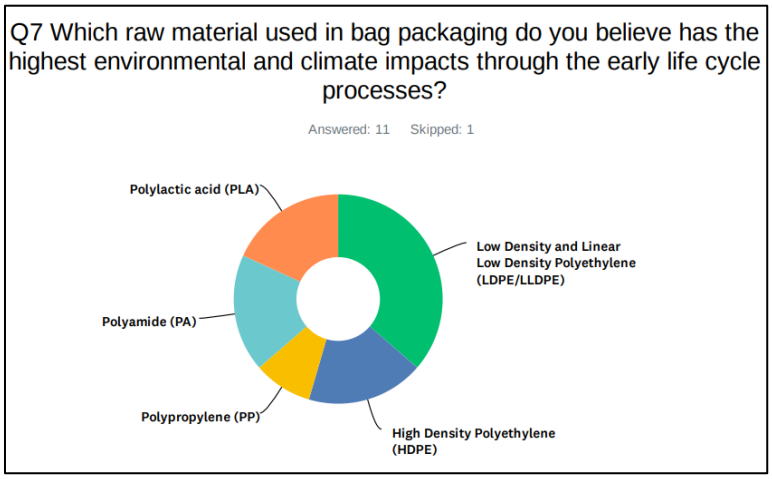
Respondents identified the industrial sector as having the highest environmental impacts (36%). followed by the consumer-packaged goods (CPG) or retailers.

Figure 7: Survey Question 6 -- Which stage of pkg lifecycle has the highest environmental impacts?



Half of the respondents (5) choose disposal as the highest impact stage. Two choose raw material extraction, two choose production phases and one selected consumer end use.

Figure 8: Survey Question 7 -- Raw material used in bag packaging with the highest environmental and climate impacts



The raw materials most chosen were the more common flexible packaging material LDPE/ LLDPE (36%). HDPE, PA, and PLA were equally selected as the next impactful. PP material was least selected (9%).

Figure 9: Survey Question 8 -- Production of monolayer vs multilayer flexible films

Q8 Is production of monolayer flexible films (typically more recyclable) more energy intensive than multilayer films?

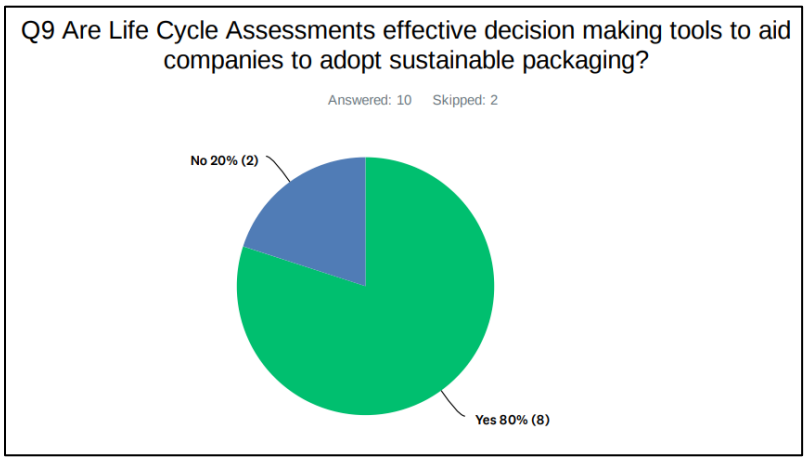
Answered: 11 Skipped: 1

ANSWER CHOICES	RESPONSES	
Yes	45%	5
No	55%	6
TOTAL		11

The production energy intensiveness of two flexible film packaging constructions were evaluated: Monolayer (typically recyclable) vs Multilayer. Results from this question were closely split with 45% finding monolayer more energy intensive to produce and 55 % indicating it is not more energy intensive.

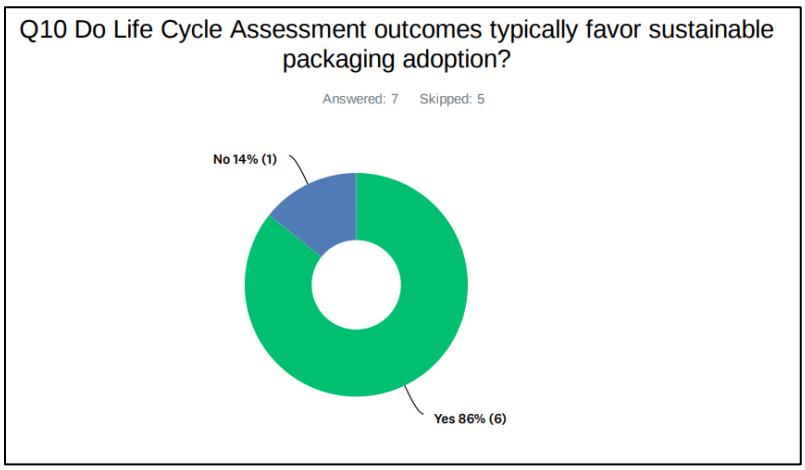
4.3 Assessment Tools:

Figure 10: Survey Question 9 -- Are LCAs effective decision-making tools?



Eighty percent of responses were yes. Some caveats were included in the responses of those who said ‘yes’ included in the discussion section.

Figure 11: Survey Question 10 -- LCA outcomes favoring sustainable packaging adoption



This question was skipped by multiple respondents. However, six respondents answered yes, and one said no. Responses were provided regarding the question in the Appendix B.

Figure 12: Value of assessment tools

Q11 How valuable are environmental assessment tools (i.e: LCAs, Carbon Footprint Analysis, Scorecards, or Material Selection Aids) to sustainable packaging adoption?

Answered: 11 Skipped: 1

ANSWER CHOICES	RESPONSES	
Extremely valuable	18.18%	2
Very valuable	45.45%	5
Somewhat valuable	36.36%	4
Not so valuable	0.00%	0
Not at all valuable	0.00%	0
TOTAL		11

No respondents answered, ‘not so valuable’ or ‘not at all valuable’. Two answered ‘extremely valuable’, five ‘very valuable’, and four ‘somewhat valuable’.

Figure 13: Survey Question 12 -- Effectiveness of material selection aids

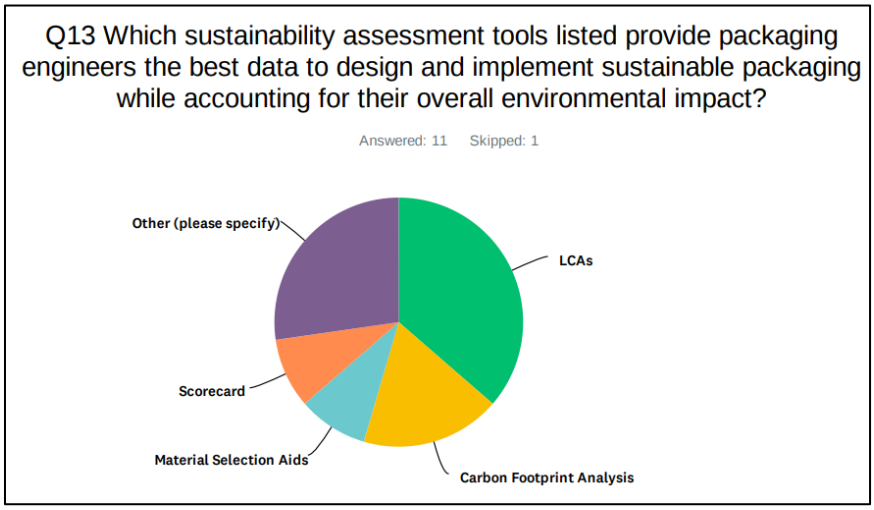
Q12 How effective are material selection aids for choosing low impact materials to design flexible film packaging?

Answered: 11 Skipped: 1

	VERY EFFECTIVE	SOMEWHAT EFFECTIVE	NEUTRAL	SOMEWHAT INEFFECTIVE	VERY INEFFECTIVE	TOTAL	WEIGHTED AVERAGE
(no label)	45.45% 5	36.36% 4	18.18% 2	0.00% 0	0.00% 0	11	1.73

Material selection aids were selected as very effective and somewhat effective (81%) by respondents. Only two selected neutral on the question.

Figure 14: Survey Question 13 -- Best sustainability assessment tools



More respondents chose LCAs than the other options. Carbon Footprint Analysis was the second most chosen tool. However more responded with ‘other’ options over Carbon Footprint Analysis. The ‘other’ responses were included in the Discussion section.

4.4 Consumer/Producer Responsibility:

Figure 15: Survey Question 14 -- Consumer driven or Producer driven changes to packaging

Q14 Do you believe consumers adapt to what's presented to them such as technology or innovations in packaging. Or do consumers drive innovation and changes to conventional packaging? Should consumers be lead down one path?

Answered: 10 Skipped: 2

ANSWER CHOICES	RESPONSES	
Producer driven	10.00%	1
Consumer driven	0.00%	0
Combination of both	90.00%	9
TOTAL		10

All respondents answered a 'combination of both' with only one who said consumer driven'.

Figure 16: Should more states adopt Extended Producer Responsibility?

Q15 Should more states adopt the Extended Producer Responsibility legislation for packaging that places more financial responsibility to recycle on producers and municipalities over consumers? (Click here for overview)

Answered: 11 Skipped: 1

ANSWER CHOICES	RESPONSES	
Yes	55%	6
No	45%	5
TOTAL		11

Most respondents said, 'yes' more adoption of EPR legislation in states (55%) and the rest answered 'no' (45%).

5.0 Discussion and Analysis:

Based on the results of the survey conducted, the LCA methodology serves as the optimum choice for sustainable packaging development with a few shortcomings. LCAs are limited by the user assumptions and system boundaries (Pauer et al., 2019). Other methodologies and tools are important and vital to use in conjunction to obtain a full understanding of the environmental impacts both internally and externally from the entity conducting the assessment (Mattia et al., 2021). Finally, a deep understanding of the materials, construction choice and product system are needed to ultimately choose the correct design as it will influence the impacts through the entire lifecycle of the product/packaging system and influence the degree of sustainability. The source of information and knowledge collected is important for packaging engineers who are responsible for designing packaging. The respondents of this study obtained information on packaging and the environment from diverse sources that extended past media influence that included knowledge and sources accrued on the job.

5.1 Media/ information:

Research Question 1: How does the media drive and influence packaging perception?

The news on climate change and the environment has grown significantly, sparking the attention and interests of consumers in addition to the advertising and actions of companies in all sectors (Tullo, 2021). Different media channels influence the perception that consumers have of packaging and its impact on the environmental challenges like plastic mounds in the ocean polluting marine ecosystems (Foodprint, 2020). At the same time, a circular influence of information exists from media to consumers to producers that shape perception of packaging.

From the survey results, there is media influence amongst consumers as well as the expert decision makers. From Survey Question 2, the experts have access to journals, vendor information, partners overseas and experience amongst team members. However, based on survey results they are consuming as many online articles and utilize social media like everyday consumers. They utilize journals and scientific studies less than anticipated as their source for information on packaging's impact on the environment. There was no correlation observed between news source consumption and opinions of media inaccuracy on packaging reporting. Respondents felt that the media was somewhat accurate in their coverage of environmental impacts from packaging. However, they felt that important benefits of packaging like shelf-life extension or product safety features protecting consumers was not typically conveyed.

5.2 Expert Opinions on Environmental Impacts of Packaging:

Research Question 2. What are the critical impacts of packaging on the environment and climate?

Insights were gained into the significance of packaging's impacts on the environment and where they occur. The industry they believed had the highest impacts were from the industrial sector with the CPG industry having the next highest. There are likely several reasons for this choice. Resource use and energy intensity are found to be major resultants from this sector of the packaging industry (Foodprint, 2020). According to *Our World Data's* breakdown of emissions sector by sector, energy usage in the 'industry' category made up 24 percent of the GHG emissions from the energy sector indicating alignment between respondents and the literature (Ritchie, 2020).

One area where literature did not align with respondents' opinions is the life cycle stage with the highest overall environmental impacts. This question specifically referred to the life cycle of flexible packaging. Again, perception played a role in which sector was thought to have the highest impacts. Half of the respondents chose the disposal phase with the rest choosing other phases which was not an expected outcome. The earlier stages of raw material extraction and production were tied for the lowest chosen. Despite the clear direction of the expert's opinions on this question, the findings in the literature review indicated the opposite finding. Studies from Morales-Mendez & Silva- Rodriguez (2018), Bishop et al. (2021), and Barlow & Morgan (2013) all found the production phase of flexible packaging to have the most harmful environmental impacts especially in terms of major indicators such as GWP and ozone layer depletion.

Five plastic raw materials commonly used in flexible packaging were compared. LDPE and LLDPE were identified by the respondents as the materials with the most significant impact indicators which aligns with the literature review findings. Extraction and processing of raw materials experienced the next highest impacts in the case of most plastics according to a study from Dalhgren et al. (2015). PLA material was found to have the next highest impacts identified in the survey and the literature. In the survey, respondents selected PA6 as having equally harmful impacts to PLA. Siracusa et al. (2014), Izhar & May (2020.), Pauer et al. (2020), and Barlow & Morgan (2013) all found reductions in PA6 material in the design phase of flexible packaging would offset much of the environmental impacts over recycling.

There were differing opinions among respondents on the level of impact from consumer's use and disposal of materials. One stated that the media didn't raise awareness on these details of material usage. Others felt that material use was not the issue but their improper disposal by consumers was the problem. Another response indicated the recycling aspect was over covered

when other solutions were available to curb environmental impacts. One significant point addressed in the responses was that the media “labels certain packaging types that do not take a lot of material, energy, or waste to manufacture as "bad" for the planet. The manufacturing process of some company alternatives are worse than the original.”

5.3 Assessment tools:

Research Question 3. Which assessment tools are most effective at identifying and creating long term solutions to environmental impacts from packaging?

Overall, the use of assessment tools was found to be valuable assets with LCAs being the most favored among the packaging professionals across industries. The literature review findings confirm this as most studies either utilized LCA entirely or in tandem with one of the other tools. The limitations raised by respondents were also noted in the literature such as how boundaries are drawn, and assumptions made. Survey question 9 responses included the following:

> *“Depends on training and proficiency of usage.”*
>
> *“LCA is entirely dependent on the assumptions that are used to create the assessment. Garbage in = garbage out meaning if the assumptions are bad it can skew your results one way or another.”*
>
> *“Waste to energy conversion not taken into account.”*

Source: Insights from Packaging Experts on Sustainability Actions SurveyMonkey

Respondents to the survey were unsure about Survey Question 10. Most answered yes however the uncertainty in responses likely resulted in this question being the least reliable. The respondents felt that LCAs, despite the many limitations, have just as many benefits when done correctly and follow the reality of the situation and environments closely. The various assessment tools were seen as valuable assets by the respondents. When asked to rank various

tools to design and implement sustainable packaging, LCA was the top choice. Other versions of the LCA method were suggested such as an “LCA lite” or “packaging specific LCA such as COMPASS”. The next preferred was Carbon Footprint analysis. A combination of the tools was suggested as best practice which followed advice from professionals in the literature and from some studies (Pauer et al., 2019). Another common insight was for users to “benchmark packaging options versus competitors, or new design versus current designs to drive continuous improvement.” Benchmarking was a recommended insight from the McKinsey Institute study to better communicate packaging impacts to the public (Feber et. al, 2021). Material selection assessments were also generally found to be effective tools on their own but not as much compared to the LCA method. Scorecard and Eco-design tools were only chosen by two respondents as preferences. Another suggestion was to couple LCA with other tools which would cover a variety of impacts, external factors from vendors and the general value chain of a product and highlight the benefits from the packaging considered.

5.4 Consumer/Producer Responsibility:

Research Question 4. Are consumers or producers responsible for packaging impacts?

Finally, the opinions of the experts on consumer vs producer responsibility for packaging environmental impacts, were examined and found to be in line with how manufacturers in general feel on the subject. When it came to adoption of the EPR legislation, the responses indicated that effectiveness of EPR in the US is unclear and dependent on the successes of states who’ve adopted these programs early.

The results from Survey Question 15 indicated that sustainable packaging design and adoption was both consumer and producer driven. One respondent found that depending on the industry and its regulations or requirements, producers were obligated to drive packaging designs. This indicated that government regulations representing the public dictated producer actions. The example used by the respondent was “In medical packaging, the designs and material selections are not as flexible as other industries due to specific requirements...” Another respondent, as a producer, indicated “Consumers drive what we make and sell. You can design the greatest innovative package design but if it costs more, they won't buy it…”

Professionals who managed the designs of packaging on the market and made decisions on creation of them had a deep knowledge base of the advantages and barriers to sustainable packaging adoption and the tools to assess them. However, Survey Question 16 presented differing views on whether more states should adopt EPR legislation in the US. States like Maine took a more hardline approach like the EU’s Directive by holding producers solely responsible for fees to finance recycling programs (Choi-Shagrin, 2021). However, places like Oregon and even Australia used more collaborative tactics by including producers in the decision-making process (Boz, 2020). There was belief among the industry that the fees imposed on producers will in turn be levied at consumers in the form of regressive tax hikes (Gleason, 2021). The difference in opinion mirrored the broader industry concern of government entities creating and running programs without buy-in from those who are experts in this industry.

6.0 Limitations:

There were limitations and challenges over the course of this research that would have enabled a more thorough evaluation of the four research categories examined. Regarding the media's influence on packaging perception, further research on the media's coverage was needed to show direct ties to stories and sources that drove people's decision making and opinions on packaging. With more time, a similar survey sent to everyday consumers with little to no knowledge about the profession and industry of packaging would have provided valuable insight into media perception as well. The idea of media influence was difficult to measure and tie to consumer behavior. There were several ways that the survey could have been improved to gain more insights. More participants in the packaging industry needed to be reached to provide more valuable input into the various topics and establish a stronger sample size. In addition to the information sources each participant used to gain packaging and environmental knowledge, a question should have been asked that specified their role and industry sector. This would have allowed a better analytical tool to review crosstabs. Another limitation that posed a challenge to this research was the lack of time and resources to conduct a basic LCA to test a common packaging item and compare it with another assessment tool. Finally, studies regarding this subject were limited and the data and research spanned various countries around the world. Despite attaining a wide range of sources and references from scientific journals, studies, articles, and books, reliance on the international spread of these studies posed challenges to understanding the quality of them. Regulatory standards and requirements for some of the methodology used varied depending on the country.

7.0 Conclusion:

This research study achieved the objective of analyzing the influence of assessment tools for identifying environmental impacts and sustainable packaging design. Several of the research questions were answered but others still require additional study. Ultimately the hypothesis was confirmed that assessment tools for packaging were effective at addressing the harmful environmental and climate impacts of packaging. In addition, these tools helped to highlight sustainable packaging development and design. In addition, the tools were found to be good communication devices to inform the public of sustainable packaging effects. The opportunities presented by sustainable packaging were identified throughout the research but also needed to be further explored to be included in reports such as the IPCC Assessment going forward to better inform the public of packaging's impacts and benefits. Answers were provided for the four overall research questions:

RQ 1: Media influence does occur amongst consumers as well as the expert decision makers on the issue of packaging impacts and recyclability.

RQ 2: LCA tools play an important role in sustainable packaging design and development. LCAs are among the best available tools for assessments of packaging environmental impacts along with packaging specific LCA tools. To drive sustainability, coupling with other tools is an optimum approach.

RQ3: Assessment tools can be used to close the information gap to consumers on packaging impacts and help communicate mitigation strategies. Most research points to better environmental outcomes when smaller 'impact mitigation' strategies are utilized to reduce harmful impacts like climate change. The lifecycle stages of raw material extraction for petroleum based plastic resins and manufacturing/ production of these

films through co extrusion and lamination have significant environmental impacts. A primary driver of sustainable packaging design and adoption from the literature is the integration of supply chains.

RQ 4: Although consumers have a say in the innovations and choices made, producers still have the knowledge and decision-making authority. When it comes to adoption of the EPR legislation, the effectiveness of EPR in the US is unclear and dependent on the successes of states who've adopted these programs early.

The hypothesis was affirmed in that the use assessment tools was an effective method of identifying harmful environmental impacts and promoting the benefits of sustainable packaging design. It can be expanded to say life cycle assessment was the most effective tool available to accomplish those aims.

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9.0 Appendices:

Appendix A: Survey Consent Form (submitted to IRB)

Johns Hopkins University: AAP Graduate Studies
Program: Energy Policy and Climate
Name of Investigators: Kevin Leggett; Dr. Michael Schwebel

Title of Project: Title of Project: Insights from Packaging Experts on Responsible Design and Sustainability

As Packaging professionals in various roles and experiences in the industry, you all have unique perspectives on the state of packaging's impact on the planet. In association with John's Hopkins AAP Graduate Program for Energy Policy and Climate, I would like to invite you to participate in an online survey providing your inputs on several research questions. The feedback from this survey will be included in a research study that explores the environmental and climate impacts of the packaging industry and the effectiveness of sustainability design tools. Responses to this survey will be de-identified. Respondents must be at least 18 years or older to take part in the survey. There are no foreseeable risks or discomforts to you for taking part in this study.

Please complete the survey by **April 20, 2022**. If you have any questions, concerns, or additional feedback not included in the survey study, please feel free to contact Kevin Leggett (klegget4@jh.edu), the primary student investigator conducting this research. Dr. Michael Schwebel (mschweb4@jhu.edu), the Principal Investigator can also be contacted.

☐ By checking this box, you are consenting to be a part of this research study. Your participation is voluntary and you can stop at any time.

Please sign and date:

_____ _____
Signature of Participant Date

Future contact: We would like your permission for our research team to contact you in the future. Please note that your decision below does not prevent other researchers at Johns Hopkins University from contacting you about other research.

Please sign and date your choice below:

Yes ☐ _____ _____
Signature of Participant Date

No ☐ _____ _____
Signature of Participant Date

Appendix B: Survey Question 4 -- Results

Showing **8** responses

Heavily focused more on recycling/consumer goods packaging but there are many way to address the impact.

4/20/2022 2:45 PM View respondent's answers

I think that packaging sometimes gets a bad reputation in the media because its easier to see and tangible compared to oth aspects of a product. The media often omits how other aspects of products impact the environment.

4/19/2022 5:50 PM View respondent's answers

material recyclability. More attention needs to be placed on waste to energy. Florida is burning laminates, producing energy extracting methane, and minimizing pollution in the process.

4/18/2022 11:43 AM View respondent's answers

the major problem is not materials - it is the way people handle and dispose of materials

4/18/2022 11:38 AM View respondent's answers

In my opinion they often bring up the non believer's opinion. Why do they let the loud minority have a say in the matter.

4/18/2022 11:37 AM View respondent's answers Add tags

Generally, most information to the public is somewhat accurate to no accurate at all. Nothing regarding why certain types of packaging are important or necessary. Just all bad.

4/18/2022 10:42 AM View respondent's answers Add tags

About the data that most governments don't reveal or the data might be misleading.

4/18/2022 3:08 AM View respondent's answers Add tags

only the misuse of the packaging has been adverised mostly, but it also needs to bring awareness on the packaging materials and disposability. Also needs to show what benefits its giving against food wastage and consumer safety

4/17/2022 12:28 PM View respondent's answers Add tags

Appendix C: Life Cycle Assessment

NCASI

(NCASI, n.d)

Appendix C: Material Selector -- SPA

Material Selector

Your guide to information on packaging materials

The challenges that exist within the new product development process is balancing the functional and mechanical properties of the product-packaging system with the marketability and consumer acceptance of packaging through to understanding environmental impacts and incorporating design options that reduce waste and environmental impacts of the total life cycle.

It is therefore important to have access to relevant information on packaging materials. In order to meet this need, SPA has compiled an easy-to-use summary of commonly used packaging materials including polymers, metals and paper based. Useful for packaging technologists, brand managers, designers, environmental managers and policy makers, the Packaging Materials Selector features information on material characteristics, packaging applications and recycling and other environmental considerations (see example below).

Packaging material	Polypropylene (PP)
Material characteristics	Rigid and flexible, tough, heat resistant up to 165oC, excellent chemical resistance, moderate barrier, oriented films.
Packaging Applications	Potato crisp bags, tubs, hinged caps, clear punnets, microwave ware, bottles, lolly wrap.
Raw materials	Crude oil Non-renewable
Density (g/cc)	0.9
Embodied energy LHV (MJ/kg)	70.6
Recyclability	Technically recyclable, PIW widely recycled, some Councils starting to collect rigid PCW PP at kerbside but limited due to low volumes, food residue contamination and limited capacity.
Recycling rate	6%
Recycled content	Recycled content possible in non-food applications.
Landfill impacts	Value of material lost.
Comments	Properties can be modified to meet requirements.

(SPA, n.d)

Appendix D: Walmart Scorecard

Illustrative example of how we use the Sustainability Index:

Consumables, health & wellness – top 10 supplier category scorecard

	PRIORITY CHEMICALS			PACKAGING			DEFORESTATION		INDEX
	Disclosure	Chemicals management program	Ingredient evaluations	Sustainable design	Raw material–end of life	How2Recycle Label (Y/N)	Fiber sourcing certification	Palm oil sourcing	Participation
Supplier A	🟡	🟢	🟢	🟡	🟡	Y	🟡	🟡	🟢
Supplier B	🟢	🟡	🟢	🟡	🟡	N	🟢	🟢	🟢
Supplier C	🟢	🟡	🔴	🟡	🟡	Y	🟢	N/A	🟢
Supplier D	🟢	🟢	🟡	🟡	🟡	N	🟡	🟡	🟢
Supplier E	🟡	🟡	N/A	🟡	🟡	Y	🟢	N/A	🟢
Supplier F	🟡	🟡	🟡	🟡	🟡	Y	🟢	🟡	🟢
Supplier G	🟡	🔴	N/A	🔴	🔴	Y	🔴	N/A	🟢
Supplier H	🟡	🟡	🟡	🟡	🔴	N	N/A	🟢	🟢
Supplier I	🟢	🟢	🟢	🟡	🟡	Y	🔴	🟡	🟢
Supplier J	🟢	🟢	🟡	🟡	🟡	N	🔴	🟡	🟢

(Wal-Mart, 2020)