MSc Program
Environmental Technology & International Affairs

Sustainable food packaging and its role in achieving a circular economy - a critical analysis

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, 13.06.2024

Affidavit

I, **IVA MARINOVA TSOLOVA-KUTSAROVA**, hereby declare

1. that I am the sole author of the present Master's Thesis, "SUSTAINABLE FOOD PACKAGING AND ITS ROLE IN ACHIEVING A CIRCULAR ECONOMY - A CRITICAL ANALYSIS", 127 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

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Abstract

Since the discovery of plastic about a century ago, humanity has leveraged its remarkable properties across various sectors, including the food industry. Fossil fuel-based packaging facilitates the containment, protection, transportation, and consumption of food, but its entire life cycle is associated with significant negative impacts, such as the depletion of finite resources, greenhouse gas emissions, and pollution. Following a linear model, once a container is opened and its contents are consumed, it becomes an environmental burden. The negative consequences are increasingly evident, prompting efforts to find solutions to the current crisis, including through the promotion of a circular economy. The objective of this thesis is to analyze whether and how the conventional food packaging sector can be transformed to become more environmentally friendly.

The study begins with a literature review and an overview of the historical development of the packaging industry, highlighting its considerable negative impact and the link between artificial enclosements, on the one hand, and food loss and food waste, on the other hand. It underscores the need for a universal definition of "sustainable food packaging", as the current lack of such a definition hinders the effective evaluation and comparison of potential solutions. Subsequently, the research considers replacing conventional plastics with biodegradable alternatives. The sustainability of an innovative polylactic acid-based product is evaluated through a comparative analysis vis-à-vis low-density polyethylene. While the renewable alternative outperforms conventional plastic in certain aspects, based on the collected information and research, the data are insufficient to conclude that its overall cradle-to-cradle performance is superior to that of fossil fuel-based plastics. Specific limitations include the need for comprehensive life-cycle assessments to evaluate the direct and indirect impact on nature, as well as the lack of current infrastructure to support adequate and effective end-of-life (EoL) treatment for alternative packaging substitutes.

The study also examines the current regulatory frameworks in the European Union (EU) and their limits. Harmonization among the EU Member States is a good starting point, but it is not enough. Concrete binding measures tailored to country-specific targets are needed to achieve optimal outcomes that transform the packaging sector. The lack of legislation regarding the use and treatment of biobased, biodegradable, and compostable materials is also noted. For the empirical part of the study, a survey was conducted among respondents in Austria and Bulgaria with the goal of evaluating their level of awareness of the negative impact of packaging and food waste on the environment, their habits, and their understanding and implementation of practices like recycling. Significant information gaps were identified in certain areas, and it can be surmised that a higher standard of living and education in sustainability are prerequisites for promoting environmentally friendly habits. The study concludes with a proposal for the creation of a one-stop-shop online platform aimed at raising awareness through targeted channels among the residents of all Member States about the ways in which they can contribute to the sustainable transformation of the food packaging industry.

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List of Abbreviations

Bio-PET	Bio-polyethylene terephthalate
BFSA	Bulgarian Food Safety Agency
CDG	Christian Doppler Research Association
CEAP	Circular Economy Action Plan
CEC4Europe	Circular Economy Coalition for Europe
CO2	Carbon dioxide
DRS	Deposit and return systems
EIC	European Innovation Council
EoL	End-of-life
EPR	Extended producer responsibility
EU	European Union
FAO	Food and Agriculture Organization
GWP	Global warming potential
HORECA	Hotels, restaurants, and cafeterias
IPCC	Intergovernmental Panel on Climate Change
LCA	Life cycle assessments
LDPE	Low-density polyethylene
MAP	Modified atmosphere packaging
MEG	Monoethylene glycol
MEP	Member of the European Parliament
PPWR	Packaging and Packaging Waste Regulation
PCB	Polychlorinated biphenyl
PE	Polyethylene
PET	Polyethylene terephthalate
PFAs	Polyfluorinated alkyl substances
PLA	Polylactic acid

PP	Polypropylene
PVC	Polyvinyl chloride
VOCs	Volatile organic compounds

Acknowledgements

First of all, I would like to express my sincere appreciation to my supervisor, Assoc. Prof. Dipl.-Ing. Dr. techn. Johann Fellner. The Waste Management course was one of the most interesting ones for me during the second year of my studies, which sparked my passion for the topic of the food packaging industry. His valuable feedback, time, understanding, advice, and guidance significantly contributed to my work throughout this process. Furthermore, I would like to thank all the interviewees for the interesting and enjoyable conversations, shared information, patience, and insights that added a diversity of perspectives to my topic. Additionally, I am grateful to the hundreds of people who responded to the survey and brought key issues to my attention.

The past two years have been extremely meaningful, not only because of the new world of knowledge that has opened up to me but also because of the extraordinary people I have met through the program—my wonderful colleagues and professors. It has been a real pleasure to communicate, learn, and work with all of them. I believe that the friendships we have made will last a lifetime. My sincere thanks to the administration of the TU Academy for Continuing Education and the Diplomatic Academy of Vienna for their continuous support and assistance throughout.

I would also like to acknowledge my deep appreciation for my husband, my parents, his parents, my dear grandmother, and my friends for their strength, courage, and unconditional support. I am fortunate to have experienced almost the entire second academic year with my little daughter, Ava, who was a wonderful companion and the youngest and most curious student of our cohort, attending lectures with interest and absorbing every word.

1. Introduction

Humanity's impact on nature is increasingly conspicuous as our footprint grows. Anthropogenic activities exert a profound influence on the natural environment, resulting in resource depletion, pollution, a substantial rise in greenhouse gas emissions, and ecosystem degradation. In this context, the packaging sector, particularly within the food industry, stands out as one of the major contributors to global waste generation (Ncube et al., 2020).

The primary material currently utilized for food packaging is plastic, followed by paper and cardboard (Mendes and Pedersen, 2021). Since its invention over a century ago, plastic has permeated the daily lives of individuals worldwide, serving myriad purposes (Plastics Europe, n.d.). This fossil fuel-derived material epitomizes convenience in contemporary consumer culture. Because of its durability, impermeability, lightweight, and cost-effectiveness, plastic has become the preferred option for food packaging (Xometry, 2023). However, this convenience carries a significant environmental cost and has detrimental consequences for both nature and the planet's well-being. After disposal, packaging quickly becomes long-lasting waste, lingering in the environment for an extended period, often surpassing 1000 years (Vasarhelyi, 2023). Any plastic packaging or container that was once carelessly discarded into nature still remains somewhere in the ground or adrift in the oceans. Today, there is scarcely a corner of the planet devoid of plastic presence (Vasarhelyi, 2023).

Beyond the material content of packaging, its core functions encompass facilitating long-distance transportation, providing consumers with essential information, supporting product marketing efforts, and prolonging product shelf life to maintain its quality until consumed (Marsch and Bugusu, 2007). Production and follow-up management processes, energy consumption, and the broader environmental impact of packaging are also garnering increasing attention. However, one critical aspect is often overlooked: the imperative of reducing food waste. While preserving product quality and extending shelf life can mitigate spoilage, addressing food waste necessitates specific focus on design, size, and functionality (Brennan et al., 2021). Excessive or non-effective packaging and the utilization of non-recyclable materials can compound food waste issues by generating unnecessary packaging waste and inefficient resource utilization. A comprehensive approach to sustainable food packaging necessitates establishing a universally applicable definition, facilitating material comparison, and enabling thorough consideration of both the impact of packaging materials on nature and their role in reducing food waste (Dörnyei, 2023).

The widespread use of plastic packaging has led to a number of environmental challenges, namely waste generation and pollution. Society is increasingly seeking solutions and leveraging technology, research, and innovation to explore potential alternative materials to address at least some of these problems. As of this writing, among the numerous options are biobased and biodegradable plastics. While these alternatives may alleviate issues related to littering by breaking down more readily in the environment, they do not fundamentally address the root problem of plastic consumption and waste generation (EEA, 2020). Furthermore, the production of these alternative materials often necessitates substantial agricultural activities, which can lead to potential conflicts with food production and land use (Cruz et al., 2022). Consequently, an expanding array of stakeholders, including governmental bodies, diverse sectors, industries, non-governmental organizations (NGOs), and individuals, are actively trying to address these escalating problems.

Research into innovative packaging materials as substitutes for plastic shows promise but remains insufficient in addressing pollution. The concept of a circular economy also assumes a central role, aligning with the global and European targets set for 2050. Circularity aims to disconnect economic growth from resource depletion and environmental degradation (EMF, n.d.). By emphasizing the closure of loops, the circular economy promotes strategies such as reuse, whereby packaging materials are designed to be reused, recycled, and regenerated (EP, 2023). To realize this vision, all stakeholders must take immediate action, beginning with the establishment and implementation of key legal frameworks. The current research will examine the regulatory frameworks at the European Union (EU) level and evaluate their impact to date in terms of implementation by the packaging industries and the commitment of individual consumers to embrace more sustainable behavior and practices.

In the light of the aforementioned developments, this thesis aims to contribute to the analysis of the food packaging sector and help pave the way for the development of a solution that will transform it into a circular and sustainable sector.

2. Objective, research questions, and hypothesis

The objective of this thesis is to explore whether and how the conventional food packaging sector can be transformed so that it becomes sustainable and circular. The study will begin by offering a historical background and then critically assessing the current state of food packaging practices. The detrimental effects of food waste will be addressed, emphasizing the potential environmental benefits of reducing food waste, even by a small fraction. Furthermore, the research will evaluate the progress made thus far in terms of sustainable packaging practices, comparing the impact of alternative and innovative materials with the impact of traditional plastic packaging. The potential advantages and drawbacks of sustainable alternative materials will be examined through comparative analysis. The study seeks to address the existing challenges to the circularization of the food packaging industry from legal and consumer perspectives. By examining the stakeholders' perceptions and attitudes, and by identifying potential obstacles to the widespread adoption of innovative solutions, the thesis aims to propose recommendations and strategies for future actions aligned with the EU's 2050 targets.

Within the framework of this study, the following research questions will be addressed:

1. What are the environmental challenges posed by current food packaging practices, and why is a unified definition of "sustainable food packaging" necessary?
2. What obstacles prevent biodegradable alternatives from solving the plastic packaging problem?
3. How do the current European regulations both contribute to and hinder the achievement of a sustainable packaging sector?
4. What is the role of end users in promoting circular economy practices?

The author hypothesizes that a comprehensive overhaul of the food packaging sector is feasible through the improvement of the current approaches and waste treatment infrastructure, the establishment of effective legal frameworks, the discovery of innovative mono-materials with comprehensive barrier properties, substantial investment and commitment, behavioral changes, and systematic collaboration among all stakeholders.

3. Methodology

Each topic analyzed in this study underwent an extensive literature review, encompassing research papers, articles, and the latest information sourced from online platforms and websites. This review included a thorough examination utilizing Google Scholar, employing keywords such as “food packaging”, “sustainable food packaging”, “biobased and biodegradable plastic”, and “circular economy”. It was imperative for the thesis to incorporate the latest findings, as advancements in packaging materials are integral to achieving sustainability objectives.

The research involved an analysis and comparison of conventional and alternative materials, drawing insights from a concrete case study and data analysis. Conventional low-density polyethylene (LDPE) was compared with the innovative solution Pack'On, which is based on polylactic acid (PLA) and developed by Lam'On, a Bulgarian startup that aims to replace traditional plastic food packaging. This study contrasts a non-sustainable plastic material that is already well-established in the international market with a product developed by a young Eastern European company. It considers not only the environmental benefits of the innovative product but also the potential for its establishment in the European market. Based on the collected information, the thesis presents specific conclusions about the potential utilization and the feasibility of reducing the adverse environmental impact of the material under scrutiny.

The transition towards sustainable practices in the food industry is underpinned by several legal regulations at the EU level, namely the Directive on Packaging and Packaging Waste, the Packaging and Packaging Waste Regulation, the Green Deal, and the Circular Economy Action Plan. Pending decisions underscore the need for additional resource investments and emphasize the importance of exploring opportunities for improvements in this specific domain. Moreover, the varying social and economic circumstances across EU Member States are considered as well.

Interviews were conducted with representatives from three different sectors, including entrepreneurship, waste management, and government. Each interviewee was selected based on their expertise and knowledge pertinent to the study's subject matter. The questions presented to the different experts were tailored to address specific topics relevant to their respective roles and knowledge. Given the busy schedules and geographic diversity of the professionals involved, interviews were conducted either in person or online using communication platforms such as Zoom. One-on-one meetings typically lasted approximately one hour. The information from the interviews was mostly woven into sections four, five, and six of the study, as well as in other places where it was deemed appropriate.

The interviewees for this study include:

- Gergana Stancheva: Co-founder and COO of the Bulgarian start-up company Lam'On. The interview was conducted on 20 May 2024.

- Radan Kanev: Member of the European Parliament (MEP); Member of the Committee on the Environment, Public Health, and Food Safety, European Parliament Rapporteur on the Industrial Emissions Directive. The interview was conducted on 21 May 2024.

- Hon.Prof.Mag.rer.soc.oec.Dr. Christoph Scharff: Former CEO of ARA AG, one of Europe's leading Extended producer responsibility (EPR) schemes for packaging wastes; initiator and founder of the Circular Economy Coalition for Europe (CEC4Europe); Member of the Scientific Board of the Christian Doppler Research Association (CDG). The interview was conducted on 24 May 2024.

In addition, an online survey was conducted among the general public in Bulgaria and Austria with the aim to gauge the level of awareness and the attitudes of the public regarding packaging-related issues, food waste, sustainable packaging approaches, and recycling. The survey consisted of 20 questions, which were translated into Bulgarian and English, and was completed by 200 respondents in Bulgaria and 171 in Austria.

The information and data presented in this thesis are primarily derived from the aforementioned sources and are supplemented by interviews providing additional valuable perspectives and the data collected through the online survey.

4. Results from the literature review

To conduct an in-depth analysis of the food packaging sector and explore its potential transformation into a sustainable one, it is imperative to have a foundational understanding of this industry, how it developed over time, the purposes of packaging, and the adverse consequences that necessitate disruptive changes. This information lays the groundwork for the subsequent chapter of the thesis. Furthermore, the data examined in this section will also shed light on the issue of food waste, which is closely intertwined with packaging practices, underscoring the importance of establishing a unified definition.

4.1. The history of food packaging

In ancient times, prehistoric societies consumed right away what they either found or produced within the areas they inhabited. Food variety was limited compared to today and the need for packaging was minimal (Hook and Heimlich, 2017). However, when people needed to protect or transport collected food items, they turned to natural resources such as shells. Over time, they also developed the ability to produce their own containers from sustainable materials like animal skin and leaves (Taylor, 2021).

Gradually, as humanity evolved and scientific discoveries were made, new materials emerged to serve similar purposes. A significant breakthrough occurred around 3500 BC when the Egyptians started storing liquids and food products in glass containers (Taylor, 2021). Furthermore, in the first century AD, Ts'ai Lun, a Chinese court official of the Eastern Han dynasty, made a significant contribution to mankind by inventing paper (Alfred, 2008). This innovation facilitated the storage of certain foods for future consumption (Taylor, 2021).

During the Middle Ages, wooden barrels played a significant role, proving particularly valuable for lengthy sea voyages and the transportation of foods and beverages overseas (Tower, 2021). Moreover, metal started to find its place in food packaging technologies. In 1810, English scientist Peter Durand validated and patented a method for tin canning. Seven years later, in England, the first commercial carton was introduced (Hook and Heimlich, 2017).

The Industrial Revolution stands as a pivotal moment in human history, ushering in a multitude of revolutionary changes across various domains (Shiloh Packaging, n.d.). Machines were integrated into manufacturing processes, enabling greater speed and the production of larger quantities of products. Naturally, this led to a need for containers, facilitating the preservation of product qualities for extended periods and their safe transportation to distant destinations (Shiloh Packaging, n.d.).

In the late 19th century, the National Biscuit Company introduced the first individually packaged biscuits with the purpose of preserving crispness through a special packaging barrier (Taylor, 2021).

Fast forward to the emergence in 1907 of a material that has since significantly contributed to environmental pollution. The invention of Bakelite, the first synthetic polymer-based plastic, unleashed boundless creativity in terms of form (Taylor, 2021). Its creator was Belgian chemist and inventor Leo Hendrik Baekeland (SHI, n.d.). Subsequent innovations in various types of plastics followed, with Saran Wrap making its debut in 1933, revolutionizing airtight food packaging (Taylor, 2021).

Tetra Pak, built on cardboard, revolutionized the storage and transportation of liquids, notably milk. By the late 1950s, aluminum cans also surged in popularity, particularly among consumers of sparkling drinks (Taylor, 2021). Two decades later, American chemist Nathaniel Wyeth introduced a significantly more cost-effective alternative to glass bottles, presenting the world with polyethylene terephthalate (PET) bottles, which were ideal for non-alcoholic soft beverages (Jansen-Parkes, 2018). Shortly after, the same material started to be utilized for the packaging of various types of food, including diverse hot-fill products (Hook and Heimlich, 2017).

Due to humanity's consumerist tendencies, the ever-expanding array of foods and products, and the growing consumer demand, significant efforts are currently being directed towards the development of diverse materials and efficient packaging solutions capable of fulfilling various crucial functions.

An example of such innovation in the food sector is active or smart packaging, which aids in preserving the quality and prolonging the shelf life of food products that typically have a limited lifespan (Taylor, 2021). The fundamental concept behind this type of packaging involves the emission or absorption of compounds into the packaged food, thereby influencing processes such as microbial growth and moisture and oxygen exchange (Ross, 2023). Some of these materials, such as packaging films, assist in reducing or eliminating unpleasant odors. Others, designed to insulate and regulate heat exchange, facilitate the heating of foods without compromising human health, allowing for direct consumption from the container (Taylor, 2021).

The advancement in polymer science has unveiled seven pivotal materials, namely polypropylene, polystyrene, polyvinyl chloride, polyethylene terephthalate, and polyethylene. These materials are the primary constituents from which 70% of all plastic production is derived (Foodprint, 2018).

Throughout human history, the only constant has been the phenomenon of continuous change, propelled by the pursuit of progress, technological and scientific advancements, the growing array of opportunities, challenging circumstances, and individuals' evolving habits, lifestyles, and needs (Taylor, 2021). This dynamism extends to the packaging industry, which is closely intertwined with the perpetual generation of waste.

In recent decades, there has been a growing realization of the tangible repercussions of humanity's negative impact on nature, prompting concerted efforts to address these issues. Because of the diverse range of food products that require protection, a wide variety of packaging materials is necessary, each serving different functions and roles. As of today, there is no universal material that can cater to all packaging needs, therefore all these different polymers are utilized. This diversity has resulted in the generation of various types of waste within the food packaging industry. However, for the scope of this thesis, the focus will be on examining the environmental impact of plastic and comparing it to the latest alternative solutions.

Diverse sectors are investing in the development of innovative materials that pose lesser harm to the environment, regulatory measures are being implemented to curtail the use of plastics, and endeavors are underway to shift the behavior of industries and consumers alike. These multifaceted aspects of the topic and the feasibility of effecting a comprehensive transformation of the food packaging sector towards sustainability will be examined in the next chapters.

4.2. The adverse environmental effects of traditional food packaging

4.2.1. The impact of each stage of conventional plastic's life cycle

The conventional linear economy, characterized by the "take, make, consume, and dispose" model, has resulted in significant environmental repercussions (EMF, n.d.). This applies to food packaging waste as well, especially concerning packaging that is challenging or impossible to degrade, or is produced from non-compostable materials (Marsh, 2021). Globally, 95% of plastic packaging is discarded annually after a single-use cycle (WEF, 2016). The complete lifespan of this type of artificial encasing typically involves extraction of fossil fuels and their transportation, production, use, and end-of-life (EoL) treatment or littering, with their frequent ending up in natural environments such as oceans or soil (CIEL, n.d).

Each of the aforementioned phases contributes to the climate change challenges currently faced by mankind because they are also linked to the release of greenhouse gases (CIEL, n.d.). The carbon dioxide (CO2) associated with one kilogram of plastic is estimated to be up to 5 kilograms (Bauer et al., 2022). If our current consumption patterns persist, greenhouse gas emissions are projected to reach 1.34 gigatons per year by the end of the decade, and cumulatively exceed 56 gigatons by 2050 (CIEL, n.d.). This constitutes around 13% of the total remaining carbon budget by 2050 (400 gigatons), which we should do our best not to surpass in order to remain below the critical warming threshold of +1.5°C (UNEPFI, 2021).

Beginning with the initial phase of the cycle, which involves the excavation and transportation of fossil fuels required for plastic raw material production, these processes are highly energy-intensive and emission-intensive. The combustion of fuels, coupled with the disruption of subsurface integrity, results in the release of greenhouse gases (CIEL, n.d.). Globally, approximately 6% of oil is utilized for plastic production, while at the European level, this figure fluctuates between 4 and 6% of the total oil and gas production (WEF, 2016). Moreover, global plastic production in 2022 amounted to 400 million metric tons, with a continuous upward trend (Statista, 2024), and packaging is the largest contributor to the single-use plastic production (UNEP, 2023).

Subsequently, the production of plastic feedstocks is also power-consuming. However, once the food enclosement is utilized and disposed of by consumers, it may end up in landfills, incinerators, or, if conditions permit, recycling facilities (CIEL, n.d.).

4.2.2. The waste hierarchy

At the European level, it is imperative to adhere to the waste management principles outlined in the Waste Framework Directive, which comprises the following five distinct steps: waste prevention, reuse, recycling, reprocessing for energy recovery, and, as a final resort, disposal (EC a, n.d.).

Figure 1. Waste hierarchy according to the
Waste Framework Directive (EC a, n.d.)

Depending on their economic, technological, and social development levels, EU Member States employ varying plastic waste management strategies that best suit their circumstances. Studies suggest that energy recovery is the most prevalent method in Europe, accounting for 42.6%, followed by plastic recycling at 32.5% and landfill disposal at 25% (EP, 2018). Due to limited capacity within Member States, the lack of technology and facilities, and sometimes insufficient budget allocations, approximately 50% of plastics earmarked for treatment and recycling are exported to non-EU countries (EP, 2018).

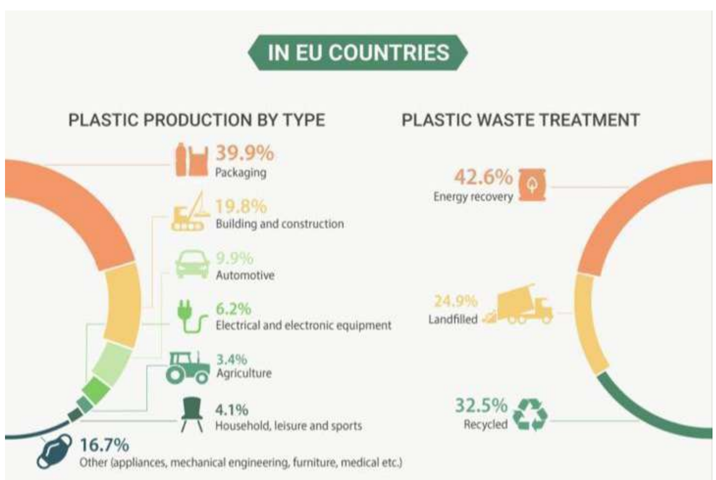

Figure 2. Plastic production by type and its waste treatment,
EU countries (European Parliament, 2018)

Looking into the EU context, on an annual basis, every citizen generates close to 180 kilograms of packaging waste. The packaging sector remains a significant user of new materials, with packaging purposes accounting for 40% of plastics and 50% of paper consumption in the EU (EC, 2022). Moreover, products intended for packaging constitute 36% of the municipal solid waste (EP, 2023). Over the last decade, packaging waste has surged by more than 20% in Europe. Without intervention, the Old Continent is projected to witness an additional 19% increase by 2030 (EC, 2022).

In the following paragraphs, this study will delve into several key waste management practices in more detail, focusing not so much on the technological aspects, but rather on their potential negative impact on the environment and human health. The first priority in the hierarchy is prevention, but the EU has not been very successful in achieving this goal (Giacomazzi, 2017). This failure is partly due to the differing circumstances and contexts of the various Member States. Additionally, the divergence in national legislative frameworks has hindered the effective adaptation of non-binding directives aimed at waste treatment (Giacomazzi, 2017). Considering the entire life cycle of plastics, the majority of emissions (61%) are generated during the extraction of fossil raw materials (Rosenboom et al., 2022). The next largest source of carbon dioxide is the production of polymers (30%). End-of-life treatment contributes 9% of the total emissions, primarily as a result of incineration (Rosenboom et al., 2022).

Incineration of plastic is a very costly and emission-intensive option (Giacomazzi, 2017). The amount of CO2 emitted from the combustion of municipal solid waste varies between 0.7 and 1.7 tons, and these emissions represent both fossil CO2 coming from plastics and biogenic CO2 (ZWE, 2020). It results additionally in the generation of a variety of highly detrimental environmental pollutants, such as dioxins, as well as the emission of particles and heavy metals (Darlington et al., 2022). Frequently, waste incineration facilities are constructed near impoverished communities, underscoring the persistence of environmental injustices that remain unresolved to this day (Darlington et al., 2022). However, considerable effort is being devoted to addressing emissions and one of the technologies currently being employed involves sophisticated air pollutant control systems in waste-to-energy plants, which leads to evident reductions (Vehlow, 2015).

Landfilling results in the lowest percentage of carbon dioxide emissions (CIEL, n.d.). However, a substantial part of all commercial and household waste, including single-use plastic products, end up precisely in these facilities (Botham, 2022). Due to the degradation of biowaste and paper, landfills account for approximately 15% of all methane emissions (Vasarhelyi, 2023). Consequently, the greater the volume of waste deposited in landfills, the larger the quantity of this highly potent greenhouse gas that is produced (Vasarhelyi, 2023).

Given the widespread use of plastic packaging, it is crucial to prioritize recycling. This method typically results in lower greenhouse gas emissions compared to incineration (CIEL, n.d.). For successful recycling, several phases must be followed. The process starts with collecting and sorting, followed by thorough cleaning and washing to eliminate any contaminants (NEH, n.d.). The material is then shredded and sorted based on quality. The next stage involves melting and transforming the material into pellets. Finally, new products are manufactured (NEH, n.d.). The primary benefits of recycling include the potential reduction of plastic waste sent to landfills and the overall environmental pollution. Recycling and reusing plastics from food packaging have the potential to minimize the consumption of new resources (NEH, n.d.). While these advantages are significant, there are also drawbacks to this waste management approach. It is important to acknowledge the power-demanding processes involved in shredding and heating, which often rely on the combustion of non-renewable fuels (Cho, 2020). However, with the existing technologies, it is possible to use renewable, environmentally friendly energy for these processes, thereby reducing the harmful impact on nature. An additional aspect that should be taken into account is the fact that consistent high quality of recycled materials cannot always be assured. Furthermore, the process itself is expensive, and the losses often outweigh the revenues, making it unappealing for the industry (NEH, n.d.).

4.2.3. The impact on the environment and human health

The accumulation of plastic products and food packaging is increasing rapidly worldwide. These items often find their way into the air, water, soil, and the bodies of living organisms (Gendre, 2024). Recent research estimates that approximately 8 million tons of plastic enter the world's oceans annually, totaling around 150 tons to date, with packaging accounting for about 62% of this amount (Jambeck et al., 2015). However, more recent studies employing improved survey methods suggest different figures, indicating an annual input of 1.7 million tons (OECD, 2022). Plastics continue to exert an ongoing impact on the environment due to their slow degradation. At the current rate of consumption, if there are no changes in the methods used in the production of packaging and its materials, plastics are expected to outnumber fish in the ocean by 2050

(WEF, 2016). In addition, if we take a global perspective, we see that once fossil-based products end up in the oceans, they deteriorate over time due to the effects of saltwater or abrasion by sand, breaking into microscopic fragments. Consequently, these fragments infiltrate the bodies of various organisms, including ones that are as tiny as plankton (Gendre, 2024).

Microplastics also pose a significant threat to both animal and human life and health. They contribute to the deaths of numerous fish and other marine mammals, highlighting the severe consequences they entail (Parker, 2024). Furthermore, these small particles disrupt the function of the Earth's largest carbon sink, which is crucial for absorbing and retaining CO2, a key process in mitigating global warming (CIEL, n.d.). Phytoplankton and zooplankton, responsible for this process, are being contaminated by microplastics, hindering the ability of phytoplankton to capture carbon through photosynthesis and impacting the metabolism and survival of zooplankton (CIEL, n.d.). While there is still limited information available, the existing data indicates that plastic waste from packaging is interfering with the ocean's natural carbon sequestration process, posing a threat to the stability of the planet's climate (CIEL, n.d.).

In addition to its impact on aquatic environments, plastic food packaging also affects terrestrial ecosystems and lands. According to some research papers, approximately 30% of this type of waste accumulates in soils (Machado et al., 2017). Studies suggest that microscopic plastic particles in terrestrial regions can have up to 23 times more detrimental environmental effects than microplastics accumulated in oceans (Foodprint, 2018). This can extend to soil fauna, such as earthworms, which may transmit diseases through the contaminated plastic that ends up in their bodies (UNEP, 2021). Fossil fuel-based polymers can also contribute to a reduction in biodiversity, affecting larvae and other organisms crucial for soil fertility (Lin et al., 2020). Plastics buried in soil also tend to absorb harmful compounds and chemicals with significant environmental impacts, such as the very toxic polychlorinated biphenyl (PCB) (Foodprint, 2018). As previously described, microplastics eventually find their way to seas and oceans through water bodies, currents, and rivers, ultimately entering the food chain and potentially affecting those who consume fish and seafood (CBD, 2019).

Figure 3. Impact of plastics on environmental,
human, and animal health (Morisson et al., 2022)

The detrimental effects of plastic food packaging pollution on the environment are extensive and complex. At every stage of its life cycle, a piece of packaging leaves a lasting imprint with far-reaching consequences. From polluting oceans and waterways to infiltrating terrestrial ecosystems and soils, plastic waste poses a significant threat to biodiversity, soil fertility, and human well-being (Kumar et al., 2021).

Although it is becoming increasingly clear that the negative consequences of the production and use of plastic materials are enormous, humanity continues to enjoy their benefits. The food industry is one of the main consumers of such artificial containers. In the following section, the main roles of food packaging are explored.

4.3. The purpose of food packaging

Based on this overview of the historical evolution of food packaging, tracing the use of different materials over time and elaborating on the negative impacts they can lead to, it becomes evident that the purpose of packaging has evolved alongside advances in technology and changes in societal needs. From the most rudimentary methods used by prehistoric societies to the sophisticated packaging solutions of our current times, the primary objectives have remained constant: to protect, preserve, and transport food products (Taylor, 2021). However, it is imperative to acknowledge the multifaceted roles of packaging in modern society. The analysis of the intended use of food enclosement reveals the complex interplay of economic, social, and environmental factors that underscore its importance in today's food industry.

The main functions of food packaging include preserving product quality, facilitating long-distance transportation, providing consumers with convenience, as well as essential information and ingredients, aiding in product marketing, and extending product shelf life to ensure its properties remain intact before consumption (Yan et al., 2022).

4.3.1. Containment

Once a food product has been manufactured, the primary consideration is how it will reach the end consumer. Consequently, the role of packaging is paramount, as it facilitates containment, storage, transportation, and distribution to the final point of use (Robertson, 2014). This aspect becomes particularly crucial for products slated for long-distance transport, as adherence to these functions can mitigate food spoilage and minimize wastage (Marsh and Bugusu, 2007).

4.3.2. Protection

Crucial function of packaging materials is to safeguard and preserve food products. Through the utilization of suitable materials and sealing techniques, food can maintain its quality for an extended period and ensure the consumer’s safety (Marsh and Bugusu, 2007). The fundamental objective is to shield the products from potential chemical, physical, or biological influences originating from the external environment (Marsh and Bugusu, 2007).

Chemical protection serves to mitigate the likelihood of alterations in the product's composition due to exposure to gases such as oxygen, thereby preventing excessive moisture content or undesirable effects caused by visible, ultraviolet, or infrared light (Marsh and Bugusu, 2007). Biological protection aims to thwart potentially harmful microorganisms or insects that could hasten product spoilage. Moreover, it can regulate ripening and aging processes by maintaining a stable internal environment (Marsh and Bugusu, 2007).

Regarding protection against potential physical damage, this entails absorbing and mitigating vibrations and hits during transportation and distribution, as well as preventing abrasion or crushing that could detrimentally affect soft foods (Marsh and Bugusu, 2007). The materials used for this purpose are similarly diverse, with a trend towards substituting glass with plastic for certain products to minimize incidents associated with broken glass packaging (Marsh and Bugusu, 2007). However, it is crucial to acknowledge the negative environmental implications associated with this shift.

4.3.3. Maintenance of freshness

The world we inhabit is characterized by accessibility and facilitated by development. It affords us the opportunity to experience products from various corners of the globe on a daily basis. Through efficient packaging, storage, and transport, these products can traverse vast distances and reach consumers worldwide (Packaging Revolution, 2022). Crucial to long-distance transport is the preservation of product freshness, ensuring that food items arrive at their destination in optimal condition for consumers, as if they had just been picked (Packaging Revolution, 2022).

4.3.4. Communication and marketing

Packaging plays a role in informing consumers about essential facts such as the ingredients used in a product, how much it weighs, what its nutritional value is, the date of manufacture or the date until which the product is going to retain its qualities and properties, as well as its price, serial number or barcode, who the manufacturer is, and other relevant information (Robertson, 2014). Legal identifications are also needed, as well as information about the composition of the packaging itself, which can help consumers to dispose of it properly (Marsh and Bugusu, 2007). Apart from these basic data, the rest is the product of human creativity, which is expressed in the design of the included texts and images (Robertson, 2014). Not to be overlooked is the fact that it is often the packaging that attracts consumers to a given item and it can be the key to choosing one item over another (Marsh and Bugasu, 2007). Branding and design can also be leveraged with the aim of increasing the recognition and market position of an item (Marsh and Bugusu, 2007).

4.3.5. Convenience

While there are many other functions that packaging fulfills and many other purposes for which it is created, for the purpose of this study, only one more of these, namely convenience, will be considered. Since ancient times, mankind has invented various marvels, not only because of its appetite for new discoveries, but also largely dictated by the desire to make its existence easier in one aspect or another. The same approach applies to food packaging.

Important features would be the ease of access, use, and emptying of a food container, the transparency of the packaging, the option of opening and closing to allow food to be stored for a longer period after some part of it has already been consumed, and the possibility of preparing it in an oven, a saucepan, or a microwave (Marsh and Bugusu, 2007). This gives consumers the opportunity to cook delicious food with much less effort required, and once the food is ready, the packaging is simply disposed of quickly and effortlessly (Marsh and Bugusu, 2007). All of this further influences consumer choices, as convenience means saving time, which ultimately becomes a selling point. Food and packaging manufacturers also know the profile of their consumer groups, which means they can adapt the shape and size of food containers to their needs (Robertson, 2014). All of these advantages may sound great and are often accepted as features that contribute to the final consumer choice. However, it should not be forgotten that once used, packaging becomes rubbish and precisely because of the different functions that need to be assembled in one package, the polymers that the industry uses can be very different and consequently their management and treatment becomes more difficult. This has negative environmental consequences in the long term (Marsh and Bugusu, 2007).

Despite the list of important features and useful functions that plastic food packaging performs, the food packaging industry continues to be a global menace of ever-increasing proportions. Non-degradable polymers and harmful chemicals cannot continue to be ignored. However, apart from these, there is one additional aspect that is often left out of the picture when talking about the packaging business, and if we are to address this challenge effectively, we need to come up with a comprehensive solution. Hence, the next section of this study looks specifically at the environmental impact of food waste, the difference between food loss and food waste, and the ways in which packaging can help reduce the wastage in question.

4.4. The role of food loss and food waste

While packaging and plastics undoubtedly have a major impact on pollution, greenhouse gas emissions, ecosystem destruction, and climate change, the food being packaged also contributes significantly, both directly and indirectly.

Currently, there are 8.1 billion people on the planet, and this number is increasing by around 200,000 births every day (The World Counts, 2024). At the same time, approximately 30% of all the food produced annually, totaling 1.05 billion tons, goes to waste (UNEP a, 2024). Despite the fact that 783 million people were facing hunger in 2022 (UNEP a, 2024), the quantity of unconsumed food that ends up in the bin could sufficiently satisfy the needs of two billion people globally (WFP, 2020). At the European level, the annual contribution of food waste to the aforementioned total amount comes at 58 million tons (EC b, n.d.), which is equivalent to a financial loss of EUR 132 billion (SWD (2023)421). On average, every European citizen generates approximately 131 kilograms of food waste, with 70 kilograms originating from households (Eurostat, 2023).

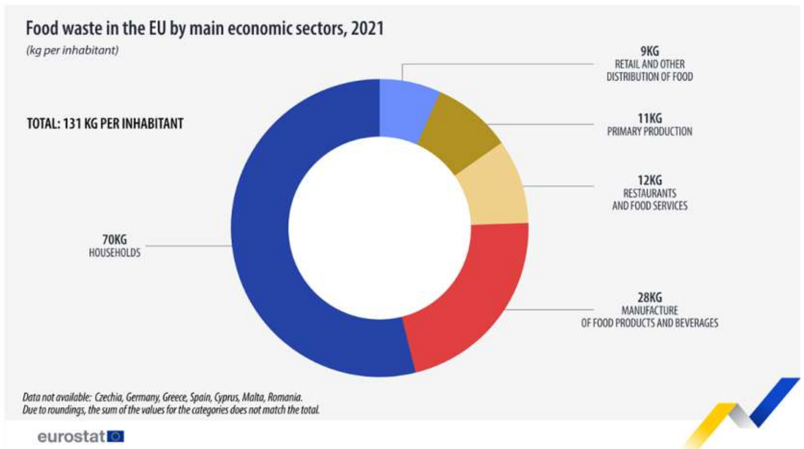

Figure 4. The main economic sectors responsible for food waste in the EU, 2021 (Eurostat, 2023)

However, when considering food waste, it is crucial to move beyond the financial aspect or the social implications, such as the millions of people worldwide who lack the means to adequately provide for themselves despite sufficient production (EC b, 2024). Even more far-reaching are the environmental consequences that uneaten food causes. It takes an enormous amount of resources to make all the quantity and variety of items produced possible. Around 30% of the land and 70% of the freshwater harvested are used to grow a wide range of crops (Wohner et al., 2019). Pesticides and fertilizers are used to maximize food production and their utilization in the process leads to 50% of the contamination of habitable land and 78% of water (Poore and Nemecek, 2018). According to some studies, wasted food can be associated with 3.3 billion metric tons of carbon dioxide and 250 cubic meters of blue water (Wohner et al., 2019). In addition, about one third of the entire agricultural area, or 1.4 billion hectares, is literally purposelessly farmed and the resources used, including energy, are simply wasted because the products made do not reach our plates and are not utilized (Wohner et al., 2019). Moreover, any food that is discarded and ends up in landfills undergoes putrefaction, leading to the production of a significant amount of methane (Foodcycler, n.d.). While all stages of the plastic life cycle result in the emission of substantial amounts of carbon dioxide, methane is considerably more potent than CO2, posing a threat to the environment that, according to the Intergovernmental Panel on Climate Change (IPCC), is 28 times greater over the span of a century (Foodcycler, n.d.).

Before exploring the connection between packaging and food loss and waste, it is important to clarify the definitions of these processes. Various studies and experts aim to establish universal definitions of the terms "food loss" and "food waste". Interestingly, some of these do not even differentiate between the two terms (Wohner et al., 2019). In the framework of this thesis, the Food and Agriculture Organization (FAO)'s definitions will be used. According to these definitions, food loss refers to the "decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain", while food waste refers to the "decrease in the quantity or quality of food resulting from decisions and actions by retailers, food service providers and consumers" (FAO, n.d.). Loss refers to the decrease in volume that occurs from production to the point of sale, whereas wastage pertains to the behaviors and practices of food handling and consumption, for example in restaurants or by end consumers (OneThird, 2023). It is believed that innovations along the various stages of the first cycle, beginning with food cultivation, coupled with education and efforts to change detrimental consumption habits that are common among end consumers, could collectively mitigate waste generation (OneThird, 2023). Intriguingly, there is a difference between developed and developing regions regarding the inefficiencies in utilizing food for its intended purpose (Wohner et al., 2019). In countries across Africa and Southeast Asia, the majority of food loss occurs during production and the subsequent logistical and sales stages. In contrast, in Europe and America, this wastage primarily happens during the consumption stages (Wohner et al., 2019).

Figure 5. Food loss versus food waste (OneThird, 2023)

4.4.1. Where and how food can be lost and wasted

Food is considered to be lost before it reaches the consumer and wasted once it is in their hands (OneThird, 2023). However, the entire human alimentary chain involves distinct and specific phases, and at each of these the initial food quantity decreases.

For a food product to reach the point where it can be utilized, its journey begins with the production phase, which largely takes place on farms. Risks during this stage arise from potential pest infestations, prompting farmers to sow a larger quantity to compensate for any potential losses (Foodprint a, 2018). Additionally, adverse weather conditions in a particular season, coupled with carelessness or lack of preparation, can also jeopardize the crop (Foodprint a, 2018). Various incidents such as diseases on the plants or unexpected global upheavals, like crises or the COVID-19 pandemic, could result in non-harvesting or disposal of the produced food, as subsequent processing would incur even more significant costs for farmers (Foodprint a, 2018). Factors such as appearance also play a role; if a product does not meet specific aesthetic standards, it is often discarded. Even if it reaches the store, the likelihood of potential buyers purchasing it is low if it is visibly deformed or unattractive (Gunders and Bloom, 2017). Sometimes large grocery chains return this type of product so that it can eventually be improved by the producer, but if the distance between the seller and the farmer is too great, the additional cost and effort can be prohibitive for small agricultural producers (Gunders and Bloom, 2017).

The next step in the process is food processing. This involves the cutting off of parts that are otherwise completely sound and suitable for consumption, such as peelings or skin(s) (Foodprint a, 2018). This can be caused by product failure or technical equipment malfunction (Gunders and Bloom, 2017). Some of the described leftovers are recovered for animal feed, but this amount is small compared to what goes to the landfill and is wasted (Foodprint a, 2018). Furthermore, epidemics can lead to morbidity among staff and a lack of personnel to carry out all the functions and activities internal to the production facility and again, this would lead to losses (Foodprint a, 2018).

Once prepared for distribution to buyers, food products, especially soft and perishable items, move on to a very problematic stage (Foodprint a, 2018). As discussed earlier, countries in developing regions often encounter losses during the initial phase of the cycle, partly due to insufficient refrigeration, infrastructure, and transportation (Foodprint a, 2018). While these factors may also contribute to wastage in the developed world, their impact is comparatively less pronounced (Foodprint a, 2018). Retail stores and food buyers themselves reject up to 5% of food due to its short shelf life (Foodprint a, 2018). Even if these rejections are avoided and the food reaches supermarket shelves, a portion of it still goes to waste because it remains unsold (Foodprint a, 2018).

Up to this point, the stages where food could be lost were explored. The subsequent phase represents the initial step where food is wasted, particularly in the way retailers manage it. Products with short shelf lives and those prone to spoilage within a brief period, such as meat, fruits, vegetables, bread, pastries, and fish, are particularly vulnerable (Gunders and Bloom, 2017). Supermarkets often perpetuate detrimental practices that contribute to this vicious cycle, including overcrowding displays, stocking large quantities of perishable foods, inadequate planning and ordering of items of low demand, and insufficient staffing to maintain counter upkeep (Gunders and Bloom, 2017).

In addition to supermarkets, other establishments that significantly contribute to food waste include restaurants, hotels, schools, and hospitals (Foodprint a, 2018). It is common for a part of the food products purchased for meal preparation in restaurants to go uneaten (Foodprint a, 2018). Excessively large portions and the inclusion of numerous options on restaurant menus, which requires the maintenance of a wide variety of ingredients, leads to further spoilage and waste (Foodprint a, 2018). Apart from food packaging, the lack of awareness and a poor food storage culture among the staff of these establishments also contribute to undesirable outcomes (Foodprint a, 2018).

Finally, those who contribute the most to food waste, namely end users, have a key role to play. Households in Europe are responsible for over 60% of the food waste generated annually (Eurostat, 2023), with about half of this waste originating from fresh fruits and vegetables (De Laurentiis et al., 2018). Common causes of waste are often related to poor storage practices, such as opening packaging and leaving some of the content unused for extended periods (Gunders and Bloom, 2017). Additionally, placing products in refrigerators in a way that obscures visibility can hinder monitoring of shelf life (Gunders and Bloom, 2017). Similar to restaurants, households may also tend to cook and serve excessively large portions over time (Foodprint, 2018). Even though household members often develop the habit of reheating and consuming leftovers, not all food items are consumed before they spoil (Foodprint, 2018).

Improper throwing of food is also common as people do not properly understand the markings on the packaging (Bello and Oelsner, 2021). “Best before” labels refer to the period of time in which a food retains its quality in relation to the required standards, while “use by” labels inform consumers of the final consumption date in which the food in question would not cause harm to human health (Bello and Oelsner, 2021). Around half of Europeans are unaware of what these labels actually mean, which further contributes to food waste (Bello and Oelsner, 2021). With greater awareness and improved labeling, there is an opportunity to save eight tons of all the wasted food in Europe on an annual basis (Bello and Oelsner, 2021).

Figure 6. Difference between
"use by" and "best before" (Euronews, 2021)

Another factor influencing household waste is buying discounted items from stores. Oftentimes, these items are not incorporated into the family's daily diet and eating habits, which results in them being left unused and potentially spoiling before consumption (Gunders and Bloom, 2017).

This issue is also related to poor planning in relation to shopping. If purchases are spontaneously made without specific clarity on what the upcoming weekly menu will be, some of the products may perish by the time it is their turn to be eaten (Foodprint, 2018).

4.5. The relationship between food loss and food waste, and food packaging

After exploring the various stages of the food supply chain and examining potential causes of food loss and/or food waste within each of them, we are now going to focus on packaging and its role in mitigating food waste.

Within production, the harvest has not yet come into contact with packaging, but as soon as it is collected and begins to be distributed, it is put into different types of packaging that should fulfill their purpose, such as containment and transport, preserving the qualities for as long as possible (Wohner et al., 2019). Accordingly, food loss or food waste caused by the packaging due to its integrity being compromised, or spoilage, can occur at any of the other stages of the food chain (Wohner et al., 2019).

Stage		Type of Packaging-Related Food Losses and Waste
Food in the supply chain	Primary production	-
	Post-harvest handling and storage	Damage of products due to contaminants, sharp edges or splinters of field containers, over-packing of field crates
	Processing and packaging	Problems in the filling process Packaging failures while sealing Packaging changes due to marketing reasons
	Distribution and retail	Packaging does not provide enough mechanical protection (inappropriate packaging material, poor stackability, no packaging at all) Damage to barcodes on packaging
Food in households		Difficult to open packaging Difficult to empty packaging Inappropriate packaging size

Figure 7. Type of packaging-related
food losses and waste (Wohner et al., 2019)

4.5.1. Causes of food loss due to packaging

The first part of a food's life cycle relates to the time until it reaches its point of sale where it becomes available for purchase. It is in these initial few stages that it can be lost. (OneThird, 2023).

The production process typically excludes packaging, but there is the possibility that large containers might help and that is why they are used during harvest before the foodstuffs move further up the chain. In this case, it is essential that the vessels in question are clean and have no irregularities or sharp points in order to protect the foodstuffs from injury as well as possible contamination (Wohner et al., 2019).

As previously indicated, the step characterized by the processing of the food produced often results in losses due to the larger quantity being obtained for the purpose of reinsurance and the removal of edible but deformed parts or packaging defects. Packaging can be manual or automated using machinery. Manual handling involves people who may make mistakes and therefore fail to properly fill the containers intended for the produce (Wohner et al., 2019). In the case of special technical equipment, if there is no synchronization between packing and filling, or additional failures leading to overfilling or underfilling during the set-up of a batch, loss may also occur. Occasionally, a problem may arise due to improper sealing of the enclosement. Continuous changes in the packaging sector for communication reasons are also a pivotal factor (Wohner et al., 2019). Marketing campaigns are implemented that change the way a product is wrapped for a period of time. This results not only in the packaging being thrown away when the promotion is over, but also in food being thrown away if it is already in the vessel and cannot be repackaged (Wohner et al., 2019).

Once the food is boxed, the next step is to handle the logistics and get the products to their desired destination. During this particular step, losses may occur due to the integrity of the container being compromised by poor or insufficient materials (Wohner et al., 2019). If the transport itself passes through roads in poor condition, this can once again cause damages, or if the delivery takes longer for unexpected reasons than the shelf life, the food will have to be discarded (Wohner et al., 2019).

An important part of distribution is the ability to stack different numbers of levels of products on top of each other, which means that the first layers have to withstand a lot of weight and still retain their solidity (Wohner et al., 2019). A collapse would result in losses, the percentage of which would vary depending on the particular product. Overall, damage in this phase can mainly be caused by poor arrangement and quality or unsuitable materials for "primary, secondary, or tertiary packaging" (Wohner et al., 2019).

Up to about 5% of all food losses on the European market occur after foodstuffs reach the destination point where they should be stored and gradually sold, namely convenience stores and large supermarkets (Wohner et al., 2019). This is often the result of spoilage related to expiration dates, which may be a consequence of slow distribution, improper packaging, or improper temperature during transportation. Packaging damage that makes the expiration date unreadable may also result in a small percentage loss (Wohner et al., 2019).

Sometimes the actual container can be difficult to handle. This leads to challenges for the removal of individual products. In the event that only a small portion of the food is spoiled, the result would be the disposal of the entire quantity, including the container (Wohner et al., 2019). This automatically produces residual waste instead of having separate disposal – organic waste (the food) and plastic or municipal waste (the container) (Wohner et al., 2019). Depending on the specific country or region, the waste is managed in different ways according to the available facilities and regulations. This means that the residual waste does not allow for separation and eventual recycling, and even if this is possible, it makes the process more difficult because of the dirty packaging that has not been cleaned of the food inside (Wohner et al., 2019).

4.5.2. Causes of food waste due to packaging

One third of the world's food production eventually fails to meet its intended purpose, with much of it being wasted rather than consumed (UNEP a, 2024). Once food has already left the retail industry and is somewhere in the food service sector or in households (UNEP b, 2024), if it goes rotten, it is usually considered wasted instead of lost, as it is largely influenced by the awareness, culture, and decisions of those handling it (OneThird, 2023). But it is not only human habits that contribute to the negative impact of discarded products on nature; packaging also plays a major adverse role in this process.

Once products are purchased, the next step is their use, which most often occurs through the packaging they come in (Wohner et al., 2019). In addition to its function as a source of protection for the food and a tool for the preservation of its qualities for as long as possible, the enclosure must also be easy to handle in order for the packaging to be opened, unpacked, and consequently emptied without much difficulty (Wohner et al., 2019). It is essential to take into account the fact that over 1.3 billion people, or approximately 16% of the world's population, are people with disabilities (WHO a, 2023). One in six individuals in the world experiences some form or degree of disability, most often physical, which means that they have a limited physical and motor function (WHO a, 2023). Those aged over 65 years, or 761 million people as of 2021, face a similar reality, and this group is expected to reach 1.6 billion by 2050 (UN DESA, 2023). Therefore, the packaging for different types of food should be designed in such a way that it can be used by every person, no matter their condition (Wohner et al., 2019). An interesting development in this direction is the introduction of specific terminology, such as "easy to empty", which is used for containers whose contents are not accessible to emptying, such as bottles (Recyclass, n.d.). In this case, the product can be poured very easily, without any effort, for example by simply turning the container upside down (Recyclass, n.d.). The other important term here is "easy to access", where it is meant that the contents can be emptied, but the consumer can do so with an additional tool, for example a spoon (Recyclass, n.d.).

The aspect of complete emptying of a food package is of great significance (Wohner et al., 2019). If there is a quantity left inside and the packing has already ended up in a separate plastic collection bin for recycling, it may spill and contaminate other items in the first place, and thus much of the intended plastic for reuse through recycling will be at risk as food residues lead to a reduction in quality and hinder the whole process (Sustainability Victoria, 2023). In terms of emptying, it is also important to pay attention to the density of a given food, as the more viscous it is, the more difficult it is to separate from the interior walls of the vessel. The shape of the container itself as well as bumps or creases on the inner wall can also lead to residue (Wohner et al., 2019). In addition to design, as pointed out previously, consumer behavior and awareness also play a role, as people who are more knowledgeable about the environment tend to act more responsibly and care more about how a food container is used and emptied (Wohner et al., 2019).

Another factor that impacts the amount of food that ends up in landfills is the size of a package. Particularly in the case of households, there are a variety of reasons for food waste. One factor is the placement of products in inappropriately sized containers, which can lead to more wasted food for households and waste in the form of packaging for retailers (Wohner et al., 2019). For example, if a product is portioned into smaller pieces and accordingly packaged in 150 grams and additional packages that are twice smaller than the aforementioned size, this automatically leads to more packaging and therefore more waste from enclosements (Wohner et al., 2019). On the other hand, it is highly likely that food waste will be reduced as there is a greater chance that open small cuts will be completely consumed before going spoiled, thus saving the disposal of products and their negative environmental impacts afterwards (Wohner et al., 2019).

Not only do consumers have the opportunity to reduce waste less by adapting the size of the packaging, but this also helps supermarket owners to manage their inventory (Woner et al. 2019). Larger packaging leads to more food spoilage as estimating the actual quantity and calories of the product is difficult (Petit et al., 2020). Studies have shown that by dividing food into smaller portions, people can clearly visualize its volume and, thus, estimate how much they would consume and, going a step further, think about the possible leftovers that could go in the bin (Petit et al., 2020). The number of members in a household is also important because one person generates twice as much food waste as four people (Wohner et al., 2019).

According to some studies, consumers believe that better planning of their weekly menu, adapting their habits, and providing product sizes and packaging that meet their needs can help reduce food waste (Wohner et al., 2019). Conversely, other studies have shown that individuals who are informed about the potential negative outcomes of food waste and believe that small cuts will reduce their footprint are nonetheless more likely to be the ones who fail to store their food well (Wohner et al., 2019).

Among low-income families, there is a tendency to stock up during supermarket sales on foods that come in large packs and, thus, oversupply their homes, again increasing the likelihood of wastage (Wohner et al., 2019). While purchasing in big vessels is also often associated with lower prices for a larger quantity, studies have indicated that as long as customers are aware of the negative impact of food that can result from its being left behind and spoiled, they tend to avoid buying large containers of food (Petit et al., 2020).

In addition to the design and size of the packaging, there is another key factor that impacts the amount of food waste that is generated, namely the underlying technology. People are becoming more and more aware that due to their consumer behavior and desire to have access to a variety of products to satisfy its needs, a large amount of both packaging and food waste is generated when enclosements fail to fulfill their key purposes. This is why a growing number of investments are being made in the search for new technologies to preserve food for longer, which is often achieved with various polymers and different layers (Wohner et al., 2019). New materials, for their part, reduce the weight of containers (Wohner et al., 2019). One of the possible solutions that can be found every day and all around us is modified atmosphere packaging (MAP), whose main advantage is preserving the freshness and the quality of the product for a longer period (Goyal, 2020). This is achieved by managing the atmosphere around the packaged product and replacing oxygen with other gases that preserve its properties (Dube, 2019). The negative aspect here is that due to the diverse nature of the different layers of the enclosement, the lack of a proper collection approach and identification, and the difficulty of separating MAP packages turn recycling into a big challenge (Tamizhdurai et al., 2024). For this reason, they usually end up in the incineration facilities. The other innovation is active or "intelligent packaging" (Wohner et al., 2019). This novelty not only takes care of extending the life of the food, but with the help of features such as "oxygen, carbon dioxide and ethylene scavenging", it can also provide information about the quality of the packaging and changes in the environment resulting from it (Kuswandi and Jumina, 2020).

In essence, it can be concluded that, on the one hand, packaging itself needs to be further developed in terms of the materials from which it is made so that its direct environmental footprint can be reduced. Novel lightweight and improved materials may sound like solutions ready to solve environmental problems, but in fact their multiple layers and complex content make them very difficult to recycle, which is even worse for the environment. There is a need to invest in the search for monomers that can provide multiple barriers at the same time (Scharff, Personal Communication, 2024).

Furthermore, according to the FAO, in terms of indirect consequences, namely food waste, packaging is key to absolutely every post-production stage if we are to be able to reduce food spoilage throughout the chain (Manalili et al, 2014). This can occur precisely by taking into account the scope for improvement of packaging design, size, and technology, and the need for greater awareness among consumers, as this can contribute to a more sustainable future altogether. However, in order to accomplish this, it is necessary to come up with a universal definition of food packaging. It is this aspect that will be addressed in the next section.

4.6. Definition of “sustainable food packaging”

As this thesis delves into the intricate dynamics of food packaging, its pivotal functions, and the adverse ramifications intertwined with the broader context of food waste, a stark realization emerges: humanity's daily decisions regarding packaging design, usage, and disposal wield substantial influence over sustainability, environmental integrity, and human well-being. While packaging is necessary to help preserve product qualities and lifespan for a longer period so that the product can eventually be consumed, its increasing prevalence is leading to pollution, resource depletion, and the destruction of ecosystems and nature as a whole. The often overlooked yet calamitous implications of food loss and waste serve as a poignant reminder of the imperative for immediate action to catalyze substantive change. Stakeholders are already mobilizing efforts to transition the conventional food packaging paradigm towards sustainability, envisaging a multifaceted approach that encompasses alternative materials, strategic management, and a circular waste management framework.

It is clear that the guiding approaches to packaging and the materials used in food packaging need to be changed, but the question that arises here is how to evaluate and decide which solution is best and most sustainable, and which type of packaging would result in minimal or zero waste and negative impact, especially when considering the "entire food value chain" (Dörnyei et al., 2023). There are various studies and academic work in this regard, but there is still no unified definition of the term "sustainable food packaging", resulting in uncertainty and often confusion among stakeholders such as end-users, packaging manufacturers and the experts on whom legislative changes depend (Dörnyei et al., 2023). The lack of awareness and sensitivity in relation to the topic could also lead to a shift in consumer choice towards unsustainable packaging, failure of new alternative and better packaging products to gain market acceptance, and an inability to extend their life through recycling and reprocessing.

Some of the current definitions for sustainability address the topic of waste reduction only, while others target pollution mitigation. However, when looking at artificial enclosements for food, it is necessary to consider the full picture, including the importance of their functions and their footprint on ecosystems, and to remember that there should be as little wasted food as possible at each step of the life cycle.

Plastic is the main material used to make the protective containers that go with the food that people eat, with around 40% of its annual production going towards this purpose (Plastics Europe, 2021). Taking into account the huge variety of food products that are sold in shop displays and on supermarket shelves, it is also necessary to pay attention to the variety of functions that a package should be able to fulfill (Marsh and Bugusu, 2007). Here the materials, the method, and the kind of characteristics that need to be fulfilled are important (Dörnyei et al., 2023). This greatly complicates the material composition of containers, leading to difficulties in the management of packaging waste at the point at which it is discarded (Marsh and Bugusu, 2007).

Taking into account all these individual constituents is very difficult, especially when the individual stakeholders and packaging manufacturers who have to comply with them are confronted with multiple requirements, legislative changes leading to the need for enormous investments in order to meet all the frameworks (Dörnyei et al., 2023). Therefore, it is important to arrive at a single definition of sustainable food packaging that industries, manufacturers, policy makers, and consumers can refer to and serve as the main basis for comparisons between different types and approaches of artificial food wrapping (Dörnyei et al., 2023). A unified definition would also contribute to ending the distortion of this topic in order to benefit certain organizations or entities that might otherwise gain from greenwashing campaigns (Dörnyei et al., 2023).

There are various approaches and research work aimed at providing possible definitions. In order for a package to have an "entirely closed-loop cycle", it should not cause any harm to the environment and mankind at any stage of its existence. It needs to fulfill its intended roles, be sourced from renewable resources, and be recyclable (Select Equip, n.d.). Furthermore, when incorporating the food aspect into the definition of sustainable packaging, it is crucial to focus on reducing as much as possible of the food currently being wasted and enhancing food safety (Vain, 2023). The packaging and the functional unit, namely the food product, must be considered as an indivisible whole.

A number of international organizations and research work are investing effort to find a unified description. There is currently a shared understanding that a core objective should be to reduce over-packaging or linear packaging products. At the same time, other aspects remain outside the overall discussion.

One of these tendencies is related to the concept of circular packaging, whose main purpose is to transform the current situation and help create conditions in which packaging can be recyclable and compostable. In this way, the use of new raw materials should decrease as recycling will recover old packaging and create new one with the current raw materials (Recycling partnership, n.d.). Sometimes recycling cannot be fully justified as it may be too energy-intensive or expensive, or it can reduce quality. Furthermore, some materials are difficult or impossible to recycle (Munger, 2013). However, such definitions overlook the crucial aspects of food preservation and food loss reduction. Furthermore, those recyclates need to be in line with current regulations as materials that are in contact with sensitive products such as food usually have multiple requirements (Schaffer, Personal Communication, 2024).

The next avenue, which will be introduced here and discussed in more detail in the following chapter, is "bio" packaging. Various terms, such as "biodegradable" and "biobased", are often used interchangeably, which is not always accurate (Bioplastics Europe, n.d.). These definitions focus on the sources of the feedstock or their ability to decompose. However, this can lead to problems with disposal due to a lack of awareness among users and challenges regarding the treatment due to a lack of established recycling strategies and approaches for such products (Dörnyei et al., 2023).

1	The protection of food products takes center stage
2	The food product-package is one inseparable unit
3	For food packaging both direct and indirect sustainability effects must be considered
4	Food packaging is a resource, not litter
5	Avoidance of food packaging is not always the best option
6	Sustainable food packaging development, in practice, is a balancing act
7	Multidisciplinary approach is needed to create sustainable food packaging solutions
8	Not all food packaging innovation is sustainable
9	Context (local) is key to food packaging sustainability
10	Regulatory landscape of sustainable food packaging is not fully comprehensive
11	Consumer knowledge and awareness on sustainable food packaging is limited
12	Food packaging is an information source on both product and packaging sustainability

Figure 8. Challenges in relation to sustainable food packaging (Dörnyei et al., 2023)

Taking into account the variety of different terminologies, as well as the omission of one or another important aspect to arrive at a concrete definition, shows that the consensus-building process is becoming problematic and a variety of challenges such as food preservation need not be overlooked, but on the contrary, put in a central position. Figure 8 represents some of these problems, namely how important it is to consider food and its artificial enclosement as an inseparable whole, together with their immediate and collateral impacts on nature, because ultimately sustainability depends on their overall performance and lifespan. Often due to a lack of awareness among consumers, even though a particular innovative solution in the field of food packaging may appear to be beneficial, it can be misleading because its ultimate impact is negative. Last but not least, those refining the legal framework aspire to achieve harmonization but the reality differs greatly from country to country, so achieving a balance appears to be a challenge as well (Dörnyei et al., 2023).

Highlighting each of the challenges described above, and understanding that the search for sustainable solutions is an ongoing process that has yet to continue to evolve, a recent study provides an attempt to define sustainable food packaging in a multi-faceted universal way, while still leaving room for future improvements with the following definition: "*Sustainable food packaging is an optimized, measured (quantified) and validated solution, which takes into consideration the balance of social, economic, ecological and safe implementations of the circular value chain, based on the entire history (life cycle) of the food product-package unit"* (Dörnyei et al., 2023).

Based on this definition, and given the challenges outlined in the preceding chapter and the significance of various factors such as materials, packaging methods, and public awareness, it becomes evident that ensuring appropriate use, collection, sorting, disposal, and treatment of packaging requires a multifaceted approach. This includes a focus on enhancing recycling facilities and methods while addressing infrastructure challenges to facilitate broader reuse initiatives, which are crucial for combatting escalating global pollution rates. Urgent and concerted action from all stakeholders is imperative to translate these aspirations into tangible outcomes.

The next section of this thesis will explore alternative materials and approaches aimed at revolutionizing traditional food packaging to minimize its ecological footprint and achieve a symbiotic relationship with nature. Our attention will be directed towards evaluating the merits and drawbacks of a specific product, along with its potential to deliver substantial positive influence.

5. Results from case study

5.1. Alternative solutions

The growing volume of waste generated by plastic food packaging has prompted scientists, entrepreneurs and industry leaders to seek solutions to this pressing issue. Various strategies are being developed to address the deluge of food containers inundating the environment. The following chapter will discuss several specific approaches to tackling this problem.

Some of the main conventional materials that are blamed for negatively impacting nature include "polyethylene terephthalate (PET), polyvinyl chloride (PVC), polypropylene (PP) and polyethylene (PE)" (Donkor et al., 2023). As previously mentioned, these materials have several advantages for food packaging: they are durable, lightweight, highly impermeable, and low-cost (Teinnovations, n.d.). However, the price that has to be paid for their use due to the fact that they are based on fossil fuels translates into increasingly higher levels of pollution from single-use packaging, an inability to biodegrade, their breakdown into microplastics after a vast amount of time, the generation of food waste due to improper size or design, hazardous emissions emitted through their whole life cycle, and putting human health at risk (Teinnovations, n.d.).

Alternative solutions emerging in the market often combine new materials and must meet specific requirements. These include being recyclable, originating from renewable sources, utilizing environmentally friendly energy throughout their lifespan, and reducing the pollution produced by their conventional counterparts (Donkor et al., 2023). Substitutes should be prevented from ending up in landfills and, thus, reduce the use of water for their treatment (Mendes and Pedersen, 2021). Simultaneously, they must fulfill all the essential functions of regular food packaging to ensure food preservation. Despite some significant efforts, developing a universal solution remains a challenging endeavor (Mendes and Pedersen, 2021).

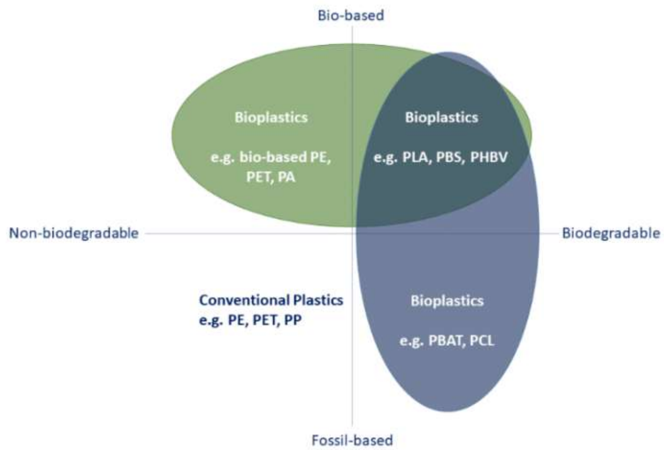

Figure 9. Properties of different plastic materials

based on the factors of biodegradability and origin (Bioplastics Europe, n.d.)

The current range of materials used for food packaging includes traditional fossil fuel-based plastics, which can be either biodegradable or non-biodegradable (Bioplastics Europe, n.d.). Alternatives to them are bioplastics, which are also divided into the same subcategories (Bioplastics Europe, n.d.). As illustrated in Figure 9, a material can be classified as a bioplastic if it is either biobased, biodegradable, or both (Bioplastics Europe, n.d.). It is important to emphasize that the term "bioplastics" cannot be used interchangeably with biobased plastics. Moreover, biobased materials are not always biodegradable, and some of them actually cannot break down (Bioplastics Europe, n.d.). In the following paragraphs, the difference between these possibilities will be clarified and one specific material will be examined in detail.

5.1.1. Biobased plastics

Biomaterials are considered as viable substitutes to standard plastics used for food packaging. A typical feature is their origin, which is entirely and partially derived from biological and renewable sources (EC c, n.d.). Concrete possibilities for natural biopolymers could be plants, animals, and microorganisms (Mendes and Pedersen, 2021). Inputs additionally include trees, algae, marine organisms, and organic waste (Bioplastics Europe, n.d.). The aforementioned sources are used to develop natural biopolymers for food packaging films (Mendes and Pedersen, 2021). However, it is important to consider that materials produced from these sources may not always be biodegradable or compostable (EC c, n.d.). In addition, the origin of biobased plastics can be first, second, and third generation (Bioplastics News, 2018).

5.1.2. Biodegradable and compostable plastics

Bioplastics can be extracted from existing natural biopolymers and in addition can be biodegradable. In the last phase of their life and depending on their chemical composition, they can decompose to natural substances, including monomers, carbon dioxide, and water (Mendes and Pedersen, 2021). The process is not specified by a concrete timescale but is strongly influenced by the biological activity of microorganisms such as fungi and bacteria present in water or soils, and whether the environment is aerobic or anaerobic (Bioplastics Europe, n.d.).

An additional sub-category of biodegradable compounds are those that can be composted. Typically, this occurs in an industrial environment with special infrastructure and particular conditions (EC c, n.d.), such as temperature, humidity, and aeration control (Bioplastics Europe a, n.d.). For this process to work, it is essential that the discarded compostable food-packaging materials can reach the appropriate facility, which requires effective collection and separation systems (EC c, n.d.). When composting biodegradation occurs, the resulting end products are non-toxic elements, including inorganic compounds, water, CO2, and biomass (GSP, n.d.).

Both processes can be characterized as natural recycling, but the difference between them lies in the decay period, which, in biodegradation, is not concretely determined, while in the case of composting, it is related to a concrete duration (GSP, n.d.). In addition, biodegradation can still leave tiny plastic residues, whereas composting eventually yields humus (GSP, n.d.). In other words, not all biodegradable materials can be composted, but if a compound is compostable, then it is also biodegradable (GSP, n.d.).

Figure 10. Comparison between biodegradable

and compostable materials (Good Start Packaging, n.d.)

It is important to draw a parallel with biobased alternatives to conventional plastics, which are derived from fossil fuels. The designation "bio" can be misleading as one of the materials with a large market share of 26%, namely Bio-polyethylene terephthalate (Bio-PET), is hardly more degradable than conventional polyethylene terephthalate (PET) (Mendes and Pedersen, 2021). The difference between the two is that PET contains "70% terephthalic acid and 30% monoethylene glycol (MEG)" from fossil sources, whereas the source for MEG in Bio-PET is renewable feedstocks (Biokunststofftool, n.d.).

Returning to the topic of biodegradable plastics, one concrete example of such a polymer that has increasingly established itself on the market in recent years as a potential alternative is polylactic acid (PLA). This type of compound will be addressed in the following chapters of the thesis.

5.2. Challenges to sustainable packaging solutions

Before addressing the specific material envisaged as a potential solution within the framework of this study, we need to look at some of the challenges that exist in terms of validating alternative packaging materials for food products. This aspect has a very important role to play in terms of realistically and adequately analyzing the sustainability of such substances.

5.2.1. Life cycle assessment

Although derived from renewable sources, different types of raw materials still impact nature. This impact can be assessed by considering their origins, which are classified as first, second, or third generation (Wellenreuthe and Wolf, 2020). For each individual production chain and its phases to be evaluated and, thus, compared in terms of the sustainability of the range of biobased plastics, analyses, life cycle assessments (LCA) in particular, are necessary (Wellenreuthe and Wolf, 2020). This is a systematic methodology that helps to assess the impact that a product or a specific process has on nature, taking into account the whole cycle from the production of the raw material to the EoL (Omolayo et al., 2021). By examining the individual stages of the scope of existence and especially the initial ones, such as production and processing, it can be estimated how the resource choice in question can change the results of the LCA (Wellenreuthe and Wolf, 2020).

The first generation of biobased plastics is characterized by sourcing substances directly from plant species generally intended for the food industry and human consumption (Wellenreuthe and Wolf, 2020). Currently, a large proportion of biobased plastics is still derived from carbohydrates obtained from crops coming from primary agriculture (Wellenreuthe and Wolf, 2020). Examples include corn, wheat, and sugarcane (Bioplastics News, 2018). This practice has significant negative consequences for nature and raises ethical concerns, as it interferes with food resources and land use (Rosenboom et al., 2022). The intensive farming practices required for these crops, including the use of fertilizers and pesticides, are particularly harmful to ecosystems and human health (Wellenreuthe and Wolf, 2020). Due to the high levels of nutrients such as phosphorus and nitrogen that are present in fertilizers, their entry into water bodies can lead to acidification and cause eutrophication (Mendes and Pedersen, 2021). At present, about 0.02% of the arable agricultural land is used to directly produce biomass to replace conventional plastics (Rosenboom et al., 2022).

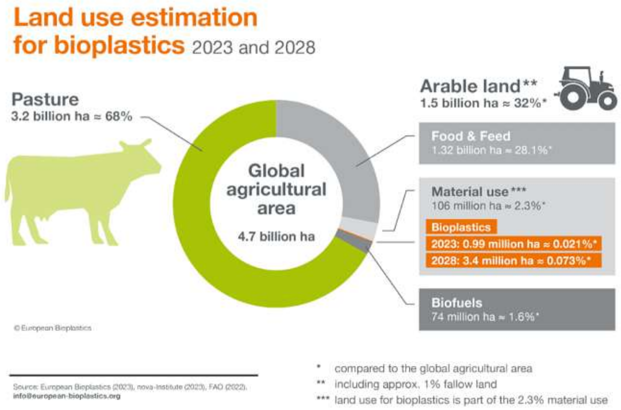

Figure 11: Land use estimation for bioplastics (European Bioplastics, n.d.)

Figure 12 gives an overview of the different phases of the life cycle of packaging products based on virgin corn, which ultimately would result in significant environmental impact.

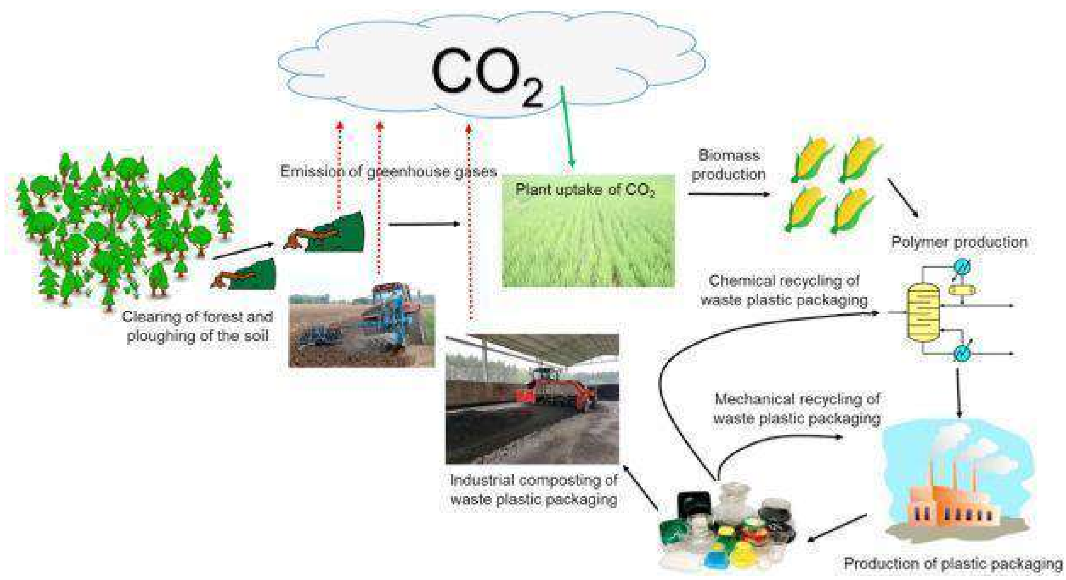

Figure 12: Life cycle of biobased compostable plastic produced from first generation maize (Mendes and Pedersen, 2021)

Due to the negative consequences associated with the production of biobased plastics from primary biomass sources, more and more work is being undertaken in the direction of sourcing second and third generation feedstock. Secondary production lines are mainly lignocellulosic sources – that is, first generation waste derived from crops not intended for human and animal consumption (Bioplastics News, 2018). These include wood, corn cobs, wheat straw, and sugarcane bagasse (Bioplastics News, 2018). Such wastes have a low cost, but in order to extract the fermentable sugars from the lignin, they need to be additionally treated (Rosenboom et al., 2022).

The third generation category encompasses methods and technologies for the utilization of materials from algae, industrial waste, and municipal waste (Wellenreuthe and Wolf, 2020). Feedstocks coming from algae have considerable diversity because of the different species that exist in nature and are attracting increasing attention due to their diverse properties (Bioplastics News, 2018). When the biomass used comes from second- or third generation waste, the climate change influence caused by greenhouse gases from first generation sources does not apply. These next generations are not burdened, resulting in better outcomes when performing an LCA (Mendes and Pedersen, 2021).

Key additional indicators directly related to packaging properties and sustainability include the ability to be easily recycled and the use of renewable energy or low-energy consumption (Dörnyei et al., 2023). However, to measure the overall footprint of both the food product and its packaging, it is necessary to consider additional parameters related to the life cycle of the food unit. These indicators could include land use, energy consumption, and CO2 emissions, among others.

5.2.2. Littering

Littering is a destructive human behavior that causes significant harm to the environment. To mitigate this issue, extensive efforts are required to build awareness through campaigns and various educational initiatives. Interestingly, the presence of bioplastics can sometimes lead to an increase in littering, as people may mistakenly believe these materials are harmless when discarded in nature (Green Home, 2007).

5.2.3. End-of-life treatment

The production of plastics, including bioplastics, is increasing. To close the loop and prevent such waste from ending up in nature, it is essential to invest in the optimization of recycling infrastructure. The current systems and strategies are not well-suited for processing biobased plastics (Scharff, Personal communication, 2024).

Although the renewable origin of biobased plastics brings advantages in terms of sustainability, if these types of materials are not treated properly, they can again become a burden for the environment (Kumar et al., 2023). With the demand for and investment in solutions that can help reduce the environmental impact, the growth in the production of alternatively derived solutions from plants is projected to increase as well. Therefore, it is imperative to find and validate as soon as possible an option that ensures their recycling, thus preventing additional pollution of our surroundings (Kumar et al., 2023).

Different EU countries, such as Bulgaria and Austria, have different approaches to waste collection, separation, and treatment. These steps are crucial because if waste is not properly collected, it cannot be separated and then it fails to be treated. However, the wide variety of bioplastics complicates their identification and sorting (Rosenboom et al., 2022). Technologies that assist in this phase include near-infrared scanners, which have a near 100% recognition rate for PLA, X-ray and UV spectroscopy, and the incorporation of artificial intelligence into the process (Rosenboom et al., 2022).

The treatment of biobased packaging in the final phase of its existence includes various methods, among them biodegradation, composting, recycling, incineration, and landfilling. Currently, two main recycling approaches are being used in the market, namely mechanical and chemical. They have the potential to be scaled further so that they can be applied to biobased plastics (Kumar et al., 2023).

Mechanical recycling is the most common and straightforward method. It is also the most financially advantageous, as the investment required to implement it is relatively low. The downside of this method is that it is often difficult to completely remove potential pollutants or to separate the different layers of the biobased materials currently in use, as they are usually not monomers (Rosenboom et al., 2022). This leads to a decrease in the quality of the recyclate, and although it could theoretically go through multiple processing cycles, this rarely happens (Rosenboom et al., 2022). Furthermore, this reprocessed plastic cannot be reused to manufacture new food packaging (Scharff, Personal Communication, 2024). However, it is crucial to find a way to improve this process, along with enhancing upstream collection and distribution, as this could significantly reduce the need for primary raw materials (Rosenboom et al., 2022). One of the benefits of the mechanical approach is that it has lower processing costs (Kumar et al., 2023).

Chemical recycling, for its part, offers advantages such as the ability to separate polymers into individual monomers, allowing for their subsequent reuse and, thus, contributing to the circular economy (Kumar et al., 2023). However, it has not been widely adopted yet, and further research is needed to explore various aspects of this process. These include determining the specific environment required for recycling different biobased materials, given their heterogeneous nature, identifying the types of additional substances needed to facilitate the chemical reactions, and assessing the financial viability of the process (Kumar et al., 2023).

Although it is an undesirable effect, a very large part of the waste that people do not know how to deal with or do not have the right facilities to handle still ends up in landfills. Accordingly, this is the final place where a portion of the bioplastics that fail to be processed are disposed of. It is extremely important for humanity to try to reduce the huge mountains of compacted rubbish that is being taken to landfills by adopting a circular approach (Green Home, 2007).

5.3. Polylactic acid

In 2023, the global volume of biobased plastics production was 2.18 million tons (European bioplastics, n.d.). One of the materials with the highest production capacity in the market is polylactic acid, which accounts for 31% of the previously mentioned amount for 2023, with potential for this share to grow to 43% in the next five years (Statista, 2024). This alternative is biobased, biodegradable, and compostable (Dana and Ebrahimi, 2022). It can be recycled up to five times before it undergoes significant reduction in its quality and properties (Kumar et al., 2023).

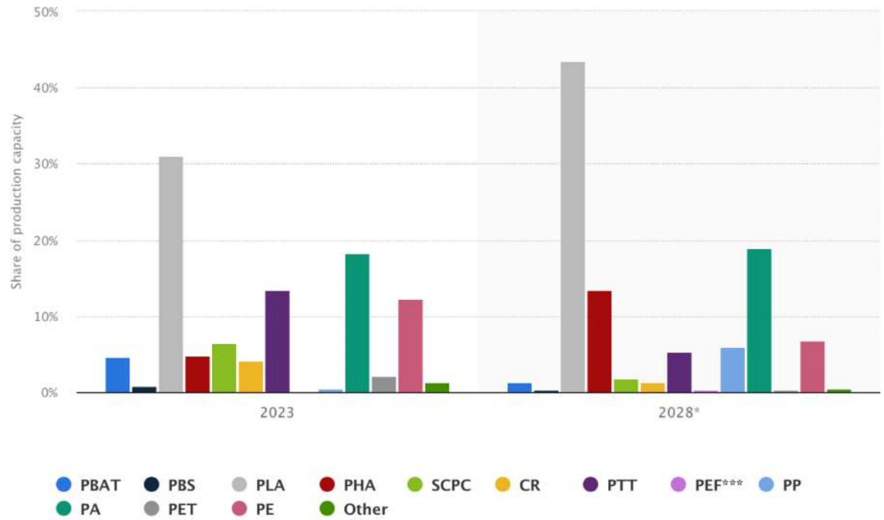

Figure 13. Distribution of the production capacities of bioplastics worldwide in 2023 with a forecast to 2028, by material type (Statista, 2024)

PLA is a thermoplastic monomer whose origin stems from the polycondensation of lactic acid (Rosenboom et al., 2022). Some of the main renewable sources for its production are corn starch (glucose) or sugar cane (sucrose) (TWI Global, n.d.).

Although it is still more expensive than its conventional counterparts, given the existing infrastructure for producing conventional plastics, an advantage of creating polylactic acid is that there is already a wide technical understanding about it. What is more, it can be manufactured using the existing facilities (TWI Global, n.d.). When PLA is derived from first generation natural sources, the production volume is higher, but sustainability becomes a concern. Therefore, it is important to use residues or waste representing next-generation feedstock (Bioplastics News, 2020).

PLA is characterized by a change in firmness in response to increases and decreases in the temperature, becoming softer or harder, respectively (Wellenreuthe and Wolf, 2020). This process can be repeated up to several times, providing the opportunity for further processing and recycling through methods such as "liquification and moulding" (Wellenreuthe and Wolf, 2020). An additional feature of this polymer is its optical transparency (Bioplastics News, 2020).

In terms of its utilization in the food industry and taking into account its transparent nature, this biodegradable polymer is a good substitute for bags or containers for cold and fresh foods, such as salads, and offers alternatives to plastic bags and cups for cold drinks (Mooney, 2024). PLA has a high barrier in terms of permeability to oxygen, as well as fat resistance (Ncube et al., 2020). It begins to melt at relatively low degrees, which makes it unsuitable for hot foods and beverages (Bioplastics News, 2020). However, it can be sealed well if the temperature used is lower than the melting point (Ncube et al., 2020). PLA-based films are coming into use to extend the life of fruits and vegetables, replacing traditional plastic films and allowing moisture to escape (Mooney, 2024). Used in combination with other materials, it provides an additional protective layer, improving the overall barrier properties (Mooney, 2024).

Despite its advantages, PLA, like any other material, has drawbacks that require trade-offs and judgment as to whether its use would be appropriate. When considering food packaging, it should be noted that some limitations of the polylactic acid, such as brittleness and low thermal stability, restrict its suitability for packaging certain types of food (Mohan and Panneerselvam, 2022). It is, therefore, not suitable for long-term food storage. Studies aimed at enhancing this polymer have experimented with the addition of different fillers, such as essential oils or organic materials, to improve these characteristics and achieve better results. However, further research is needed in this direction (Mohan and Panneerselvam, 2022).

In terms of recyclability, the low melting temperature of PLA makes it impossible to co-recycle with other plastics, posing challenges for reprocessing. Apart from recyclability, it can be incinerated, which is not the best potential approach, but additionally by boiling water or steam it can hydrolyse (Ncube et al., 2020). Furthermore, its relatively small market volumes and lower financial attractiveness further complicate recycling efforts (Bioplastics News, 2020).

5.3.1. Case study - Pack'On: packaging material based on polylactic acid

A variety of alternative substitutes for conventional plastics are already on the market, with new products continually emerging to address the issue of plastic food-packaging pollution. This study examines in detail a product from a Bulgarian startup that has been in the research and development phase for the last six years. The company’s portfolio of solutions was officially launched on the European market in May 2024.

Lam'On was founded in 2018 with the aim to create biodegradable laminate based on polylactic acid that has the potential to replace plastic-based laminates. Although the company was established with zero initial capital, it gradually received recognition and support from funds and investors, including the European Innovation Council (EIC). Its intellectual property is protected by a European utility model patent for the biodegradable film production process and the product formula in relation to the ratios of the individual biopolymers. The products additionally have biodegradability certification from the TUV Institute (Stancheva, Personal Communication, 2024).

The first product created by the company is called Lam'On – a biobased thermal laminating film for paper and board. Pack'On, for its part, is a series of packaging products, and two of them are already available on the market: Pack'On Classic and Pack'On Shrink. Pack'On Classic is versatile and suitable for various applications, including food packaging for salad bags sealed with heat seams on both sides, to give just one example. Pack'On Shrink is a shrink film used for logistics and a variety of shrink packaging purposes, such as multi-pack beverages (Stancheva, Personal Communication, 2024).

Figure 14. Pack'On packaging film (Lam'On Presentation, 2024)

Pack'On Oxygen, the third product, is expected to receive its final production facility approvals and certifications from the Bulgarian Food Safety Agency (BFSA) within the next six months. It is designed for the food industry and features high barrier properties. The polymer provides protection against microorganisms and serves as a protection from water vapor, oxygen, and UV light, making it suitable for vacuum-sealed products as well. The company has conducted internal tests demonstrating the film's successful performance in food packaging, including during freezing and microwave heating. Further tests on migration from the packaging to the food, such as fresh produce, have shown no detectable transfer (Stancheva, Personal Communication, 2024).

For the purposes of this study, we are going to focus on Pack'On Classic. This is a biobased product suitable for industrial composting. It is certified under the European standard EN 13432. According to Stancheva, Pack'On decomposes into natural materials such as water and carbon dioxide. Figure 15 shows the complete disintegration of the material after the sixth week under industrial composting conditions (Stancheva, Personal Communication, 2024). Complementing the interview findings as described, it is important to note that bioplastics cannot be turned into compost. Usually, nothing will be left from this material (Ghomi et al., 2021).

The manufacturing process uses standard equipment, specifically blown film co-extrusion machines, which the team has optimized, so the process consumes less electricity than traditional petroleum-based film production. Furthermore, no water is used during production. In addition to the lower electricity consumption, no toxic substances, such as volatile organic compounds (VOCs), are present in the polymere. While polylactic acid-based films are typically brittle and not very durable, Lam'On has conducted tests to assess the performance of its products, which have demonstrated that they are stronger, more durable, and less prone to tearing, allowing for a wider range of applications (Stancheva, Personal Communication, 2024).

The cost of the product is currently between 20 and 30% higher than that of conventional plastics (Stancheva, Personal Communication, 2024). Staff expenses in Bulgaria are comparatively lower, taking into account the average monthly salary in Bulgaria (Marinova, 2024). The production method, which is based on blown film co-extrusion, contributes to the optimization of energy costs. However, the factors that explain the higher price of Pack'On include the high raw material costs and the still limited scale of production. With higher fees expected to come in gradually for fossil fuel-based materials, the cost of substitutes for conventional plastics is likely to go down in the near future. The price is expected to drop further as a result of improvements in the production process and enhanced capacity (Stancheva, Personal Communication, 2024).

In terms of the environmental footprint, the company has done a cradle-to-gate assessment as they have not had the opportunity to track what happens to their product in the long term after it is purchased by their customers. The Global Warming Potential (GWP) of Pack'On from cradle-to-gate is estimated to be 500 grams of CO_2 per kilogram of the film. The next step to be taken is a cradle-to-cradle analysis (Stancheva, Personal Communication, 2024). According to Stancheva, the way traditional plastics and the Pack'On alternative can be recycled is identical – it can be done in the same plants, with the same infrastructure, and through the same number of cycles (Stancheva, Personal Communication, 2024). While recycling represents a promising solution in principle, it is essential to address certain limitations. For instance, the low melting point of PLA-based materials can render them susceptible to thermal degradation at elevated temperatures, leading to a decline in molecular weight, compromised mechanical properties, and lower quality of the polymer. Moreover, moisture content can exacerbate degradation processes (Velghe et al., 2023). Proper drying to remove moisture and controlling the temperature during treatment would help optimize the process and, thus, reduce degradation (Velghe et al., 2023). Moreover, there are studies that explore the possibility of improving recyclability by blending it with a primary polymer or additives, such as chain extender, which report positive results (Beltrán et al., 2018). More work towards improving the recycling technology is needed, as in this way, PLA-based polymers can be reused, which can also improve their performance in an overall LCA (Beltrán et al., 2018).

The decomposition period in an industrial composter is 30 to 60 days at most, as Pack'On products degrade to food for microorganisms and there are no toxic substances present. This period in home composting lasts for up to four or five months, depending on the thickness of the sheet, which can range between 15 and 80 µm, and its recipe (Stancheva, Personal Communication, 2024).

Figure 15. Evolution of the disintegration

of Pack'On performed by Normec (Lam'On Presentation, 2024)

Figure 16. Observations of Pack'On cut into 10 cm × 10 cm pieces during the composting process (Lam'On Presentation, 2024)

At present, calculations regarding greenhouse gas generation set the company's savings targets at 2.4 kT CO2 equivalent per month by the end of 2024 within the production process. Looking at the raw materials, namely the corn starch residues that come from certified producers in the United States, and their use, the pre-sale storage period also plays an important role in estimating these emissions. Europe cannot provide a sufficient quantity of raw materials due to the lack of land space (Stancheva, Personal Communication, 2024). According to studies, regional supply chains can potentially be improved at the European level through approaches involving both standard utilization of waste from the agricultural industry and the extraction of relevant raw materials from waste sources, including food processing, kitchens, and canteens, as well as from municipal waste, as they can lead to the production of substantial amount of PLA per year (Abdelshafy et al., 2023). The aforementioned CO2 savings figure can be further optimized if the next steps, namely the use and subsequent treatment of the alternative packaging through recycling, are taken into account. If even just one recycling plant is dedicated to the treatment of bioplastics in Europe and if the factors that need to be adapted are considered so that the process can be optimized to reduce the possibility of downgrading the material, this could have positive impact on the treatment and overall performance of such substitutes (Stancheva, Personal Communication, 2024).

With regard to the disposal of Pack'On Classic packaging, it is necessary to take into account the specific context in a given country and even at municipal level. Although there are European regulations aiming to unify processes and infrastructure, there are still many differences. The product could be disposed of in a biowaste, which would allow for the disposal of biopolymers and bioplastics, with the idea being that all disposed materials would then go into industrial compost. One alternative is the disposal of the product in the general waste, which would result in combustion in an incinerator, or, as a last resort, its being landfilled, with both of these options being undesirable. In the Bulgarian context, since biowaste containers have not yet been introduced, all compostable materials and packaging are disposed of in the general waste. There are only a few facilities in the entire country that treat grass and plant residuals from parks and gardens, but due to the lack of biowaste bins, large-scale composting is not an established practice as of this writing (Stancheva, Personal Communication, 2024).

According to Stancheva, Lam'On's products are suitable for replacing traditional transparent packaging, such as enclosement for salads, nuts, cheese, and chips, which usually have layers of plastic bonded to a layer of aluminum. In terms of reducing food wastage, the product is suitable to pack fruits, including grapes and cherries, during transportation for storage. However, the team has yet to make further comparisons regarding the percentage of food that can be saved from being lost or wasted (Stancheva, Personal Communication, 2024).

Currently, the production capacity is 150 kilograms of film per hour, and beginning in September, their manufacturing facility will be operating 24 hours a day, seven days a week. Starting next year, their plan is to double the hourly output to 300 kilograms (Stancheva, Personal Communication, 2024).

In order to make the market more welcoming for alternative materials, specific regulations can play a major role in this transition. Potential measures include the introduction of fees and fines for the use of conventional fossil fuel-based plastics and incentives for companies using biobased materials, the organization of public information campaigns, and the creation of conditions and stimuli that help build a sense of personal responsibility. Another increasingly important step is the consideration of regulatory frameworks for the approval of packaging based on recycled PLA that authorize the use of this type of packaging in the food industry (Beltrán et al., 2018). However, before this can occur, comprehensive research and an evaluation of the overall performance and environmental footprint of these products must be conducted to determine whether they are genuinely more sustainable, safe, and environmentally friendly.

5.3.2. Sustainability comparison between Pack'On and low-density polyethylene

This research has so far addressed key aspects related to achieving sustainability in food packaging, looking at both the role and impact of packaging enclosements on nature and human health, their inextricable link to the packaged food itself, and the risks of its loss and waste. It has also arrived at a specific definition of the term "sustainable food packaging" given by Dörnyei et al.

As a next step, the current section will examine a selection of indicators and compare the alternative solution Pack'On Classic with low-density polyethylene. Figure 17 is provided only as a visual representation of a food unit, specifically a salad, that can be packaged in the form of heat-sealed bags made either from conventional plastic or from the alternative film. For the purposes of this study, the characteristics and features of the packaging materials, namely laminates, will be compared.

Figure 17. Salad packed
in a plastic bag (Mysupermarket, 2024)

LDPE was chosen for the comparison as a material with similar characteristics as the one of PLA. It is a thermoplastic derived from ethylene, one of the most common commercial fossil fuel-based monomers. Although non-degradable, it is recyclable (Laird Plastics, n.d.). In 2022, the global production volume of polyethylene reached 130 million metric tons (Statista a, 2024). It can be identified as one of the most common types of PE (ACC, 2022). LDPE is valued for its transparency, flexibility, and durability, making it ideal for the food packaging industry. It is used for various purposes, including kitchen film, clear plastic bags, and frozen-food bags (Laird Plastics, n.d.). LDPE offers protection against microorganisms and provides a good moisture barrier, although it is less effective against oxygen (Toppr, n.d.).

Studies on the performance and environmental impact of LDPE from cradle-to-gate reveal a decrease in carbon emissions and electricity use when comparing data from 2010 and 2020 (ACC, 2022). Figure 18 shows a 6% reduction in CO2 emissions attributed to improved manufacturing processes and the use of different fuel compositions for LDPE production, specifically the increased usage of natural gas, which emits about one-third less CO2 compared to oil (ACC, 2022). Figure 19 indicates a 4% reduction in energy consumption driven by the growing utilization of renewable energy sources – a trend that is expected to continue (ACC, 2022).

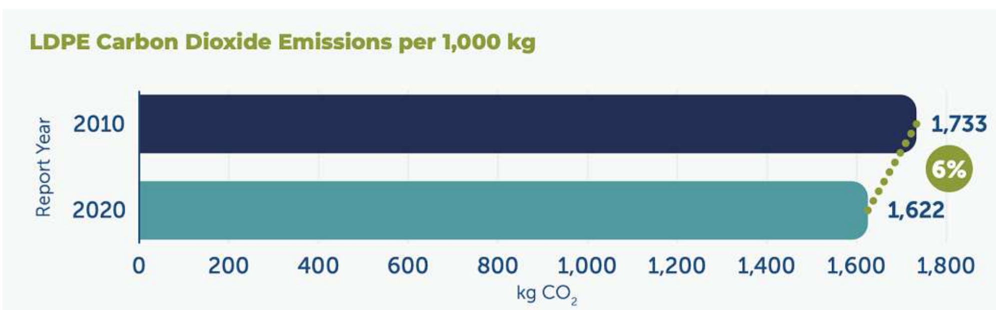

Figure 18. LDPE carbon dioxide emissions per 1 kilogram (ACC, 2022)

Figure 19. LDPE energy consumption per 1 kilogram (ACC, 2022)

Table 1 illustrates the individual sustainability indicators for the two material types:

Indicator	Pack'On PLA-based material	LDPE-based material
Carbon footprint	500 grams CO2 per kilogram of the packaging material (cradle-to-gate estimation); the same amount of packaging unit is needed from Pack'On and its counterpart (Lam'On Presentation, 2024)	2,133 kilograms of CO2 equivalent for the production of LDPE (cradle-to-gate estimation) (Fellner, Personal Communication, 2024)
Resource depletion	No. Based on renewable sources – Corn starch residues (Lam'On, n.d.)	Yes. Based on fossil fuels (Xometry, 2022)
Energy consumption	Improved equipment and lower energy demand (Stancheva, Personal Communication, 2024)	80 MJ – energy consumption per 1 kilogram of LDPE (ACC, 2022)
Biodegradability	Yes (Lam'On, n.d.)	No (Laird Plastics, n.d.)
Industrial compostability	Yes – 30 to 60 days (Lam'On, n.d.)	No (Laird Plastics, n.d.)
Recyclability	Yes, but currently no optimal infrastructure (Lam'On, n.d.)	Yes (Laird Plastics, n.d.)
Toxicity	No (Lam'On, n.d.)	No (Xometry, 2022)
Water footprint	No water is used during the production. Irrigation to grow the corn, but in the case of Pack'On, there is no burden (Stancheva, Personal Communication, 2024)	High, during the life cycle stages, such as extraction, processing and production (Hoekstra et al., 2011)

Market price	Currently 20 to 30% higher than its counterpart (Stancheva, Personal Communication, 2024)	No information
Job creation	Increasing (COM (2018) 28 final)	Decreasing (Pineda, 2021)
Supply chain	Raw materials from the USA, not enough supply in the EU (Lam'On, n.d.)	Dependent on the availability of fossil fuels and the current geopolitical situation
Consumer health and safety	Safe – breaks into natural materials such as water and carbon dioxide (Lam'On, n.d.)	Safe. However, when recycled, there is a possibility for contamination (Xometry, 2022)
Legislation and policy	Requirements for certifications and fees. No concrete framework for biobased plastics (Stancheva, Kanev, Personal Communication, 2024)	Requirements – directives and regulations
Durability	Yes, but Pack'On is not designed for long-term or repeated use (Lam'On, n.d.)	Yes, but "too" durable for single use (Laird Plastics, n.d.)
Shelf life	Extended (Lam'On n.d.)	Extended (Laird Plastics, n.d.)
Ease of use	Yes (Lam'On, n.d.)	Yes (Xometry, 2022)
Food safety compliance	No migration (Lam'On, n.d.)	No migration (Xometry, 2022)
Barrier properties	Microorganisms, moisture, UV light, and oxygen (Lam'On, n.d.)	Microorganisms and moisture, lower towards oxygen (Toppr, n.d.)
Transparency and aesthetics	Yes (Lam'On, n.d.)	Yes (Laird Plastics, n.d.)

Table 1. Comparative analysis of the properties and the environmental impact of polylactic acid and low-density polyethylene in the context of sustainable food packaging approaches (Own Representation, 2024)

Table 1 offers a comparative analysis of two separate materials suitable for packaging fresh salads, namely Pack'On, which is based on polylactic acid, and low-density polyethylene. The aim of this study is to consider a list of indicators that simultaneously take into account social, economic, ecological, and safety aspects in order to achieve sustainable food packaging approaches. The analysis takes into account the current findings based on a literature review and personal interviews with key experts.

The first indicator considered relates to the carbon footprint of the two materials, with polylactic acid having a significantly lower carbon footprint (500 grams of $CO2$ equivalent per kilogram of Pack'On) compared to LDPE (2,133 kilograms of $CO2$ equivalent per kilogram of LDPE), making it more sustainable. It is important to note that the information on carbon dioxide release is based on a cradle-to-gate assessment for both products (Lam'On Presentation, 2024; Fellner, Personal Communication, 2024). To fully evaluate the overall impact, a cradle-to-cradle approach is necessary, considering the complete life cycle, including the results during the final treatment of the materials (Ghomi et al., 2021). Research has indicated that the total emissions associated with LDPE heavily rely on the waste management practices utilized. In a scenario where conventional plastic is incinerated without energy recovery, emissions would include those from its production and those from its incineration, amounting to an additional 3,142 kilograms, making a total of 5,275 kilograms of $CO2$ equivalent per kilogram of LDPE (Fellner, Personal Communication, 2024). Conversely, recycling the material significantly reduces emissions, with only an additional 29 kg above the baseline of 2,133 kilograms of $CO2$ for the final treatment, resulting in a total of 2,162 kilograms $CO2$ equivalent per kilogram of LDPE (Turner et al., 2015). However, a comparable evaluation has yet to be conducted for Lam'on's product.

The PLA-based solution also performs better in terms of resource use, as it is produced using renewable resources, whereas the traditional plastic material is dependent on an ever-dwindling supply of fossil fuels. Although the production process of conventional materials is improving and the use of renewable energy sources is gradually increasing, according to Stancheva, it remains more energy-intensive than the production process of Pack'On. The indicators related to biodegradability and industrial composting again offer significant environmental advantages, as PLA can both biodegrade and compost, reducing the build-up of landfill waste.

While both materials can be recycled, this indicator is not in Pack'On's favor, as the current infrastructure, sorting, and treatment processes are primarily designed for fossil fuel-based plastics. Focusing specifically on the EoL stage for PLA-based plastics, for which recycling methods are not well established yet, studies suggest that landfilling is more effective compared to LDPE. Conversely, incineration treatment results in worse environmental outcomes for PLA-based materials (Choi et al., 2018). Improvements in processes and methodologies for recycling biodegradable plastics are necessary to reduce the risk of degradation and to maintain the quality and properties of recyclates. More lobbying is needed in the direction of establishing recycling practices for biobased plastics because they have the potential to play a critical role in achieving a closed loop.

It can be concluded that both materials are safe, with LDPE posing a small risk of contamination when recycled. Different studies show different information regarding the depletion of water resources, as a large amount of water is used in the production of PLA feedstock, but this is when primary generations of virgin material are grown for irrigation purposes; when the biomass is second generation, it has a smaller impact. For Pack'On, second generation material is used, and no water is utilized during the manufacturing process. In the case of conventional plastics, the extraction and processing of raw materials typically require a lot of water resources (Hoekstra et al., 2011). It can therefore be concluded that Pack'On has significantly lower environmental impact.

Given the current market situation, the price of LDPE is more cost-effective than that of the innovative product, mainly due to high raw-material costs, which may be a barrier to the widespread distribution of the latter. However, Pack'On offers better prospects for job creation, contributing positively to the economy as the green transition theme is gaining ground and is expected to continue to do so in the future.

Lam'On's product relies on supplies from the US market, which is not the most sustainable solution due to the considerable distance between Bulgaria and the USA. Although regional raw material supply is currently limited, this issue could be addressed in the future by sourcing raw materials from alternative waste sources, such as food processing or municipal waste. LDPE's dependence on fossil fuels, which is being affected by resource depletion and geopolitical relations, is also causing instability.

Looking at safety, Pack'On is safer due to its decomposition properties. In terms of the regulatory framework at the EU level, LDPE benefits from clearer regulatory frameworks, whereas the environment for biobased and biodegradable products is still underdeveloped. However, it is crucial to introduce regulations for the processing of biodegradable materials for use in food packaging, as no such guidelines currently exist.

Both materials are durable for food packaging applications and provide similar advantages in terms of shelf life. However, it can be argued that LDPE is unnecessarily durable for a single-use plastic, and in general, Pack'On is not intended to store products for an overly long period. Another similar feature is their ease of use in packaging applications – both Pack'On and its rival meet food safety standards.

Regarding the products' barrier properties, Lam'On's solution offers better barrier properties, as it covers the requirements for microorganisms, moisture, UV light, and oxygen, whereas the conventional plastic does not have as good a barrier to oxygen, which contributes to food spoilage. Last but not least, both materials are visually appealing to consumers, which enhances their communication and awareness-raising role.

Although the PLA-based material has significant environmental advantages, including a lower carbon and water footprint, biodegradability, and compostability, it is currently more expensive and faces challenges in relation to the existing legal frameworks and recycling infrastructure, which is more accommodating of conventional plastics. The traditional material, LDPE, while less sustainable in terms of environmental impact, benefits from better established recycling approaches and lower costs. However, there is a disconnect somewhere along the chain, as very little of the plastic produced globally is recycled, meaning that this activity is not yet efficient and needs improvements to achieve circularity.

Additional robust scientific studies and data are needed to substantiate the claim that renewable, biobased packaging has a lesser impact on the environment. Moreover, novel solutions need greater financial support and innovation-promoting legal frameworks. Consequently, even if such products have the potential to transform the market, they may be hindered at an early stage.

It is important to note that alternative plastics still hold a relatively small market share, which complicates their processing. Consequently, attention must be paid to EoL treatment methods for these products, particularly whether they even fall into the "recycling-oriented waste stream" (Scharff, Personal Communication, 2024). According to a survey conducted among Austrian municipalities and local communities by ARA, the leading Austrian non-governmental organization in the field of waste collection and recovery, most of them believe that consumers currently cannot distinguish between biodegradable and non-biodegradable packaging despite the use of labeling (Scharff, Personal Communication, 2024). Specific concerns include the possibility of throwing these materials into biowaste bins and what the end results will be, as home composting is usually not applicable. When fossil and alternative plastics are thrown into the biowaste bins, most of the time both will be removed during mechanical sorting and, therefore, the biodegradable will not go to the industrial composting facility. In other words, what will happen is simply contamination of the biowaste (Scharff, Personal Communication, 2024). Another ARA study indicates that even if biodegradable plastics can be detected using near-infrared detectors, the wide variety of materials on the market results in too many fractions. This makes it inefficient to separate a specific waste stream for renewable plastics, given their limited volume. The economic reality is that separation and recycling of these materials often do not occur because it is not cost-effective. Additionally, as mentioned in section 5.3, due to their low melting point, biodegradable plastics cannot be recycled with conventional plastics. Consequently, the final destination for these types of plastics often ends up being energy recovery, which is counterproductive because this is also the fate of fossil plastics (Scharff, Personal Communication, 2024).

It can be concluded that the choice between alternative and conventional plastics depends on prioritizing environmental benefits over economic and practical considerations in terms of concrete regional and local situations. It is also important to consider the regulatory environment, as institutions should be the key actors trying to contribute to unification in the pursuit of positive change. The following chapter of this study provides an analysis of key European legislation aimed at promoting more sustainable approaches to food packaging aligned with the principles of a circular economy.

6. Results from analysis of current legislation in the European Union

So far, this study has addressed the issues related to the negative impact of food-packaging waste and food waste on the environment, and the approach to tackle this challenge through the development of innovative and alternative substitutes to conventional fossil fuel-based plastics. The scale of pollution is so pervasive and ever-growing that it requires not only understanding and awareness, research, and input from society and the industry, but also active work at the institutional level.

The EU and its 27 Member States have a specific responsibility to work together and try to find the most effective potential solutions to the pressing issues that European citizens are facing. The responsibility for this rests on the shoulders of the EU's institutions, where action plans are created and legislation is drafted, negotiated, and then voted on in order to put them into effect at national level. Some types of EU legislation, such as directives, are recommendatory, while others, such as regulations, are binding.

6.1. Directive 94/62/EC on Packaging and Packaging Waste

Addressing the unfolding environmental crisis around the world has been a fundamental priority and focus for the EU for several decades. One of the key pieces of European legislation, first adopted 30 years ago, is Directive 94/62/EC on packaging and packaging waste. Its main objective is to achieve a balance between the individual Member States in the way they manage packaging and the waste it produces, and, thus, help to prevent its generation and negative impact on nature (Directive 94/62/EC).

The Directive has been amended several times, including by Directive (EU) 2018/852. It takes into account all types of packaging, including for food. Key measures recommended for implementation at national level are related to the responsibility of the producers themselves, including economic mechanisms to reduce the negative influence (Directive (EU) 2018/852). The focus is also on increasing the production of packaging that can be used more than once without compromising the safety of food products in any way (Directive (EU) 2018/852). Another trend is the inclusion of deposit and return packaging systems (DRS). Specific recycling targets are introduced for packaging in relation to the materials from which it is made. By the end of 2025, the target is for 65% of the weight of all packaging to be recycled, and by the end of the decade, this percentage should reach 70%. The respective targets for plastics are 50% by 2025 and 55% by 2030 (Directive (EU) 2018/852).

There are also specific requirements and limits for the packaging produced by Member States aimed at reducing its weight while maintaining its quality and guaranteeing its hygiene (Directive (EU) 2018/852). The emphasis is on reducing the use of hazardous substances in synthetic enclosures. Moreover, their production should not be geared towards linear consumption but rather towards reuse or recovery. The Directive addresses oxo-degradable plastic packaging, stipulating that it cannot be classified as biodegradable (Directive (EU) 2018/852).

6.2. The Green Deal and the Circular Economy Action Plan

The key frameworks at EU level, which aim to lay the foundations for a future development strategy in harmony with nature, are the Green Deal and the Circular Economy Action Plan (CEAP). These contribute to the formation of the backbone of the Member States' approaches to promoting sustainable food packaging and achieving a circular economy (Kanev, Personal Communication, 2024).

For the EU to stand a chance of realizing its highly sought-after and ambitious objective of becoming the first climate-neutral continent by mid-century, it is crucial for all stakeholders to collectively take every possible action to reverse the detrimental correlation between the expansion of the linear economy and the ongoing depletion of nature's finite resources. Instead, a circular approach must be adopted (EC d, n.d.).

The European Parliament defines the term "circular economy" as "a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible" (EP, 2023).

Figure 20. Circular Economy Model (European Parliament Research Center, 2023)

This is precisely the approach advocated by the Green Deal strategy, which has been created in response to the global COVID-19 pandemic and encompasses 10 specific pillars, including "Farm to Fork" (EC d, n.d.). The concept of this element is to make the food system equitable and nature-friendly (EC e, n.d.). The current approach to food production, consumption, and disposal leads to the degradation of ecosystems, the depletion of precious natural resources, and the generation of greenhouse gases (EC e, n.d.). It is crucial to transform the way we source and treat food throughout its whole life cycle, including how and with what we package it, in order to reduce its loss and waste. If we achieve this goal, in the long term, we can reach a situation where food has a neutral impact on nature and does not contribute to climate change, while at the same time everyone has equal access to "sufficient, safe, nutritious and sustainable food" (EC e, n.d.). The Green Deal is binding in its targets to reduce net greenhouse gas emissions by at least 55% by 2030 (EC f, n.d.).

One of the main components of the Green Deal is the CEAP, which can be characterized as a European strategy aimed at achieving sustainable development (EC g, n.d.). It focuses, to a large extent, on the packaging sector, taking into account the continuous increase of waste generated by it. Accordingly, some of the ideas set out in the action plan are aimed at improving Directive 94/62/EC through concrete measures, such as trying to reduce waste even more, banning the use of specific materials and replacing them with alternative ones, simplifying packaging, and reducing the number of polymers used (COM(2020) 98 final). Attention is drawn to the creation of universal labeling across the EU to make recycling easier and the development of specific recycling safety frameworks related to food packaging (COM(2020) 98 final).

Measures are envisaged to combat the ever-increasing use of plastics and attempts to work together at global level in this regard. In order to contribute to this work, the action plan highlights the need to introduce a specific proportion of recycled plastic in packaging (COM(2020) 98 final). It also calls for the creation of a legal framework for the use of biobased plastics, provided that they are truly beneficial to the environment in terms of their overall performance, and the prevention of their improper disposal through labeling (COM(2020) 98 final).

Last but not least, the link between packaging and food loss and waste is also addressed. The CEAP emphasizes the importance of transforming current approaches to food distribution and consumption. One proposal in this direction is to introduce a ban on single-use packaging (COM(2020) 98 final).

6.3. Packaging and Packaging Waste Regulation

Although Directive 94/62/EC was adopted three decades ago and has since been amended several times, for one reason or another, it has not been successful in achieving multifaceted results. There is a growing trend in terms of pollution from packaging and the negative impact it has on the environment (Kanev, Personal Communication, 2024). For this reason, several years ago and as part of the Green Deal and the CEAP, the European Commission launched an initiative to create a binding framework aimed at building on the achievements of the Directive and setting even more ambitious criteria and targets. Members of the European Parliament adopted the regulation in April 2024. The implementation of the next steps depend on the newly elected Parliament and the Council of the EU, with plans for the regulation to become operational by 2026 (Kanev, Personal Communication, 2024).

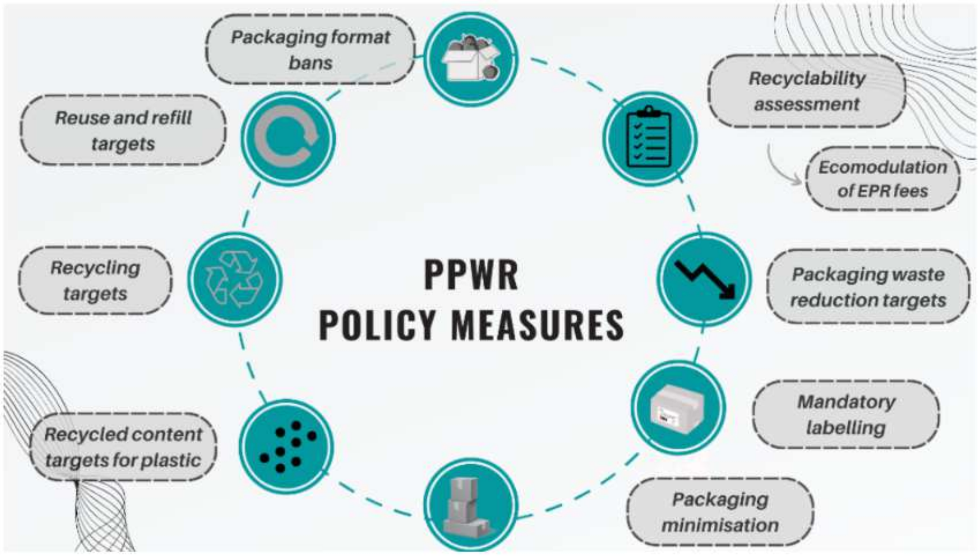

Figure 21. Main measures of the Packaging and Packaging Waste Regulation (Personal Communication, 2024)

This lays the foundations for the Packaging and Packaging Waste Regulation (PPWR). Due to the nature of this law, the hopes associated with it are to transform the packaging industry and, consequently, change the design, use, and treatment of packaging at every stage of its life cycle. Achieving a unified approach is also an expected result precisely because the regulation introduces specific rules that must be followed and implemented everywhere (Kanev, Personal Communication, 2024).

Key areas within the scope of the legislation concern the prevention of waste arising from packaging materials through restrictions on the type of packaging that can be used and the reinforcement of the concept of reusable or refillable packaging. The topic of recycling is addressed, but recycling that does not lead to downcycling of recyclates and that is cost-effective. Specific harmonisations are also introduced with the aim of eliminating the different approaches to product labeling and the reduction of empty spaces in packages. Additionally, concrete targets are set for recycled content in packaging (DS Smith, n.d.).

The regulation introduces requirements covering the entire life cycle of packaging and its sustainability, establishes a set of requirements for producers, and stresses the importance of proper collection, treatment, and recycling of packaging waste. This should contribute to achieving a circular approach that is in harmony with the waste hierarchy (CoEU, 2023).

The PPWR targets all types of packaging, as well as the variety of materials from which they originate and, consequently, the waste that is generated from them. Specific definitions are set out and new ones are introduced in relation to recycling and reusable packaging, which should further contribute to a common understanding across all Member States (CoEU, 2023).

The document sets out specific measures that address the topic of packaging sustainability, including limiting the concentration of heavy metals in packaging (CoEU, 2023). Packaging destined for food enclosement that has a greater amount of polyfluorinated alkyl substances than it is allowed (PFASs) is restricted (CoEU, 2024).

Recyclability of all packaging is required and this is to be achieved in two stages: first, all packaging is expected to be in line with the design for recycling standards by 2030, and secondly, recycling at scale is to become a reality by 2035 (CoEU, 2023). Emphasis is placed on producers' responsibility – they are expected to contribute financially according to the level of recyclability in line with their extended producer responsibility obligations (CoEU, 2023).

In addition, the regulation focuses on the minimum amount of recycled content to be in place by 2030 and includes targets of 30% for contact sensitive packaging made from PET, 10% for contact sensitive packaging made from other plastic materials, 30% for single-use plastic beverage bottles, and 35% for other plastic packaging (CoEU, 2023). Derogations from the scope are also foreseen if deemed necessary (CoEU, 2023).

PPWR defines the conditions for accepting a piece of packaging as compostable. It specifically emphasizes that self-adhesive labels used for fruit and vegetables, as well as very light plastic bags, must be compostable within two years after the regulation comes into force. For other types of packaging, adequate labels should be created in line with the requirements for material recycling (CoEU, 2023). Pieces of packaging that are similar in terms of biodegradability and compostability can be disposed of with biowaste, but it is important to ensure that this type of waste eventually reaches the organic waste management stream and does not compromise other streams (CoEU, 2023). The creation of harmonized technical specifications targeting compostable packaging is also envisaged. Three years after the regulation enters into force, an assessment should be made regarding the level of technological development of biobased plastics in order to be able to determine the specific requirements regarding the content of the renewable share in a package that should be introduced (CoEU, 2024).

If a piece of packaging contains biobased content, the concrete material must first be proven to be sustainable throughout its life cycle. This is also presented as information in the Communication from the Commission on an EU policy framework on biobased, biodegradable, and compostable plastic. If manufacturers want to inform consumers about such content, a uniform label for this is needed (CoEU, 2023).

The legislation underscores the necessity of minimizing the weight and volume of packaging while ensuring the safety and functionality of artificial containers. This should be the new standard practice. Consequently, packaging introduced to the market must be designed for multiple reuses and refills (CoEU, 2023).

Additionally, there is an objective to achieve a harmonized labeling approach and to provide information on the composition and correct disposal of packaging. Labels can also provide data on the amount of recyclate used in the packaging, and the possibility of reusing it will be facilitated by QR-code systems (CoEU, 2023).

With regard to packaging suppliers, it is their responsibility to make available all the information necessary to ensure that the encasing meets the requirements (CoEU, 2023). Operators dealing with deliveries to end-users in bulk packaging, as well as packaging for transport or e-commerce, have to comply with the requirement of a maximum ratio of up to 50% between the empty space in the packaging and the packaged product. Again, it is the responsibility of the economic operator to provide a dedicated reuse system in case it produces reusable packaging (CoEU, 2023).

In terms of containers that can be reused by refilling, hygiene standards should be ensured and specific information given on the current rotation of use to end users. Industries involved in the provision of cold or hot beverages are required to offer at least 20% of these containers in refillable or reusable format by 2030 and 80% by 2040 (CoEU, 2023). For the packaging used by hotels, restaurants, and cafeterias (HORECA) and for take-out packaging for instant consumption, requirements are also set for a change, with expectations for 10% of all packaging to be refillable by 2030 and at least 40% to be refillable by 2040. In addition, frameworks are also set for possible exemptions from obligations, as well as for modifications. The rules for calculating this share are clarified in order to achieve the previously mentioned targets (CoEU, 2023).

Particular attention is paid to the annual consumption of plastic bags. From 2025 onwards, it should not be more than 40 bags per person annually, but leaves the right for exceptions in case of hygienic necessity or commercial bulk food packaging in order to prevent their waste. Single-use packaging for products such as fruit and vegetables, food and beverages, condiments, and sauces within the HORECA sector is banned (CoEU, 2024).

Packaging format	Restricted use	Example
Single-use plastic grouped packaging	Plastic packaging used at the point of sale to group goods sold in bottles, cans, tins, pots, tubs, and packets designed as convenience packaging to enable or encourage consumers to purchase more than one product. This excludes grouped packaging necessary to facilitate handling.	Collation films, shrink wrap
Single-use plastic packaging for unprocessed fresh fruit and vegetables	Single-use plastic packaging for less than 1.5 kg pre-packed fresh fruit and vegetables. Member States may set up exemptions to this restriction if there is a demonstrated need to avoid water loss, or turgidity loss, microbiological hazards or physical shocks, oxidation, or if there is no other possibility to avoid commingling of organic fruits and vegetables with non-organic fruits and vegetables in compliance with requirements in regulation EU 2018/848, on certification or labeling, without entailing disproportionate economic and administrative costs.	Nets, bags, trays, containers
Single-use plastic packaging	Single-use plastic packaging for foods and beverages filled and consumed within the premises in the HORECA sector, which include all eating areas inside and outside a place of business, covered with tables and stools, standing areas, and eating areas offered to the end users jointly by several economic operators or third parties for the purpose of food and drinks consumption. Establishments in the HORECA sector that do not have access to drinking water are exempted.	Trays, disposable plates and cups, bags, boxes
Single-use plastic packaging for condiments, preserves, sauces, coffee creamer, sugar, and seasoning in HORECA sector	Single-use plastic packaging in the HORECA sector containing individual portions or servings that is used for condiments, preserves, sauces, coffee creamer, sugar, and seasoning, except where such packaging is provided together with take-away food intended for immediate consumption without the need of any further preparation.	Sachets, tubs, trays, boxes
Single-use accommodation sector packaging	Single-use packaging for cosmetics, hygiene, and toiletry products for the use in the accommodation sector intended for an individual booking only and intended to be discarded before the next guest arrives.	Shampoo bottles, hand and body lotion bottles,

intended for an individual booking		sachets for bar soap
Very lightweight plastic carrier bags	Very lightweight plastic carrier bags, except for those required for hygiene reasons or provided as primary packaging for loose food when this helps to prevent food wastage.	Very thin bags provided for bulk groceries

Table 2. Summary of the restricted packaging formats under the PPWR (Own Representation, 2024)

Member States shall implement measures, such as economic instruments, to enforce the waste hierarchy in order to prevent packaging waste and minimize the environmental impact of packaging (CoEU, 2023).

The PPWR sets the ambitious target of reducing the amount of packaging waste generated by Europeans by 5% by 2030 and 15% by 2040. This is to be achieved through a combination of measures, including financial mechanisms in the form of "incentives through extended producer responsibility schemes and requirements on producers or producer responsibility organizations to adopt waste prevention plans" (CoEU, 2023). To ensure that producers comply with the requirements, there will be a specific register and organizations that will monitor compliance (CoEU, 2023).

A framework is put in place regarding the introduction of a deposit and return system which should ensure the separate collection of up to at least 90% of the weight of single-use plastic beverage bottles and single-use metal beverage containers per year (CoEU, 2023). Glass can also be included, but it is important to ensure that all requirements are met. The establishment of reuse systems is to be encouraged as well (CoEU, 2023).

The recycling targets from Directive 94/62/EC are repeated in the PPWR with specific indicators for individual material types by 2025 and 2030. For plastics, the goals are respectively 50% and 55% (CoEU, 2023). In case a country needs to postpone the attainment of these figures, it has to show a concrete plan aimed at achieving them. These targets are regulated by specific calculation schemes (CoEU, 2023).

Moreover, conditions are placed on producers or producer responsibility organizations to raise public awareness about "prevention and management of packaging waste with respect to the packaging that the producers supply within the territory of a Member State" (CoEU, 2023). This includes the important role of end-users themselves in waste prevention, the reuse of packaging, and its proper disposal, the importance of labeling, and the need for littering to be eliminated as it is extremely harmful not only to nature but also to mankind. This can be accomplished through websites, channels for public information, campaigns, and education in this regard (CoEU, 2023).

6.4. Discussion

Environmental preservation through the adoption of a circular approach has become a priority for many stakeholders. For a unique international structure like the EU, building a unified vision for future development that is in line with nature's well-being and its conservation requires consensus and the implementation of measures that lead to a certain level of harmonization among all Member States.

The responsibility for achieving this uniformity lies with European institutions and policymakers, who are striving to find the best possible balance. This chapter discusses four key mechanisms aimed at regulating the packaging industry, promoting circular economy values and practices, and achieving climate neutrality by mid-century. There are two types of approaches that can be implemented in such policymaking: seeking the optimum or aiming for alignment (Scharff, Personal Communication, 2024). The easier route is harmonization, using directives that set out a specific framework and recommendations. However, it is up to each of the 27 Member States to decide how to implement these directives, and there is no guarantee that the ambitious targets in the legal scope will be realized.

Overregulation from numerous legal acts may lead to confusion and delays in some localities. The extreme diversity in cultural, economic, social, and market realities in each country must be considered, along with the potential for unexpected events such as Russia's war against Ukraine and the COVID-19 pandemic. These factors can cause delays and difficulties in achieving unified goals, even if they are theoretically attainable (Scharff, Personal Communication, 2024).

A concrete example is Directive 94/62/EC, which, despite being introduced three decades ago, has failed to mobilize stakeholders to effectively achieve its objectives within the EU. Directives and strategies can set a common baseline framework with uniform targets. The European institutions are tangibly picking up on the important issues and trying to contribute to their resolution. This is precisely the case with the Green Deal, as it demonstrates the efforts being made to find a balance between nature and anthropogenic action (Scharff, Personal Communication, 2024). With regard to the CEAP, it can be stated that it does not contribute to the direct fulfillment of the set objectives, but it is a unified framework containing the vision for the next key pieces of legislation to be adopted in the future. The uniformity provided by specific definitions and the ability to derive reliable statistics are two compelling arguments in favor of standardization. Additionally, the single market and the ability to sell within it enable products based on renewable sources to be marketed freely, without requiring adaptation for each individual country (Scharff, Personal Communication, 2024).

However, it is important to find a mechanism that facilitates the promotion of more concrete and measurable results. When it comes to tackling the packaging waste crisis, hopes are currently being pinned on implementing such a mechanism through the PPWR. A complementary approach, while fragmented, could potentially yield more optimal results by implementing a cost-benefit analysis or conducting a country-by-country environmental impact assessment based on current realities. For instance, an approach that works well in Germany may not be as effective in Greece. Such an analysis could determine the best specific and binding combination of values and approaches for waste treatment, recycling, elimination of specific packaging, or introduction of new packaging, creating an environment for realistic and optimal results tailored to each country's capabilities (Scharff, Personal Communication, 2024).

It is also essential to note the gap between different stakeholders regarding the time needed to introduce key topics into legal frameworks. The scientific and industrial sectors have been researching and developing alternative solutions to conventional plastics, aiming to replace them with renewable-based options. While these alternatives are still not fully sustainable throughout their life cycle, significant scientific and research efforts are underway, and the market share of biobased materials is expected to increase in the coming years. Therefore, a specific legal approach focused on these alternatives should be developed as soon as possible. Consideration should be given to the establishment of regulatory frameworks that, as long as it is deemed sustainable and safe, approve packaging based on recycled PLA. The current EU policy framework on biobased, biodegradable, and compostable plastics, as well as the few articles of the PPWR that simply scratch the surface on this issue, brings the topic of alternative substitutes to the European decision-making table but much more work is required.

Nevertheless, it is crucial to consider all potential consequences that a law might entail. Restrictions can prompt industries to seek loopholes to comply with regulations, sometimes resulting in even greater negative environmental impact. For example, beyond materials based on alternative sources, some substitutes for all-plastic packaging currently include cardboard or paper coated with a thin layer of plastic to ensure quality protection and multiple barriers (Scharff, Personal Communication, 2024). Although these materials contain less plastic, they are not recyclable due to their multilayered nature. Thus, the actions of industries are pivotal in how laws are enforced, making it essential to provide specific and clear explanations to the corporate sector as to what should be avoided to protect the environment. Regulations should be tailored to each country, kept as simple as possible, and designed to avoid market distortions. Complex and cumbersome frameworks create more opportunities for "freeriding," undermining the intended environmental protections (Scharff, Personal Communication, 2024).

7. Survey results

7.1. Empirical findings

Within the framework of this study, an online survey was conducted among the general public in two European countries with differing levels of economic and social development: Austria and Bulgaria. This particular approach was chosen as it allows reaching a broader audience. End users in particular have a crucial role to play in terms of how food is packaged, stored and consumed. Accordingly, their educational, cultural, and social backgrounds are antecedents to their behavioral patterns. The questionnaire aimed to explore their understanding and awareness of the negative impact of packaging and food waste on nature, their current habits, and the topics about which they need more information.

A total of 171 individuals from Austria and 200 individuals from Bulgaria responded to the survey questions in May 2024. The specific objective was to investigate whether and how the different economic and cultural backgrounds influence the responses of the citizens from these two EU Member States. One set of the questions was focused on the respondents' age group, level of education, and monthly income.

The study aimed to observe the role of education and social status in food preservation habits, the frequency of food wastage and disposal, and the possible reasons for these behaviors. One hypothesis was that a high social status will lead either to excessive purchasing power and, thus, more waste because of higher levels of consumption, or to greater sensitivity to the issue of waste and its environmental impact, prompting a pursuit of environmentally friendly packaging alternatives and behaviors. Respectively, the other hypothesis was related to the question as to whether people with a lower monthly income and no higher education are predisposed to save higher quantities of food from wastage and whether the topic of sustainability matters to them at all.

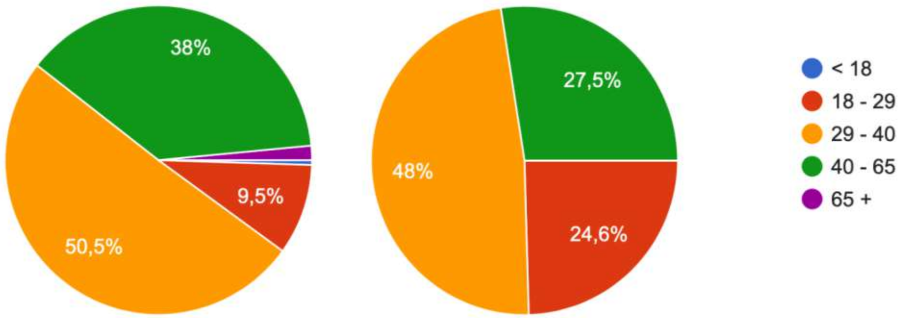

Figure 22. Age representation of the survey respondents in Bulgaria (left) and Austria (right) (Own graph, 2024)

One of the first questions addresses the age limit of the respondents. It can be concluded that the share of those between 18 and 29 in Austria is almost three times higher than in Bulgaria, while in both countries about 50% of the respondents are in the next age group between 29 and 40. There is also a higher representation of respondents aged 40 and above in Bulgaria (38%), compared to 27% for Austria.

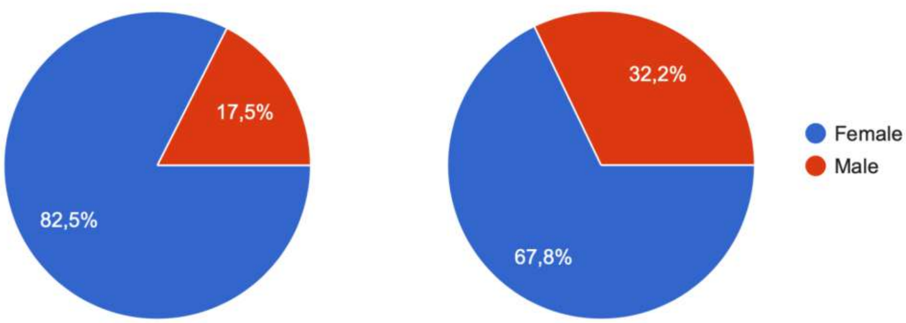

Figure 23. Gender representation in Bulgaria (left) and Austria (right) (Own graph, 2024)

The next question, which concerns the demographics of both countries, shows that the majority of the participants are female, with 17.5% of men in Bulgaria and 32% in Austria.

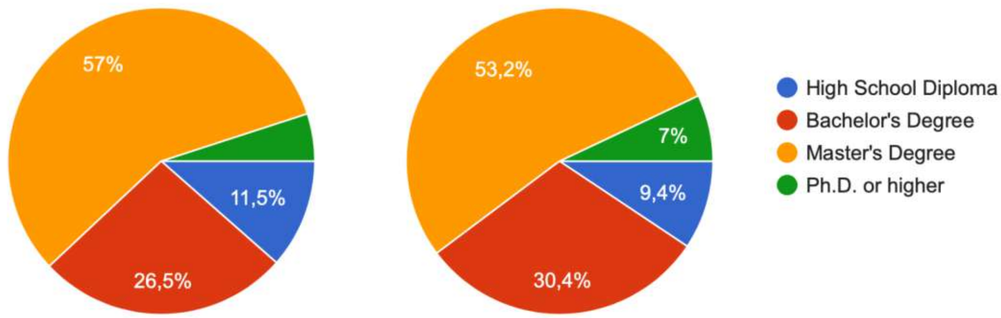

Figure 24. Educational background of the respondents in Bulgaria (left)
and Austria (right) (Own graph, 2024)

Regarding the education of the participants, the picture in both countries is similar , differing only by a few percentage points (between 2 and 4% in the different categories).

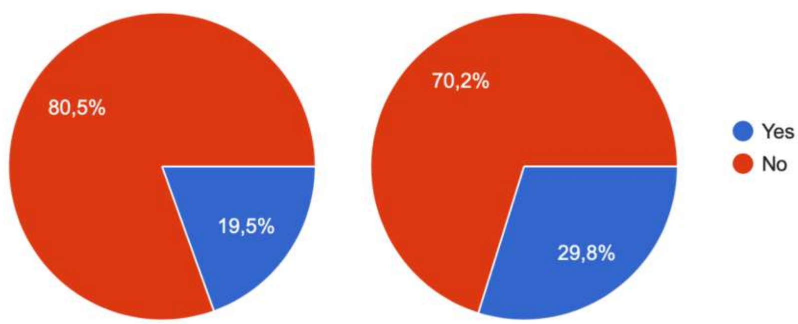

Figure 25. Proportion of participants with or without an additional qualification or education in sustainability/environment in Bulgaria (left) and Austria (right) (Own graph, 2024)

Although environmental protection is a topic that should concern a growing share of the population nowadays, given the continuous and abrupt changes related to climate, environmental protection, and pollution problems, it still does not occupy a central position in terms of the choice of an educational field or an area for further qualification. In both countries, the majority of the respondents have not studied anything related to this field, with only 20% having gained knowledge in this area in Bulgaria, while in Austria 30% of people responded positively.

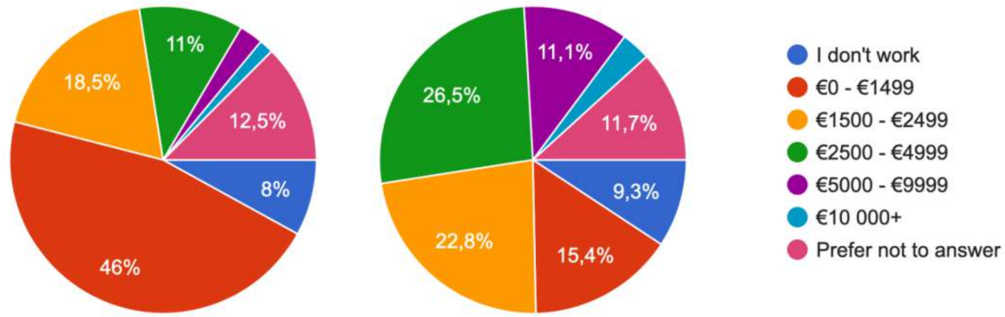

Figure 26. Monthly income representation in Bulgaria (left)
and Austria (right) (Own graph, 2024)

The question regarding the respondents' monthly income and standard of living may, for the first time in the context of this survey, demonstrate a significant difference between the respondents in these two EU Member States. The average monthly wage in Bulgaria was BGN 2,123, or about EUR 1,085, for the last quarter of 2023 (Marinova, 2024). In contrast, the average monthly wage in Austria for the same period was EUR 2,240 (ABA, n.d.). Almost half of the Bulgarian respondents receive a monthly salary of between EUR 0 and 1,499, compared with 15% in Austria. The next wage group (EUR 1,500 and 2,499) encompasses 18.5% of the respondents in Bulgaria and almost 23% in Austria. For the remaining monthly income categories, the Austrian reality shows significantly higher shares than Bulgaria. Regarding the response rates of people who do not work or prefer not to share this information, despite the anonymous nature of the survey, the two countries show similar results.

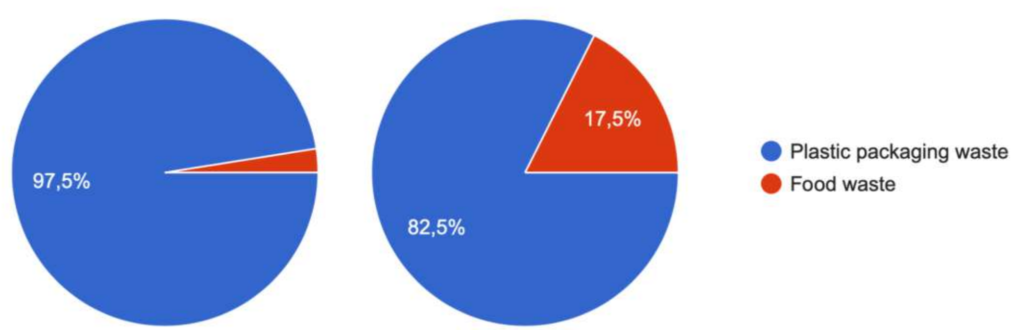

Figure 27. Opinion of respondents in Bulgaria (left) and Austria (right) on the question as to which has greater negative impact on nature — plastic waste or food waste (Own graph, 2024)

Respondents' attention is drawn here for the first time to the negative environmental impact of plastic packaging waste and food waste (i.e., food that is thrown away). Almost all respondents in Bulgaria (97.5%) believe that plastic packaging waste is more detrimental for the environment than food waste. This result for Austria is 15% lower, but this still means that people tend to think that plastic pollution has worse consequences for the environment than food waste.

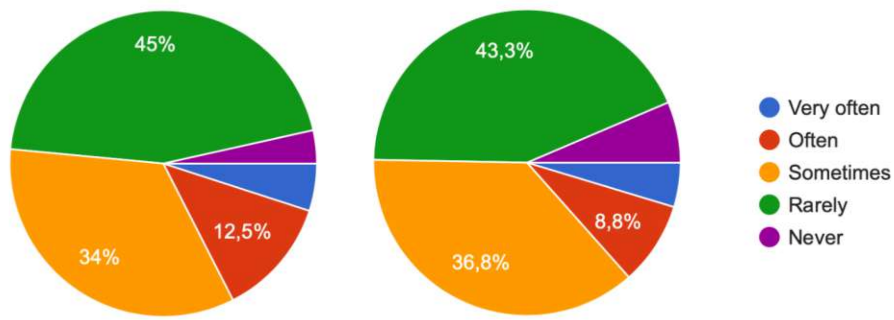

Figure 28. Representation of how often respondents in Bulgaria (left) and Austria (right) throw away food (Own graph, 2024)

The next question examines the frequency of discarding food for reasons such as spoilage or expiration. Despite the economic disparity between the two countries, the two graphs indicate nearly identical results.

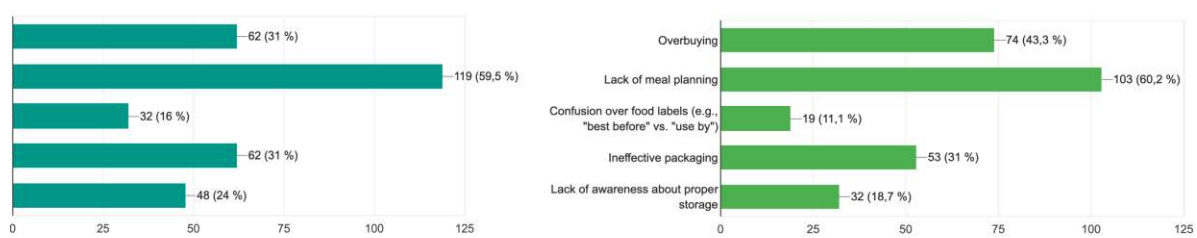

Figure 29. Main preconditions for food waste generation in households in Bulgaria (left) and Austria (right) (Own graph, 2024)

Several open-ended questions were included in the questionnaire with the purpose of allowing the respondents to select all the options that they considered relevant to them. The discussion centers on the specific obstacles that individuals identify as hindrances to addressing food waste at the household level. Once again, similar findings have emerged, with inadequate meal planning being the primary concern in both countries, closely followed by tendencies to overbuy. The inefficiency of packaging is another significant issue.

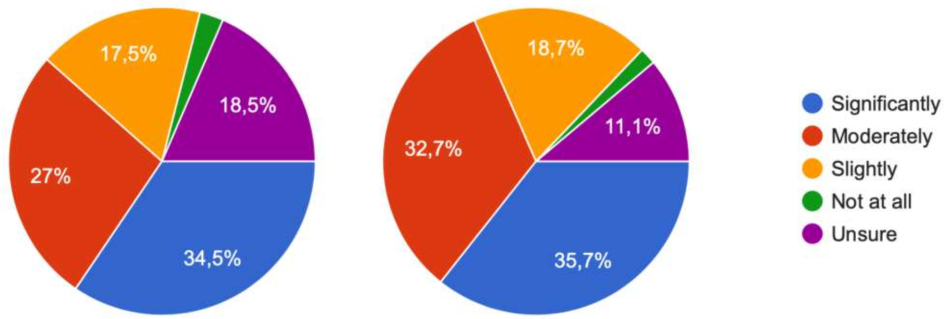

Figure 30. Role of packaging in food waste according to respondents in Bulgaria (left) and Austria (right) (Own graph, 2024)

This question explores the perception of citizens in the two countries on the extent to which packaging makes a difference to a food product not being recovered but ending up in the waste stream. Again, similar results are observed, with just over a third of the respondents in both countries believing that packaging plays a “significant” role, followed by "moderately". In addition, collectively around a third of the respondents in both countries admit that they are not sure or have an opinion that does not support the thesis that packaging has any importance at all.

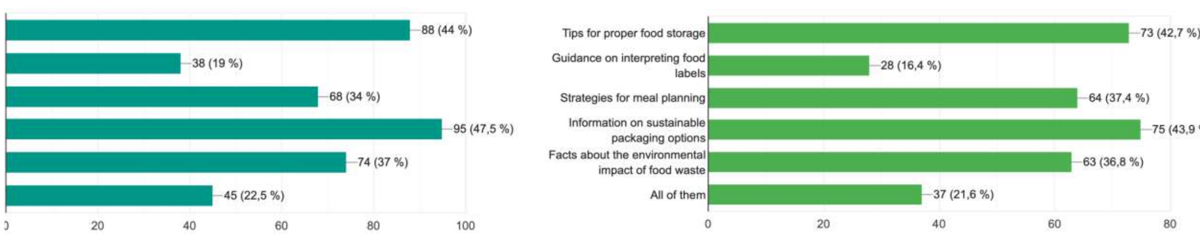

Figure 31. Type of information that would be useful to respondents in Bulgaria (left) and Austria (right) to prevent packaging-related food waste (Own graph, 2024)

This question explores topics that could provide people with additional knowledge to mitigate food waste stemming from packaging. Once again, similar patterns emerge regarding the most frequently selected answers. Interestingly, while the previous question highlighted poorly planned meals as the leading cause of waste, strategies to enhance meal planning now rank third in Austria and fourth in Bulgaria. In both countries, the top priority for the respondents is to have more information about sustainable packaging, followed by their interest in receiving proper food storage tips. Additionally, respondents emphasize the importance of understanding the negative environmental impact and footprint of wasted food, indicating a desire for more information on this aspect of the topic.

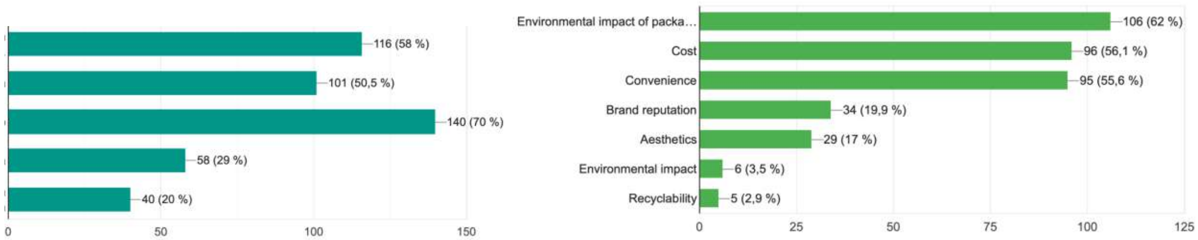

Figure 32. Main factors influencing consumer choice of packaging type in Bulgaria (left) and Austria (right) (Own graph, 2024)

The factors that induce consumers to opt for a particular type of packaging vary between the two countries. For Bulgaria, convenience comes first, followed by the environmental impact of the packaging and the price. For the respondents in Austria, the number-one priority is the impact of the packaging on the environment, followed by the price and, very close behind it, convenience.

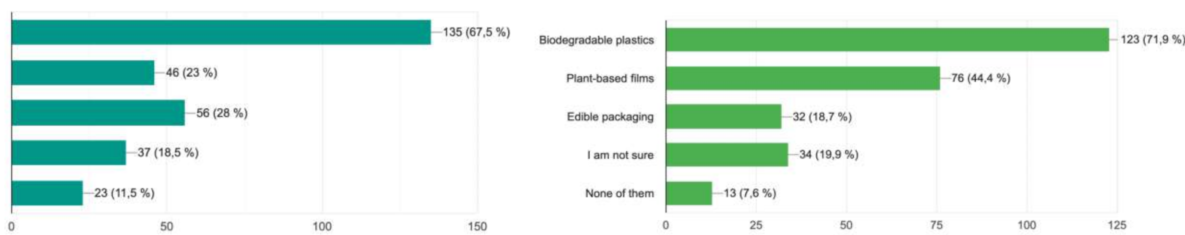

Figure 33. Alternative packaging types encountered by consumers in Bulgaria (left) and Austria (right) (Own graph, 2024)

The survey also introduced the respondent groups to alternative packaging options and aimed to find out if and what specific substitutes they encountered and used in their daily life. For both EU Member States, the most popular answer is biodegradable packaging, followed by plant-based packaging in Austria and edible packaging in Bulgaria. However, in both countries there is a significant number of people who cannot say for sure whether they have used packaging substitutes so far.

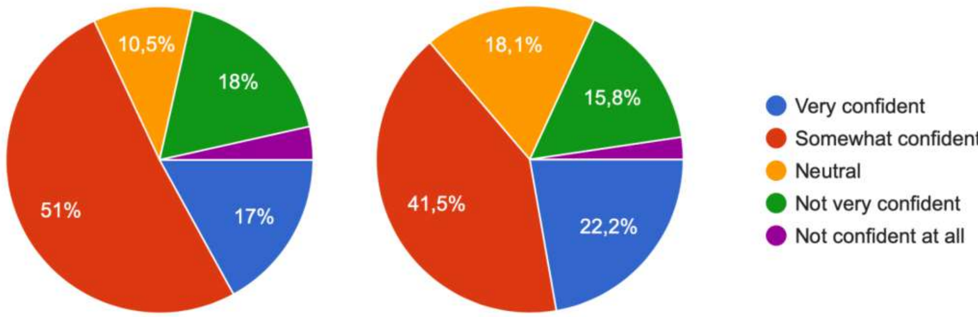

Figure 34. Level of understanding about the proper disposal of different types of food packaging in Bulgaria (left) and Austria (right) (Own graph, 2024)

Examining the two pie charts regarding the level of understanding about the proper handling and disposal of various food packaging materials, it is evident that the majority of individuals in both countries express "somewhat confidence." Roughly half of the respondents from Bulgaria selected this option, whereas in Austria, this figure stands at 41%. "Very confident" responses amount to approximately 20% in both countries. Surprisingly, around 30% of the public in both nations appear to be uncertain about the proper steps to be taken to ensure that used packaging is appropriately disposed of at the end of its life cycle. This uncertainty represents a significant portion of the population in both countries.

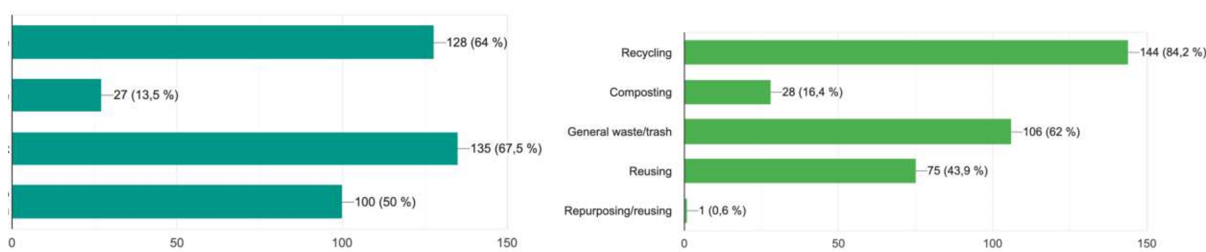

Figure 35. Most frequent methods of food packaging waste disposal in Bulgaria (left) and Austria (right) (Own graph, 2024)

The survey proceeds to delve into the topic of the most common methods of disposing of food packaging. Despite the prior conclusion that a majority of the respondents in both Bulgaria and Austria believe that they are adequately informed about the destination of various food packaging materials, this question reveals distinct patterns in disposal practices. In Bulgaria, the primary method reported is disposal in general waste, followed by recycling, with reuse ranking third, garnering 100 responses, which constitutes half of the survey participants. The relatively low percentage of respondents indicating composting reflects the underdeveloped composting infrastructure in the country. In contrast, the results show a prevalence of recycling among Austrian respondents, followed by disposal in general waste, with reuse once again coming in third place. Since 1995, Austria has implemented a well-established system for separate collection of biogenic waste nationwide (Herczegl, 2013). In contrast, such a system is not yet widespread in Bulgaria, although efforts are underway to advocate for its adoption, as it is set to become mandatory across the EU starting from 2024 (Bibinovska, 2024). Despite the differences in waste separation practices and Austria's most substantial experience in this regard compared to Bulgaria, the respondents from both countries demonstrate similar levels of support for composting.

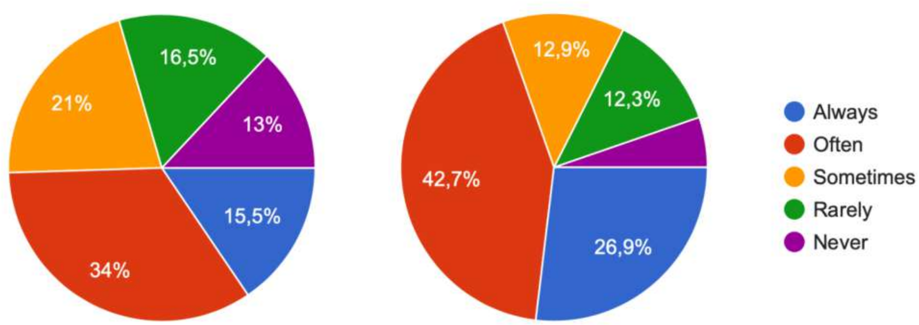

Figure 36. Frequency of recycling or composting of food packaging in Bulgaria (left) and Austria (right) (Own graph, 2024)

This question specifically addresses the frequency of recycling and composting in the two EU Member States. The majority of the responses favor the option "frequently" in both countries, with Austria leading by nearly 10% over Bulgaria. In Bulgaria, the second most frequently selected option is "sometimes", whereas in Austria, the second most common response is for recycling to occur "always". Additionally, the percentage of individuals who rarely or never compost or recycle is higher in Bulgaria than in Austria. It can be concluded that the Austrian respondents have a more entrenched recycling culture than their counterparts in Bulgaria.

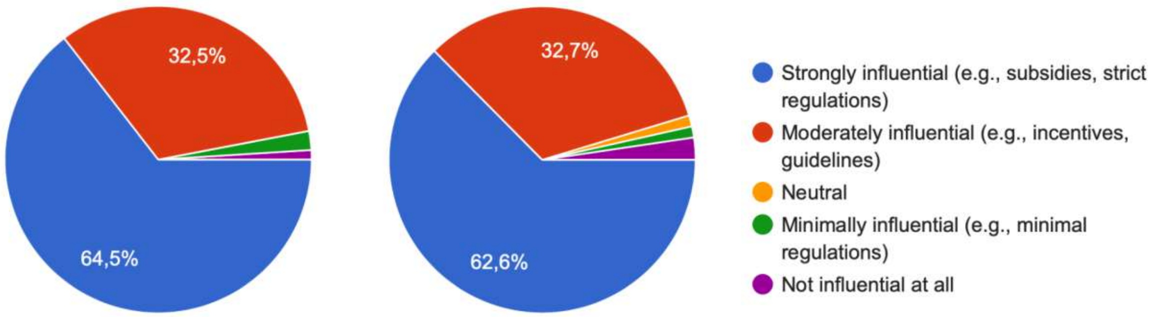

Figure 37. Views in Bulgaria (left) and Austria (right) on how strong a role governmental policies should play in promoting sustainable food packaging (Own graph, 2024)

Seeking the views of respondents regarding their attitudes on the importance of the role of governmental frameworks in the pursuit of more sustainable food packaging, it can be concluded that, while a very small percentage of the respondents give answers associated with uncertainty or in favor of "minimal influence", two-thirds in both countries believe that laws play an important part, and almost a third see governmental policies as "moderately influential". This indicates a belief in the capacity of the government to bring about concrete changes through legal mechanisms.

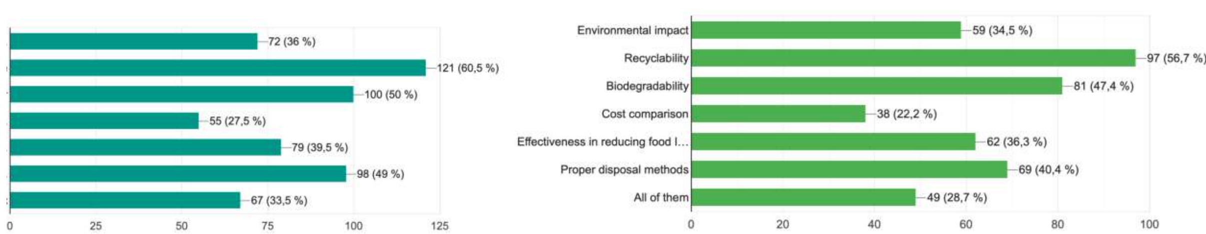

Figure 38. Aspects related to food packaging about which people need more awareness in Bulgaria (left) and Austria (right) (Own graph, 2024)

The subsequent question aims to explore further the food packaging topics that individuals are interested in learning more about. In both Bulgaria and Austria, the most common response pertains to the recyclability of packaging, followed by the topic of biodegradability. Understanding the correct disposal methods ranks third, indicating that although two-thirds of respondents in both countries feel reasonably confident about disposal according to the previous question, they still want to expand their knowledge and understanding about this topic. Additionally, participants express an interest in learning about techniques for food waste reduction.

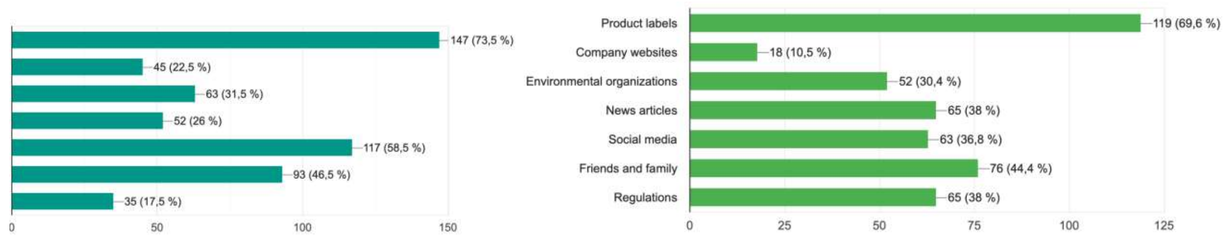

Figure 39. Main sources of information about sustainable food packaging that people in Bulgaria (left) and Austria (right) rely on (Own graph, 2024)

This question aims to shed light on the primary sources of information individuals in both countries rely on in relation to sustainable food packaging. Once again, a similar trend emerges, with product labels being the top choice. In Bulgaria, social media and friends and family are the next most trusted sources of information. Similarly, in Austria, friends and family rank second in trust, followed by regulations. Although the previous question indicates strong support among respondents for the significant role of regulations, nearly 40% of the Austrian respondents utilize them as a source of information, compared to only 17% of the survey participants in Bulgaria.

The last survey question allowed for an open-ended response, aiming to identify specific sources of information that help to better understand the topics of sustainability, packaging reduction, and food waste, as well as proper recycling practices among participants in both countries. Overall, the answers are extremely heterogeneous in both countries. In Austria, 40 individuals say that they do not have a specific source of information, with the answers "internet" or "Google" mentioned five times each. Austrian respondends also rely on regulations, family members, friends, influencers, media outlets such as ORF and Der Standard, the Ellen MacArthur Foundation, various international companies such as Kaufland and Danone, scientific articles, YouTube channels, etc.

In Bulgaria, the same variety of responses is observed, but once again, the most common one, which is mentioned 49 times, is "No specific source", followed by "internet" or more specifically "Google" as next preferences, with a few repetitions of these answers. Several non-governmental organizations are mentioned, including Caps for Future, which is a nationwide movement for the collection and recycling of plastic caps aimed at raising money for the purchase of incubators for children's wards in hospitals across the country, and Zero Waste Bulgaria. In general, the Bulgarian respondents demonstrate trust in leading local NGO actors and seek information through them. The Bulgarian respondents further rely on other sources such as influencers, social media, podcasts, grassroot movements, articles, TV commercials, etc.

Several main conclusions can be drawn based on the aforementioned survey responses. In terms of demographic information, despite the many similarities between the EU countries, two particular patterns are observed. It is possible that the slightly higher levels of sustainability-related education and the much higher income rates in Austria contribute to greater awareness and understanding of environmental issues, as well as wider adoption of sustainable practices, such as recycling. This suggests that economic stability and access to education are essential in fostering environmentally conscious behaviors.

Delving into the environmental impact of plastic packaging waste and food waste, there is a strong belief in both Austria and Bulgaria that plastics have a much more negative influence. Having carefully explained in chapter 4.4 of this study how and why food loss and food waste have much more severe consequences for the environment than food packaging, it can be concluded that there is a clear lack of awareness about this issue in both countries. This, in turn, could lead to even more negative consequences because when the general public is not aware of a given problem, it cannot even begin to tackle it. Addressing these knowledge gaps in a structured and country-specific manner is key to filling them.

The next few questions, which focus on the frequency of food waste and its potential causes, demonstrate similar findings in both locations. Interestingly, in addition to over-buying and poor meal planning, consumers cite inefficient packaging as a key problem. It can be concluded that food waste is not only a problem of behavior and human habits, but also of the way in which foods are packaged.

Regarding the role of packaging in protecting food from spoilage and disposal, respondents in both countries are of the opinion that it has a significant role to play. Interesting patterns are observed with regard to the additional characteristics that induce individuals to choose one packaging over another. In Bulgaria, where the level of monthly incomes is considerably lower than in Austria, people put convenience first, with concerns about the environmental impact of plastic containers and the price coming in second and third place, respectively. In contrast, people in Austria think about environmental protection first. It is noteworthy, however, that for Bulgarians, despite their significantly lower incomes, nature seems to be more important than price. In addition, a parallel can be drawn here with the higher standard of living and perhaps the slightly higher awareness due to the higher percentage of respondents with education or experience in sustainable development in Austria. It appears that Austrian residents attach more importance to nature conservation.

As part of the survey, the level of awareness among people regarding the disposal practices of various types of packaging materials was also assessed. Approximately one-third of the respondents in both countries displayed uncertainty about their understanding of this process, which is a significant proportion. It can be inferred that the lack of awareness is a contributing factor when it comes to the inability to achieve optimal levels of recycling and proper waste treatment in these EU Member States.

In evaluating the findings and drawing specific conclusions, it is crucial to consider the diverse backgrounds and disparities in waste treatment methods and infrastructure between the two countries. Bulgaria still needs to make significant progress in this regard. Meanwhile, for Austria, enhancing current practices and providing access to continuing education in the latest sustainable technologies and methods can further improve environmental performance. In Bulgaria, targeted interventions aimed at raising awareness and offering effective practical solutions for sustainable living can yield beneficial outcomes. However, it is important to consider economic constraints, highlighting the necessity of offering accessible and affordable sustainable options that are more relevant to the population.

The respondents' belief in the significant role of government regulations in promoting sustainability indicates that legislative measures, if structured appropriately, can effectively drive change. Governments should therefore prioritize the development and implementation of policies that promote sustainable food packaging and waste reduction. However, it is important to consider how these legal frameworks can most effectively reach the various stakeholders, especially end consumers. While one part of the newly adopted PPWR refers to the need to inform and engage individuals, this is still proving rather difficult to achieve.

The final aspect of the study focuses on the key channels from which the respondents gain knowledge and information about sustainability, reducing packaging waste and tackling food waste. The first information channel for the respondents in both Bulgaria and Austria is product packaging. In addition to fulfilling its role in food preservation, product packaging apparently also fulfills the purpose of providing valuable information to consumers. This suggests that more efforts are needed to make packaging even more targeted so that it can contribute even more to raising public awareness. It is interesting to note that people living in Bulgaria tend to get their information secondarily from social networks, which cannot always be considered as sources that provide the most accurate, up-to-date, and/or trustworthy information. Their third channel turns out to be family and friends, where confusion can often arise due to misunderstanding or one person's particular biased position influencing another person's behavior in a negative way. For Bulgarians, laws are the least popular source of information about this topic, which can be related to their lack of trust in politicians and government, mostly due to the current political instability in the country, or their lack of understanding and a sense of remoteness vis-a-vis legislation. For the Austrian respondents, the second most popular source of information is family and friends, followed by regulations, which implies a higher level of trust in the political system. To be effective, the methods used to reach the general public in different countries should be clear and specific. This clarity would aid in effectively targeting individuals and utilizing the relevant channels to convey messages successfully.

Furthermore, taking into account that most often in both countries people do not have a specific source to inform themselves about sustainability and ecological topics, leads to the conclusion that one could think at the level of the European Union and develop a mechanism and a targeted educational campaign including a tailored mix of online and offline channels relevant to each individual country, taking into account what would work best according to the specific locality.

Furthermore, the fact that people in both countries do not usually rely on a specific source of information about sustainability and ecological topics leads to the conclusion that one could think at the level of the European Union and develop a mechanism and a targeted educational campaign including a tailored mix of online and offline channels relevant to each individual country, taking into account what would work best according to the specific locality. This joint initiative should lead to a one-stop-shop space where important and relevant information can be gathered from partner organizations to build on existing sources and optimize effort and time. In addition to a unified definition of terminologies related to the topic of food packaging, a unified source of information is needed to facilitate a faster and more effective transition to environmentally friendly habits.

In terms of infrastructure optimization and regulatory measures, approaches should correspond to the specific realities in individual countries, as local differences are influenced by economic, educational, and cultural factors. It is therefore necessary to come up with country-specific strategies for the promotion of sustainable food packaging and practices.

8. Discussion

Since the dawn of human history, people have harnessed natural resources to continuously improve their living conditions and ease their daily lives. This development is evident in the food industry, particularly in food packaging. Technological advancements, scientific breakthroughs, and economic, social, and cultural evolution have significantly altered human habits. As consumer demands have increased and diversified, so has the variety of products, many of which must travel thousands of kilometers to reach their final destination and, ideally, be consumed rather than spoiled and discarded. The food packaging industry plays a crucial role in ensuring the quality and safety of food products.

While the processes of production, packaging, consumption, and waste management of food might seem straightforward, the reality is much more complex, especially regarding their combined environmental impact. This section will discuss the findings of the study, providing critical insights and addressing the research questions posed.

8.1. Answering of the research questions

What are the environmental challenges posed by current food packaging practices, and why is a unified definition of "sustainable food packaging" necessary?

Based on the findings of the study, it can be concluded that each stage of the life cycle of plastic adds to its negative impact on the environment, as it leads to a critical amount of carbon dioxide emissions, water use and pollution, and soil contamination. Nature's capacity is limited, which means that the environment cannot take this pollution indefinitely.

Plastics are vital in food containment, handling, packaging, transport, information, consumption, disposal, and final treatment. However, these stages also lead to significant food loss and food waste, which impacts the environment more severely than plastic pollution due to methane production. Reducing food waste, even slightly, can greatly benefit the planet.

Food waste often results from excessive or improper packaging, poor sealing, wrong material choices, and inappropriate design. The final stages of the food life cycle, influenced by individual behavior and habits, also lead to spoilage.

For the food packaging industry to become sustainable, the packaging and the food unit must be considered together. Their combined performance should be evaluated through LCA to determine if new materials or products are truly environmentally friendly or merely conceptually appealing.

A common definition of "sustainable food packaging" is needed to serve as a universal reference point for all stakeholders. This definition should consider social, economic, cultural, and environmental factors, and include specific indicators for the measurement of sustainability. The principles of reuse, recycling, and recovery, which are central to the circular economy, should also be included. Currently, there is no consensus on the term "sustainable food packaging." Achieving agreement requires significant efforts from both the scientific community and European and other international organizations, which play a crucial role in promoting and implementing these concepts at European and global levels.

What obstacles prevent biodegradable alternatives from solving the plastic packaging problem?

Alternative biobased materials aim to match conventional plastics in function while being biodegradable, recyclable, and environmentally friendly throughout their life cycle. While tackling the littering problem, they do not significantly reduce the quantity of plastics. Their adoption faces barriers such as user confusion about disposal and ambiguous terminology, since biobased plastics are not always biodegradable or compostable. If not decomposable, they function like conventional plastics. Moreover, biobased plastics from first generation feedstocks can conflict with sustainability goals due to land use, food production competition, and significant resource use.

A comparison between an alternative PLA-based packaging material, Pack'On, with conventional LDPE material, based on available information from a literature review, research, and personal interviews, indicates that the substitute product outperforms its conventional counterpart. However, several critical factors still impede the mass adoption of such materials. Despite growing market interest, biobased alternatives remain a tiny fraction of conventional plastic use. Effective recycling of biodegradable plastics requires efficient collection and sorting, which current systems and consumer habits do not support. Even when sorted, the small quantity of renewable plastics makes recycling economically unviable, which often leads to incineration like conventional plastics, which is very controversial and, according to some studies, even more detrimental than conventional plastics. The recycling approach itself needs to be further adapted as the low melting point of biodegradable materials poses degradation hazards.

A potential solution is a dedicated European recycling plant for these materials tasked with evaluating economic viability. Additionally, improvements in collection, distribution, and recycling processes are crucial to managing existing plastic waste and addressing the recycling challenges of multilayer packaging. Research into coatings for enhanced barrier properties and a mono-material offering superior protection could make mechanical recycling more efficient and cost-effective (Scharff, Personal Communication, 2024).

How do the current European regulations both contribute to and hinder the achievement of a sustainable packaging sector?

As part of the basis that the EU is continuously building on, a concrete definition of "sustainable food packaging" is needed because it can guide stakeholders in material choices and development of food packaging. This thesis examined key documents, including Directive 94/62/EC, the Green Deal, the CEAP, and the PPWR, which aim to combat packaging pollution and establish a circular economy, targeting climate neutrality within the next 25 years.

While EU frameworks guide development and set targets, their non-binding nature limits effectiveness. Although harmonization provides common ground, it can also limit the potential for achieving maximum results tailored to national realities. An alternative approach could involve assessing each country's specific conditions and setting clear and binding targets to achieve concrete sustainability results.

Clearer frameworks are needed for biobased, biodegradable, and compostable plastics. It is also important to consider the possibility of regulating food packaging based on recycled biodegradable materials. An ongoing dialogue with stakeholders is essential for fostering innovation. Even though new products can reduce environmental impact, their widespread market adoption often takes years. Clearer guidelines and active engagement can help accelerate this process, ensuring sustainable innovations are quickly implemented.

What is the role of end users in promoting circular economy practices?

Finally, this study highlights the critical role of EU residents in the transformation of the food packaging sector. A survey conducted in Austria and Bulgaria provided significant insights into the respondents' demographic profile, knowledge, and habits. While some answers are similar, there are notable differences, suggesting that environmental education and higher living standards lead to better understanding and the implementation of practices like recycling.

Gaps in awareness were identified, particularly regarding the negative impact of food wastage, proper plastic waste disposal methods, and effective communication channels. The differing EoL approaches in the two countries influence final outcomes in terms of packaging and waste treatment. Results from a small-scale questionnaire highlight diverse situations within the EU. A broader EU-wide inquiry could confirm the need for tailored approaches to education and awareness due to unique state characteristics. Residents' behavior significantly impacts waste management, particularly in the collection, separation, and recycling phases. Effective execution of the first two phases has the potential to lead to optimal recycling outcomes, aligning with the circular economy's vision of resource reuse and reduction of raw materials need.

The relationship between citizens and institutions is crucial for effective law implementation. To be successfully implemented, regulations must be understood and accepted by society. In Bulgaria, political instability, inconsistency, and corruption hinder this process. Information distribution methods also vary, often leading to ineffective public awareness efforts.

The study suggests that one step in the right direction could be the creation of a centralized information hub to improve public knowledge about sustainable practices. This one-stop-shop should utilize existing information resources and turn into the ultimate place for people to increase their awareness by delivering targeted messages through online and offline channels, tailored to the habits of citizens in each Member State. Such a resource can guide the general public on adapting their behaviors to support the transition towards a sustainable food packaging sector and a circular economy.

9. Conclusion

The food packaging sphere is undeniably of key importance to humanity today, but at the same time, it leads to a very unhealthy relationship with the environment due to both plastics and food waste. While there is a growing need to transform it in order to reduce and gradually eliminate its footprint on nature, this endeavor is proving to be challenging and dependent on multiple factors and stakeholders.

This thesis examined essential aspects needed to better understand the current level of development of the food packaging industry and what needs to happen to make it more sustainable and help move towards a circular approach.

Following the desire to achieve maximum convenience and satisfy their consumption needs, people are looking for an increasing variety of foods that need packaging solutions to get to them. However, the waste generated once the food product is used or discarded because it is spoiled includes both the container and the food residue, and this should not be neglected or forgotten. LCAs targeting both can be used to measure the overall negative impact on nature. Future research should focus on developing a comprehensive and universally accepted reference definition of sustainable food packaging, which can be used as a baseline definition that encompasses environmental, social, economic, and cultural factors and establishes clear indicators to measure sustainability. This concept needs to take into account the continuous developments related to research and technology in order to allow the definition to evolve as necessary.

Taking into account innovative biobased materials that are currently attracting the interest of multiple stakeholders, it becomes evident that further research is needed. Among the most established and commercialized solutions at present are polylactic acid-based products. Through a comparison conducted on the basis of a literature review and personal interviews, this thesis found that an alternative PLA-based product outperforms conventional LDPE. However, even with this study and the information available overall, there is still insufficient data to paint a complete picture of the dimensionality of the environmental impact of biobased and biodegradable substitutes from a cradle-to-cradle aspect. This leads to an inability to confidently conclude that they are the solution to sustainability and economic viability and to confirm the point for large-scale deployment. This can be resolved with the help of further research and in-depth LCA to ensure that the renewable substitutes are superior to fossil-based plastic in every aspect.

More work is necessary in the pursuit of mono-materials that have better barrier properties, as it is currently assumed that with the existing infrastructure, mono-materials should be more easily recycled and their cycling should, in theory, result in a minimal environmental footprint. This idea needs to be additionally explored and validated. In parallel with this process, it is also necessary to act in a timely manner and look for ways to improve the efficiency of the collection, distribution, and treatment of waste in its mix as it currently exists and as it is already accumulated in nature so that the present infrastructure and final waste treatment facilities can continue to be improved.

In terms of European regulatory frameworks, the effectiveness of key current regulations for this industry was considered, including the most recently adopted act, the PPWR. While harmonization using a statutory approach is important to set a common basis, this is not sufficient and the alternative approach of tailor-made targets was suggested, as could lead to more effective policies. Future research could focus on the topic of how exactly these targets should be set, what analyses are needed, and how binding targets can be most effectively tailored to individual Member States to contribute to the transformation of the food packaging industry and, at the same time, strengthen the implementation of circular economy principles.

A final consideration was the role of public participation in meeting these ambitious goals, which are inextricably linked to the knowledge of the general public. A survey conducted with participants in Bulgaria and Austria showed both similarities and differences in the two countries. It can be concluded that education in the field of sustainability and higher living standards correlate with better implementation of sustainable practices. Gaps in awareness exist, particularly regarding the impact of plastic packaging and food waste, as well as proper waste disposal methods. The presence of stability and corruption-free government leads to greater trust in political actors, which can, in turn, contribute to the continuity of legislation and its enforcement. Future studies could be carried out across the EU to get a comprehensive picture of each individual environment and should focus on specific areas that need improvement. Effective communication strategies are essential if we are to achieve knowledge accumulation, raise awareness, and bring about behavioral adaptation, especially with regard to waste collection, separation, and recycling. One specific recommendation proposed by this thesis involves the creation of a centralized information platform that could become a one-stop-shop for citizens with regard to the sustainable transformation of the food packaging sector and circular practices.

Due to the all-encompassing nature of this sector and the involvement of multiple stakeholders, the exploration of the economic and social implications of moving towards an environmentally friendly approach should be prioritized. This includes an analysis of the potential impact on industry, labor markets, and the actual implementation of the measures, ensuring that the transition is both beneficial to all people and in harmony with nature.

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Appendix

A.1 Interviews

A.1.1 Radan Kanev

Role: Member of the European Parliament; Member of the Committee on the Environment, Public Health and Food Safety, European Parliament Rapporteur on the Industrial Emissions Directive.
Method: Personal Interview (Offline in Sofia)
Date: 21 May 2024

Interviewer: Iva Tsolova-Kutsarova

ITK: Brief introduction:

RK: My name is Radan Kanev. I am a Member of the European Parliament, Member of the Committee on the Environment, Public Health and Food Safety, Rapporteur for the European Parliament on the Industrial Emissions Directive.

ITK: How would you define the current food packaging sector? And if we put the word "sustainable" in the definition, what else would need to change in the description?

RK: It is the main producer of non-degradable waste. National regulations have a different approach to addressing the fate of this waste. In Bulgaria, it is mainly landfilled.

ITK: What measures and actions are needed for it to become sustainable and environmentally friendly? On whom does this depend?

RK: It is very important to introduce uniform rules within the single market for the different types of packaging. For example, a Bulgarian in Spain would have no idea what to do because of the lack of information. At the moment, the sector is unsustainable.

ITK: From your point of view, what are the main obstacles to implementing sustainable packaging solutions? Is the problem in the legislative frameworks, the lack of enforcement, the industry, or in people's behavior?

RK: It depends, there is a need for shared responsibility by Member States and institutions. Additionally, it is important to achieve harmonization. Without it, tensions are created between countries, because at the moment, in most locations, the infrastructure and the ways of dealing with waste are different.

ITK: What needs to happen to drastically reduce the production and use of conventional plastics in packaging?

RK: I cannot judge.

ITK: What is your opinion on alternative biobased/biodegradable/compostable materials? There is a EU policy framework of biobased, biodegradable & compostable plastics, but no specific law on their use, proper labelling is also needed.

RK: Yes, you are correct, there is currently no specific law. I support these materials as they open up a large field for research and development of innovative solutions. They additionally give a boost to the industry.

ITK: Is there a risk that replacing conventional plastics with biodegradable plastics will slow down the development of the circular economy and the packaging reuse approach?

RK: In my opinion, there is no such risk, as I do not believe in extremes. Just as it is impossible to fully achieve reuse and recyclability, so I expect that there will always be a need for these kinds of substitutes.

ITK: How would you describe the dialogue between industry, NGOs and policy makers in terms of policy making? What is needed to accelerate the adoption of sustainable practices?

RK: In general, this dialogue is framed as an established procedure and requires compromise. It constitutes legitimate lobbying and functions well in Brussels.

ITK: What are the main legislative frameworks driving the packaging market at the moment?

RK: The PPWR is the regulation that has just recently been adopted by the European Parliament and is a very ambitious plan.

ITK: Are there any policies or initiatives that you are currently advocating to encourage the introduction of new approaches and practices to achieve sustainable food packaging?

RK: I am mainly trying to work towards achieving concrete results for Bulgaria. At the moment, separate collection and recycling are hardly happening and this is a personal mission I am fighting for.

ITK: What are the biggest successes and failures of the Directive on Packaging and Packaging waste in your opinion?

RK: Many green organizations have so far given mostly negative evaluations because there are too many exemptions and a lot of freedom is given to Member States. From my knowledge and my contacts with the industry, I can rather say that this stakeholder is satisfied with the Directive.

ITK: The Packaging and Packaging Waste Regulation is expected to enter into force very soon. What are the hopes and objectives for it?

RK: Our ambition with this regulation is to get on the road to harmonization with common European legislation. Once one or two revisions have been achieved, which usually takes about 5 years, an evaluation of the effect so far should be made. There has been partial resistance from some countries that do not agree with the isolation of plastics from the landfill mix. The idea is to switch some of the coal-fired units to burn RDF, but if there is no plastic in it, it will be low in calories. This is the position of states that have a tolerance to waste combustion. Bulgaria is generally not in favor of incineration, Croatia is strongly against it.

ITK: Is the plastics industry expected to take legal action against the law and have disapproval?

RK: I rather think there will be no lawsuits.

ITK: What are the European Parliament's key actions to reduce food waste related to packaging? 30% of food is wasted.

RK: The circular economy is very energy intensive and needs a lot of water, which is a difficult balance. Environmental performance limit values presents targets for overall sustainability and circularity levels, water and resource efficiency can be measured accordingly. It can be indicative for everything else, but binding for water. BAT could also be sought in terms of water efficiency, but in general the balance between circular economy and water use is difficult.

ITK: The circular economy is at the heart of the Green Deal and Circular Economy Action Plan. Do you think the targets set there are achievable, especially those related to the packaging industry? Since the plan is not binding, how exactly does it contribute to real change?

RK: The CEAP does not contribute to the implementation of the set objectives, but it is a framework that should contain the concept for the next legislation to be adopted.

ITK: What is needed for countries such as Bulgaria, which are still lagging behind in terms of waste treatment and a large proportion of plastics still end up in landfills?

RK: In Bulgaria, for example, it is key to communicate with the public and give clear instructions when laws are changed. It is important to introduce quality measures for separate disposal. The current number of bins is very limited. New mechanisms for waste separation need to be introduced. Accordingly, smaller and more effective tax schemes should be introduced. The municipal waste tax should not be based on the value of a property, but on the number of family members or the amount of waste produced.

ITK: How can Parliament's work get closer to the people?

RK: With the help of the media, but so far rather not effectively. However, people are gradually becoming interested in it.

ITK: What role does international cooperation play in tackling the global challenges of packaging waste? Our desire at the moment is to be a leader in climate neutrality, but what about the rest of the world?

RK: It is very important, but there is a need to further parallelize the approaches as they are currently different. Europe wants to be neutral by 2050, the US also, China by 2060 and India by 2070. The US is a great example of a country that invests heavily in technology and innovation.

ITK: Do innovative products from startups with a positive impact on the environment, which demonstrate quality, functionality and a smaller carbon footprint, have the potential to be widespread in the EU? How? What are the barriers to this happening now?

RK: There are many funds and funding opportunities that encourage this type of projects.

A.1.2 Hon.Prof.Mag.rer.soc.oec.Dr. Christoph Scharff

Role: Former CEO of ARA AG, one of Europe's leading EPR schemes for packaging wastes; Initiator and founder of the Circular Economy Coalition for Europe (CEC4Europe); Member of the Scientific Board of the Christian Doppler Research Association (CDG). The interview was conducted on 24 May 2024.
Method: Personal Interview (Online via Zoom)
Date: 24 May 2024

Interviewer: Iva Tsolova-Kutsarova

By prior arrangement, the questions prepared for Prof. Scharff were sent to him in advance to familiarize him with the specific topics of the study. During the very interesting and engaging conversation that followed, the questions were addressed, albeit in a shuffled order. Consequently, his answers are provided after the questions.

ITK: Brief introduction:

What needs to happen to drastically reduce the production and use of conventional plastics in packaging?

What are the primary challenges associated with recycling of plastic food packaging that you have observed in your work experience?

What is your perspective on the potential of biobased(biodegradable/compostable) plastics in reducing environmental impact? (PLA, algae)

What about the challenges associated with recycling of these alternatives?

Which should be the first priority - development of better EOL treatment technologies or further research and development of improved and more sustainable alternative packaging monomaterials?

How can the balance between optimal food protection, simplicity in product design and high-barrier mono-materials be achieved?

How feasible are innovative bio-packaging solutions in the context of large-scale implementation?

How have European directives and the Austrian legislative framework influenced ARA's operations and strategies?

There is currently an EU policy framework of biobased, biodegradable & compostable plastics, but no specific law on their use, nor on their proper labeling. How would such a measure contribute?

The Packaging and Packaging Waste Regulation is expected to enter into force shortly. What do you think are the most important hopes and objectives related to it?

The circular economy is at the heart of the Green Deal and Circular Economy Action Plan. Do you think the targets set there are achievable, especially those related to the packaging industry?

What improvements or changes in policy do you believe are necessary to further support the transformation towards sustainable food packaging and a circular economy?

Do alternative and innovative products from start-ups with a positive impact on nature, which are functional and have a smaller carbon footprint, have the potential to be widely distributed in the EU? How? What are the barriers to this happening now?

Is there a risk that replacing conventional plastics with biodegradable plastics will slow down the development of the circular economy and the packaging recycling approach?

Austria is among the leading countries in recycling rates. What is the way for the targets to be achieved? Especially for the countries that fall far behind the desired numbers?

Are there any emerging trends or technologies in packaging that you are particularly excited about or believe will have a significant impact in the coming years? Waxworms?

What advice would you give to policymakers, industry leaders, and consumers to accelerate the transition towards more sustainable packaging and a circular economy?

CS: Current barriers for recycling include the presence of multitude of materials, and too many polymers used for specific reasons. Additionally, there are compounds of different polymers, composites that cannot be mechanically separated and remaining residuals in the packaging, such food traces which leads to contamination.

The value chain is the key niche that has to be addressed in order to find how to improve recycling. There are three steps in the process, namely collection, sorting and recycling. If the collection is not properly done, then the sorting cannot happen in a high quality way, then the recycling process is challenged and the potential of a secondary raw material to be produced is declining.

Even if a package is suitable for recycling and because one reason or another doesn't reach the recycling facility, or is too dirty so it cannot be cleaned, the whole process will be jeopardized. Therefore the whole process has to be looked at as an inseparable one. The same accounts for the consumers habits - in case the used package is disposed of in the household waste instead in the separate collection bin, the recycling won't happen. These barriers are not technical barriers but can be qualified as human, social, behavioral and emotional barriers.

In an environmental aspect, when packaging is concerned, the concept of functional units has to be considered. Analyzing only the packaging is not enough because it has a purpose (protection, marketing, logistics) but the functional unit can be 200 grams of butter or a marmalade. Therefore, the functional unit is always the combination between the packaging and the product, otherwise the challenge with food loss cannot be taken into consideration. If this concept also includes the aspect for biobased and biodegradable materials, then the key metrics that should be looked into can be CO2 emissions, water and resource consumption, land use. Specific metrics can be evaluated which technology and material is more sustainable than others.

Biobased packaging is available on the market. However, the question is if these types of plastics ever enter a recycle oriented waste stream. According to a survey done by ARA among Austrian municipalities and local communities, almost all of them are of the opinion that consumers are currently not in the position to distinguish between biodegradable and non-biodegradable packaging despite the logos and labeling. They are afraid that once it is announced that such packaging can be disposed of in biowaste because it is biodegradable but the question here is under what exact condition it is biodegradable - in garden or industrial compost. In home composting, these materials are practically non-degradable because a specific environment is required, such as aeration and temperature. Therefore in case a fossil and plant-based plastic pack enter a biowaste, then a sieve or other mechanical instruments will remove both because this technology would also remove the plastic bag and it will not enter in the compost facility. Therefore municipalities are afraid if they give the end consumers information that biobased bags can be tossed in the green bins, that consumers will also throw away the fossil based bags because they cannot distinguish them. Generally speaking, the population will be encouraged to contaminate the biowaste. Official recommendation of the Austrian is that these biobased bags should not be put in the biowaste. Therefore the effect of the separate plastic collection comes into question. Another study with the university of Leon was done on whether plant based plastics can be automatically detected with near infrared detectors - they have different emission spectrum and can be identified. But when in a sorting facility 10 or 12 different plastic fractions are sorted, this means there should be one sorted waste stream with plant based packaging, the question which other waste should you get rid of because of a sorting capacity. This means you would lose something else. The current quantities on the market are too small, there are only traces, a couple of thousand tons compared to for example 300 000 tons of plastic packaging in the Austrian market. There is no economic justification for this waste to be sorted even if it is possible. Additionally, it cannot be mixed with the fossil based plastics because of the lower melting point. There should be a dedicated recycling stream and with the current stage of market penetration it doesn't make sense. Therefore it will eventually end up in the residual waste and the recycling options will be energy recovery. The energy value here will be utilized but the question is where is the difference between plant based and fossil based if they share the same faith. If it always ends up for energy recovery in the incinerator, does it justify the input. This is the current situation.

It takes a long time to achieve a transition, so it is not a question of either or. A robust collection scheme and sorting and recycling facilities are needed for all the quantities that are already out in the market because they will occur today and tomorrow and for a long day afterwards. Until there are alternative technologies fulfilling the requirements, humanity needs to deal with what it currently has produced.

How can a highly elaborated packaging be achieved? The first and most important thing is the creation of a mono-material rather than a composite that has all possible barriers (CO2, humidity, UV). This will be a huge step forward if a mono-material without any harmful materials can achieve this.

Compared to that even if it is a fossil-based material, it won't be so bad because there will be an enormous potential in mechanical recycling.

There is a whole set of regulatory frameworks which are actually posing a barrier towards recycling especially when it comes to food packaging. The ultimate goal is to have a loop - high quality recycling, maybe even for food packaging which is the top level because it is a food-sensitive material. Generally speaking, today it is forbidden to use recyclates for food contact in the EU. There are only non-critical applications which remain possible for separately collected whether is for fossil or biobased. The only workaround is chemical recycling where the macromolecules are broken up into tiny units and then they can be recombined and get rid of all the additives and stabilizers and other harmful substances.

Finding an umbrella view from the top - we have to answer 3 questions:

- Plastic is a very interesting material, lightweight, versatile, cheap, you can build everything but there are downsides. We have to ask what would be the future of plastics - it is hardly possible to have a hospital without plastics. In which areas do we prefer to phase it out because we have better alternatives? If we do not have the alternatives now?
- If we have applications of plastics in the future, will this even be in the food industry because of its good properties, the question would be how exactly to produce them? What should be our feedstock? Is it crude oil based, or plant based or CO2 based? This leads to the question of carbon management. This is the same carbon in the plant and its branches, or in the wood, and in the tires of the cars, or in the oil. It is an aspect of carbon management. If we want to keep it in the loop it can be a plant because it draws nutrients from the soil and it grows and you can harvest, extract, produce food, fuels and plastics. But there are other alternatives that can support this process like CO2 capturing or chemical recycling. This should be estimated through specific sustainability indicators.
- We have stocks, there are plastics stocks in the built environment, in our consumption, in the buildings and packaging. Humanity will still produce it in the future. But how can we keep these materials efficiently in the loop? The way is through efficient collection, then through efficient automatically sorting and recycling them but with a good quality and not downcycle them. Losses and littering should be avoided because land and marine littering means loss of resources in addition to the environmental effects. What is lost to the oceans can be recycled.

These three questions need political consensus. An alternative could be a ban of plastics. There is a shift away from plastics in the last three years but there is an increase of composites. Now there is a paper packaging with a very thin layer of plastics. Yes, the plastic quantity is less but before the only-plastic option was recyclable. Now the new composites are not recyclable because they are glued to paper or cardboard. This is very controversial because it is environmentally detrimental. Although there is less plastic, it is worse than before.

Currently there should be more focus on the treatment methodologies in order to be possible to handle the current solution. But treatment is not enough, collection and sorting is essential. But there should be additionally more research towards new materials and technologies as well.

There is a growing momentum in the industry to improve packaging and more openness to make a simultaneous change. The focus should be to handle what is on the market and extract as much as possible from the current waste streams.

Once there is a solution in the packaging sector, there is a long feed time until this comes already in the market. There is research, then legal approval, then testing phase due to food contact and production capacities. It takes a couple of years until a new packaging is on the market, it doesn't happen just like that.

Regarding the PPWR: What is currency observed are several EU policies that are micromanaging the situation due to overregulation. There is no solution. There is a union of 27 states and the idea is to regulate the recycling field. There is the choice for going for the optimum or going for harmonization. Harmonization is rather an easy approach and it can happen through a Directive which for example gives a target that needs to be achieved by a specific time period. But there are 27 members with different environmental, social, industrial situations, different markets and capacities and the optimum would be a cost benefit analysis or an environment impact assessment which can evaluate the best mix for recycling, treatment, or technologies for France or Bulgaria. But this would lead to different recycling targets and fragmentation. What we have in the EU is a homogeneous and harmonized target, political targets which do not allow for aiming towards the optimum. There is no evidence based or scientific background to support the targets, it is more like a political message to voters.

The industry would show far more acceptance if there is a reasonable explanation why a regulation is needed and how it would help climate protection. The other crucial thing is to avoid loopholes and freeriders. The regulations should be as simple as possible and avoid distortions of markets (domestic production vs. imports from Asia). If these two things are there, the industry will have understanding and will demonstrate commitment which is what is needed. Innovation and motivation cannot be regulated.

Europe touches more and more the relevant areas. The Green Deal was a substantial step and commitment towards climate protection and resource policy. The current situation shows that the MS wont reach the recycling targets. Covid happened and everyone had new priorities. The same repeated due to the war between Russia and Ukraine. When there is a shift in priorities and supply chains are shaken, there are impacts and the general public has to be flexible. It is not possible to avoid the changes happening all around us. There are new priorities currently and recycling is not the most pressing issue at the moment. We have to adjust because today we are in a war economy. Energy is much more important. As an example, Austria is 80% dependent on Russian gas.

We are bound by a regulation that suffocates innovation and flexibility which is a barrier. This can be applied to every regulation. Especially in Covid-19, everyone understood how important packaging is for food. How is it possible for people to receive and store and protect their food without packaging?

The Green Deal also has good aspects, namely the harmonization. What was observed in the past was the lack of concrete definitions, weak statistics, no concrete numbers which were distorting comparisons. Therefore the harmonization of definitions and standards is very important. To get a critical mass of biobased packaging is crucial for better acceptance. Without harmonization innovative biobased products would need individual approval from all 27 member states separately. This is already a huge step, which opens many doors.

Carbon credits is a very powerful instrument in curbing carbon emissions because it puts a price tag on them. Price of fossil plastics would make a lot of sense and this price would be a good approach for the producers because this way we can then distinguish between fossil and plant based plastic. The producers from the Middle East should pay the price. This approach shows results in the energy sector. Plastics are only a tiny fraction of the whole crude oil production but this gives a comparative advantage for the plant based plastics.

Key concern for biobased plastics - they won't end up where biodegradation happens. They would either not be collected in the proper waste stream or won't reach the facility. It is a distraction, it is not the most important concern. More important is the land allocation when we still have hunger. It is not a barrier but we should think of.

Regarding the technologies and how to fulfill all technical requirements with a monomaterial? If we take a step forward here, this would lead to a great improvement. The improvement of barrier technology has an enormous potential. Once this is achieved, the current facilities can still be used but with much higher efficiency. The improved sorting process will also have much higher results for the recycling. Because it will have less impurities. With the existing technology there will be quantitative and quality output. Getting rid of one layer is already an achievement.

Chemical recycling is like a magic wand. It leads to pure recycled materials but there are 20 to 30% residues, and it is energy intensive. From an economic point of view mechanical recycling is superior. But after chemical recycling, the material can be reused again for food packaging. Maybe the future will lead to a mix of measures - improvement of packages, improvement of EoL treatment.

A.1.3. Gergana Stancheva

Role: Co-founder and COO of the Bulgarian start-up company Lam'On.
Method: Personal Interview (Online via Zoom)
Date: 20 May 2024

Interviewer: Iva Tsolova-Kutsarova

It is important to note that only a part of the information obtained from the interviews with Radan Kanev and Hon.Prof.Mag.rer.soc.oec.Dr. Christoph Scharff was incorporated into the study. Since the Pack'On product was used as a case study within the research, all the information gathered from Gergana Stancheva was synthesized and integrated into the research, as it was crucial for comparing conventional plastic material with the biodegradable alternative. Consequently, only the questions posed to Mrs. Stancheva are included in this chapter.

Brief introduction:

Could you also introduce Lam'On with a few words and your path so far?

What is innovative about your products? Can you share a bit more about them?

What are the advantages of Pack'On?

What is its environmental footprint? In terms of the whole life cycle of your product? What does it break down into and how long does it take?

What are the emissions generated throughout its life span?

Where can it be disposed of and can it be recycled?

Can Pack'On be used for food packaging? For what kind of food items?

What kind of barrier does Pack'On provide - protection from gases, microorganisms, moisture?

What exactly are you trying to replace? Which material and which type of packaging?

Do you have any idea if your product packaging reduces the potential for food loss and waste? If yes, how and by how much?

What strategies are you using to promote acceptance of your products among the packaging industry and other potential customers of your company?

Are European regulations helping or hindering your development? How exactly?

How do you balance environmental sustainability with business profitability in your company?

What role do you think start-ups and small businesses play in driving innovation in sustainable packaging? What are the biggest obstacles for you? What support do you receive?

Does your product have the potential to be widely distributed in the EU? How?

In terms of production - can you use machines that produce the conventional products you are replacing or do you need new ones? Can you answer the same question with regard to packaging manufacturers.

What do you think needs to happen to drastically reduce the production and use of plastics?

What measures and actions are needed to achieve a sustainable food packaging sector by 2050? On whom does this depend?

From the current practices and excluding your product, which do you think is the most sustainable material and packaging for food in the EU today?

A.2 Survey questions

Within the context of the study and to better understand key aspects related to the research questions, an online survey was conducted among residents of Bulgaria and Austria. The questionnaire included 20 questions, translated into both English and Bulgarian. This section presents the questions along with their possible answers:

Survey: Sustainable food packaging and its role in achieving circular economy

(1/20). Your age:

- < 18
- 18 - 29
- 29 - 40
- 40 - 65
- 65 +

(2/20). Your gender:

- Female
- Male
- Other:

(3/20). What city do you live in?

(4/20). What is the highest degree or level of education you have completed?

- High School Diploma
- Bachelor's Degree
- Master's Degree
- Ph.D. or higher

(5/20). Have you completed any education or additional qualification courses in sustainability or environmental protection?

- Yes
- No

(6/20). Which of the following best defines your monthly income (gross)?

- I don't work
- €0 - €1499
- €1500 - €2499
- €2500 - €4999
- €5000 - €9999
- €10 000+
- Prefer not to answer

(7/20). Which do you think has a worse impact on nature?

- Plastic packaging waste
- Food waste

(8/20). How often do you find yourself discarding food due to it spoiling or expiring before you can consume it?

- Very often
- Often
- Sometimes
- Rarely
- Never

(9/20). What barriers do you face in reducing food waste in your household? (Select all that apply)

- Overbuying
- Lack of meal planning

- Confusion over food labels (e.g., "best before" vs. "use by")
- Ineffective packaging
- Lack of awareness about proper storage

(10/20). How much do you think packaging contributes to food waste?

- Significantly
- Moderately
- Slightly
- Not at all
- Unsure

(11/20). What type of information would help you better manage food waste related to packaging? (Select all that apply)

- Tips for proper food storage
- Guidance on interpreting food labels
- Strategies for meal planning
- Information on sustainable packaging options
- Facts about the environmental impact of food waste
- All of them

(12/20). What are the main factors that influence your choice of food packaging? (Select all that apply)

- Environmental impact of package/Recycability
- Cost
- Convenience
- Brand reputation
- Aesthetics

(13/20). Which types of alternative food packaging have you used or encountered? (Select all that apply)

- Biodegradable plastics
- Plant-based films
- Edible packaging
- I am not sure
- None of them

(14/20). How confident are you in your understanding of how to properly dispose of different types of food packaging?

- Very confident
- Somewhat confident
- Neutral
- Not very confident
- Not confident at all

(15/20). How do you typically dispose of food packaging waste? (Select all that apply)

- Recycling
- Composting
- General waste/trash
- Reusing

(16/20). More precisely, how often do you recycle or compost your food packaging?

- Always
- Often
- Sometimes
- Rarely
- Never

(17/20). What role do you think government policies should play in promoting sustainable food packaging?

- Strongly influential (e.g., subsidies, strict regulations)
- Moderately influential (e.g., incentives, guidelines)
- Neutral
- Minimally influential (e.g., minimal regulations)
- Not influential at all

(18/20). Which aspects of food packaging do you feel you need more information about? (Select all that apply)

- Environmental impact
- Recyclability
- Biodegradability
- Cost comparison
- Effectiveness in reducing food loss
- Proper disposal methods
- All of them

(19/20). What sources do you rely on for information about sustainable food packaging? (Select all that apply)

- Product labels
- Company websites
- Environmental organizations
- News articles
- Social media
- Friends and family
- Regulations

(20/20). Please name a concrete source/sources that inform/s you about sustainability, packaging and food waste reduction, and recycling practices: