UNIVERSITY OF GOTHENBURG

DEPARTMENT OF BIOLOGICAL AND ENVIRONMENTAL SCIENCES

ENVIRONMENTAL POSSIBILITIES OF UTILIZING RECYCLED PLASTICS AS FOOD CONTACT MATERIALS

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Degree project for Master of Science (120 hec) with a major in Environmental Science
ES2510, Examination Course in Environmental Science and 60 hec

Semester/year: Autumn 2023
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Environmental possibilities of utilizing recycled plastics as food contact materials

Abstract

Using recycled plastics as food contact materials can significantly reduce environmental impacts and enhance environmental benefits to nature. Environmental impact categories of global warming potential, abiotic depletion and acidification were evaluated for food packages made from recycled plastics and compared with their respective virgin alternatives. The properties of the recycled and virgin plastic components were estimated from the literature. The results indicate that food packages made of recycled plastic can significantly reduce global warming and resource consumption. Food packages made from virgin plastics are much more energy and material-intensive compared to their recycled components. Mechanical recycling of plastic food packages displayed the best performance among other recycling technologies. PET (polyethylene terephthalate) is the most promising polymer to use as a recycled component for food contact material. Polystyrene (PS) is also a low diffusive polymer, therefore a promising candidate which can be utilized in the near future in recycled food packaging. However, food contact material production using recycled plastics has been limited due to the migration of hazardous chemicals to the contacted foods.

Key words : food contact materials, recycled plastics, environmental impact, food packaging, LCA

Contents

1. Introduction

Single-use plastic(SUP) packages result in generation of several billion tons of garbage till date, which pollutes the environment. Microplastics obtained due to slow degradation of SUP present in oceans, are also being consumed by marine organisms such as fishes and shellfish species which disturbs marine life extensively. Hence, finding the right strategy to mitigate the plastic waste related issues has become inevitable today. Utility of single-use plastic (SUP) in packaging has emerged due to its excellent preservation capabilities, protection abilities and low prices (Mangaraj et al. 2009; Gahleitner and Paulik 2017). It is defined as the product whose life cycle is less than a few hours, non-biodegradable under domestic composting or landfill conditions, non-retrievable and which loses more than 95% of its economic value after single use. Huge amount of plastic waste is generated due to our ‘‘throw away culture’’ (Maguire et al. 2019). Post-consumer plastic waste generation across the European Union (EU) was 24.6 million tonnes in 2007 (PlasticsEurope 2008b). According to the prediction of Lebreton et al. (2018), ‘‘at least 79 (45–129) thousand tonnes of ocean plastic(in pacific ocean) are floating inside an area of 1.6 million km^2’’. This directly affects marine life as well as raises the pollution in nature.

Nelsen (2020) stated that ‘‘An estimated 8.3 billion tons of virgin plastics have been produced to date, of which 4.9 billion tons have ended up in landfills or natural environments’’ (Nelsen et al. 2020). In Europe, ‘‘25 million tonnes of post-consumer plastic waste is generated every year’’ as reported by Horodytska et al. (2018). According to Maguire et al. (2019), 2018 is the year which is marked as a turning point in the history of ‘‘plastic pollution’’. In this year, USA, The European Commission, UK, Chile, banned the use of SUP products (Cristi et al. 2020; Godfrey 2019). In order to find effective remedies to mitigate the ever increasing pollution, anti-single-use plastic movement has been initiated all over the world. With the immediate effect, supermarkets and many companies phased out light weight plastic bags.

In view of the recent literature, it is found that biopolymers, bio-based polymers, and edible polymers are under focus in recent days but its many drawbacks limit its usage. Prime limitations include: (i) high process cost, (ii) low production rate, (iii) brittle characteristics and (iv) inferior barrier characteristics (Mendes, A. & Pedersen, G.,(2021).

Recycling is another thought to control the plastic pollution through converting the waste into meaningful products which are also drawing attention of the researchers as an effective solution to the plastic waste. Consequences of the ban imposed by the government brings about development of several products by simply mixing the non-biodegradable plastics with biodegradable plastics by industries. Mixing or blending processes limits its recyclability and exhibits partial degradation. Even after degradation, the non-biodegradable part is fragmented into microplastics which have notable ecological impact (EU commission, 2018). Hence, finding the right and most feasible strategy to mitigate the plastic waste related issues has become crucial today (Hopewell et al., 2009).

Beside this, migration of toxic components from recycled plastics to food has also become a concern for the use as food contact materials (Etxabide et al., 2022). Many literature reviews have reported the migration chances of toxic contaminants like heavy metals, organic additives

or breakdown products that may contaminate the packaged food items. Migration of toxic contaminants from recycled plastics has become the cause of many health hazards (Etxabide et al., 2022). Hence, it is one of the major concerns today for the use of recycled plastics as food contact materials.

Current methodologies employed in plastic recycling encompass closed-loop recycling and mechanical PET recycling. Closed-loop recycling involves a systematic approach of collecting, processing, and utilizing recycled materials within a closed system, thereby minimizing the reliance on virgin raw materials and mitigating environmental impacts (Hopewell et al.,2009). Mechanical PET recycling entails the collection, sorting, cleaning, and processing of Polyethylene Terephthalate (PET) plastics into pelletized forms for subsequent utilization in manufacturing processes. These established techniques contribute significantly to the sustainable management of plastic waste.

The legislation pertaining to food contact materials oversees materials and articles designed or expected to come into contact with food. It covers a wide range of items, including packaging, kitchen utensils, tableware, processing machinery, and agricultural equipment. The main aim of the legislation is to safeguard human health. All food contact materials should need to fulfil Commission Regulation (EU) No 10/2011; plastic materials intended to come into contact with food and Commission Regulation (EU) 2022/1616; recycled plastic materials intended to come into contact with foods and repealing regulation (EC) No 282/2008. All food contact materials (FCM) must be produced following the guidelines of good manufacturing practice (GMP) outlined in Commission Regulation (EC) No 2023/2006. Evaluating the risk associated with food contact materials and substances is the responsibility of the European Food Safety Authority (EFSA). Welle (2023) mentioned that once the risk assessment done by EFSA, the EU commission decides whether the recycling technologies will be classified as "suitable" technology. Novel recycling technologies are those on which the European Commission has not yet taken a final decision, based on an opinion by EFSA. Compliance with the regulations governing FCM is essential, as stated in the Declaration of Compliance (DoC). It is mandatory to make sure that all suppliers and sub suppliers have provided sufficient DoC and followed Good manufacturing practices (GMP) throughout the whole supply chain (Hopewell et al.,2009).

In addition to these prevailing methods, there exists the potential for the integration of innovative technologies into plastic recycling. The viability of such novel technologies hinges upon their ability to conform to the criteria outlined in the most recent legislation governing recycled plastic materials intended for contact with food, as stipulated in EU Regulation 2020/1616. Adherence to these regulatory standards ensures the safety and compliance of recycled plastic materials for applications involving food contact.

2. Aims

1) Evaluate environmental benefits of utilizing recycled plastic in food packaging compared to conventional packaging materials.
2) Assess the challenges and limitations associated with utilizing recycled plastic in food packaging. (food safety concerns, regulatory aspects, technical limitations and consumer acceptance of recycled plastic packaging)
3) To increase the awareness of food packaging producers to create effective sustainable packaging materials for foods.

By conducting research that addresses these aims, a comprehensive understanding of the environmental possibilities and potential implications of using recycled plastic materials for food packaging can be obtained.

3. Scope

This investigation predominantly concentrates on materials intended for food contact, specifically encompassing food containers, food packaging, kitchen equipment, cutlery, dishes, and kitchen utensils derived from recycled plastics.

4. Methodology

By contacting several companies in Sweden that separate, manufacture and distribute food packaging materials from recycled plastic, investigate their current methods for this and assess the most feasible technology which provides a minimum environmental impact for making food packaging materials from recycled plastic. The evaluation will focus on the environmental benefits of using recycled plastics in food packaging compared to conventional food packaging materials, by comparing environmental impact categories throughout the life cycle of the packaging. A survey has been made with Swedish companies who deal with recycled plastics for food packaging and obtained their current recycling polymers used for food packaging and current technologies used for that. Swedish Food Agency (Livsmedelsverket) and Research Institute of Sweden (RISE) have assisted to gather information for this study.

The following food contact materials manufacturing companies in Sweden were selected for this study. An online survey was sent to a designated contact person within each company:

1. Trioworld
2. Stenquist AB
3. Orthex Group
4. Treform Packaging AB
5. Elby Produkter AB
6. Alfapac AB
7. Tara Pac AB
8. Draken i Reftele AB
9. Marka Pac AB
10. Kulleborn Gruppen

These companies were chosen based on their prominence in the industry and their relevance to the study's objectives. The survey aimed to gather detailed information on their practices, compliance with regulations, and innovations in sustainable packaging. This study was conducted utilizing a dual approach that integrated both primary data from an online survey and secondary data from comprehensive review of the literature. The online survey provided insights from industry professionals and stakeholders, while the literature review offered a thorough understanding of the current state of knowledge, practices, and advancements in the field. Combining these sources allowed for a robust analysis and a comprehensive understanding of the subject matter, ensuring that the findings are both well-grounded in empirical data and aligned with established research. The results and insights gained from this investigation will be compiled and submitted to the National Food Agency in Sweden for review and further consideration.

5. Results

5.1. Impact from EU regulation

All food contact materials made from recycled plastics must fulfil 3 plastic regulations; Commission Regulation (EU) No 10/2011; plastic materials intended to come into contact with food and Commission Regulation (EU) 2022/1616; recycled plastic materials intended to come into contact with foods and repealing regulation (EC) No 282/2008 together with good manufacturing practice (GMP) outlined in Commission Regulation (EC) No 2023/2006. All recycled plastics FCM companies must submit their petitions to the European Food Safety Authority via Livsmedelsverket to evaluate the risk associated with that FCM. After the risk assessment or the validation done by EFSA, the European Commission issues a legal confirmation to use that certain recycled polymer and recycling technology.

5.2. Survey Results with several FCM companies in Sweden

According to the survey, the current consolidated version of plastic legislation; Commission Regulation (EU) No. 10/2011 and legislation on recycled plastic materials intended to come into contact with foods; Commission Regulation (EU) 2022/1616, plastic recycling companies in Sweden mainly use recycled PET (polyethylene terephthalate) as a food contact material, as PET is the most promising polymer for reuse as a food packaging material and mechanical recycling is the most feasible recycling technology for food contact materials (Walker et al.,2024). Hopewell (2009) stated that mechanical recycling is most practical when the polymer constituent can be (i) effectively separated from sources of contamination and (ii) stabilized against degradation during reprocessing and subsequent use. The risk from contaminant migration into food would be expected to be negligible by using recycled PET (Triantafyllou et al.,2002).

To gather information for the online survey, a contact person from each food contact materials manufacturing company was contacted. The following individuals played a crucial role in assisting with the data collection.

Contact Person	**Organization and Designation**
Catharina Svenningsson	R & D Director Consumer Packaging at Trioworld
Mattias Anderson	PhD Researcher, Materials and Production, Department of Polymeric Materials and composites, Unit Polymeric Materials & Recycling, Research Institute of Sweden
Stina Gustafsson (works alongside at RISE, mainly within the member organization Normpack)	Division Bioeconomy & health, Department Pulp, Paper & Packaging, Unit Product Safety & Barriers, Normpack

An online survey has been disseminated to selected Swedish companies involved in the manufacturing of food contact materials. The selection criteria for these companies primarily focused on those already incorporating recycled materials into their products or planning to do so in the near future. The polymers predominantly used by these companies include Low-Density Polyethylene (LDPE), Polyethylene Terephthalate (PET), Linear Low-Density Polyethylene (LLDPE), Polystyrene (PS), and Polypropylene (PP).Currently, these companies do not utilize recycled PP and PS for food contact applications; instead, they primarily use recycled PET. Conversely, virgin polymers of PP and PS are widely employed as direct food contact materials. This practice is influenced by existing legislation, specifically Commission Regulation (EU) 2022/1616, which presently permits only the use of recycled PET in food contact materials. However, future legislative developments are necessary to ensure the safe recycling of plastics other than PET for food contact purposes (European Commission, 2020).

Most companies have used recycled LDPE polymers for freezer storage bags intended for cinnamon and cardamom buns before the introduction of recent legislation. However, these companies have temporarily halted their use and are awaiting legal confirmation from the EU Commission to resume. Under low temperatures, the migration of chemicals is negligible, thus not compromising food safety and consumer health (Welle, 2023).

All the food contact materials manufacturing companies involved in this survey are compliant with relevant food safety regulations and standards. The suppliers of these virgin or recycled polymers, primarily based in EU countries, have adhered to all necessary regulations and submitted a Declaration of Compliance (DoC). Additionally, material suppliers have conducted migration tests and organoleptic tests to ensure that the materials and polymers used for producing food contact materials do not leach harmful substances into foods. These tests also confirmed that essential attributes such as appearance, texture, taste, and aroma are preserved.

The percentage of recycled polymer utilized for food contact materials typically constitutes around 30% of the total weight, with a few companies using 100% recycled material, specifically recycled PET. A stratified approach, which incorporates insulating layers of both virgin and recycled plastics in the construction of multilayered food packaging, has facilitated this practice (Franz et al., 2022). Using recycled PET as the middle layer, sandwiched between virgin polymer layers on the top and bottom, is a more practical solution to ensure the packaging meets food safety standards. Simultaneously, some companies are not currently using recycled polymers for food contact materials due to the high production costs. However, their long-term targets include increasing the recycled content in their food contact materials to meet EU recycling plastic goals in the coming years. Most companies have opted for recycled PET as their food contact material because of its low input contamination levels together with high decontamination efficiencies (Welle, 2023). Currently, various types of food packages utilize recycled PET, including single film plastics, plastic liners, packaging films for frozen foods, and recyclable multilayered films.

Survey results are attached into the appendix.

5.3. Environmental benefits associated with recycled plastics in food packaging

Rajendran (2011) conducted a comprehensive life cycle impact assessment study, affirming a noteworthy contrast in the utilization of recycled plastics over virgin plastics for packaging purposes.

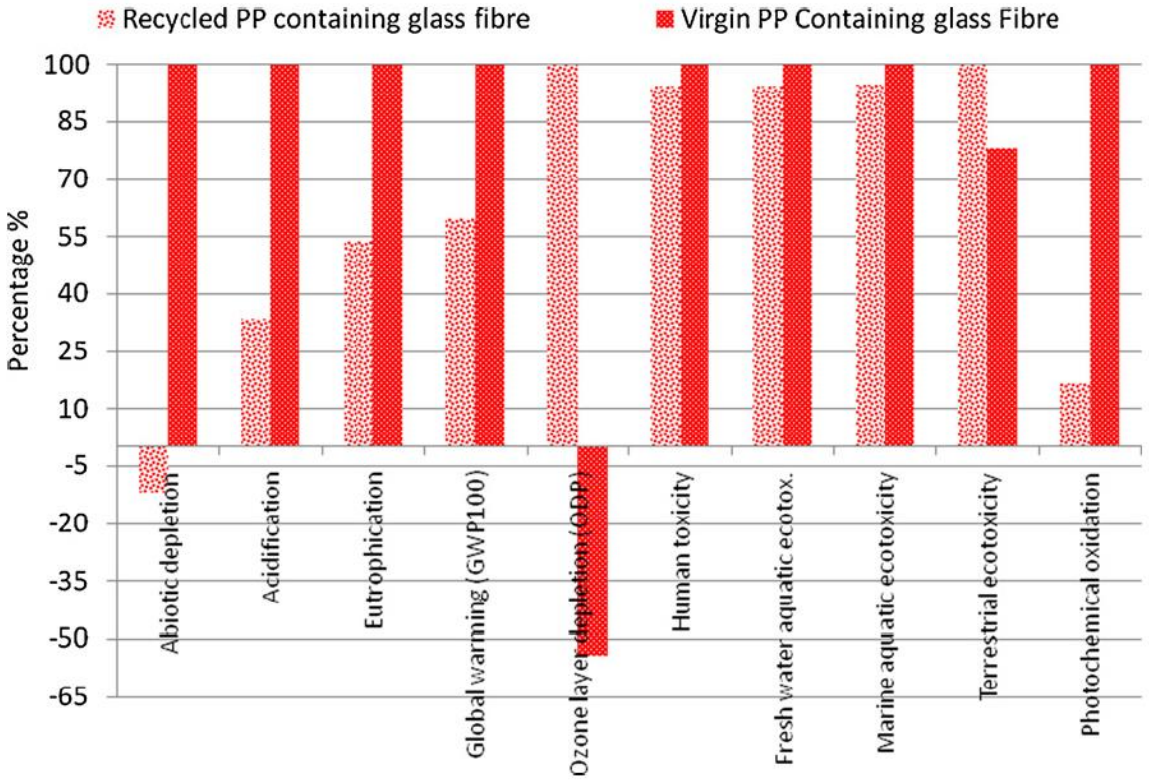

Figure 1 : Life cycle impact assessment results of plastic packages containing fibrous components (Rajendran et al.,2011).

According to the results shown above, it is clear that recycled plastic packages offer less abiotic depletion and less global warming potential compared to virgin plastic packages. The most relevant environmental impact categories, that are internationally accepted for evaluation of environmental impact of food packaging include natural resource depletion, acidification, photochemical ozone creation, eutrophication, human toxicity and aquatic toxicity (Hann et al., 2020; Vignali & Vitale, 2017; Maga et al., 2019). The results depicted that, having recycled plastic packages has reduced acidification, eutrophication, human toxicity, freshwater and marine water toxicity and photochemical oxidation compared to virgin plastic packages. It depicted the environmental benefits of having recycled plastics over virgin plastics for the food packages.

According to figure 1, percentage environmental benefits of having recycled plastic packages over virgin plastic packages can be quantified by rounding off to its near value with reference to its environmental impact categories.

Life cycle impact category	Percentage environmental benefit (%)
Abiotic depletion	110
Acidification	65
Global Warming Potential	40
Photochemical Oxidation	82.5
Freshwater ecotoxicity	5
Marine water ecotoxicity	5

5.4. Situation of Sweden

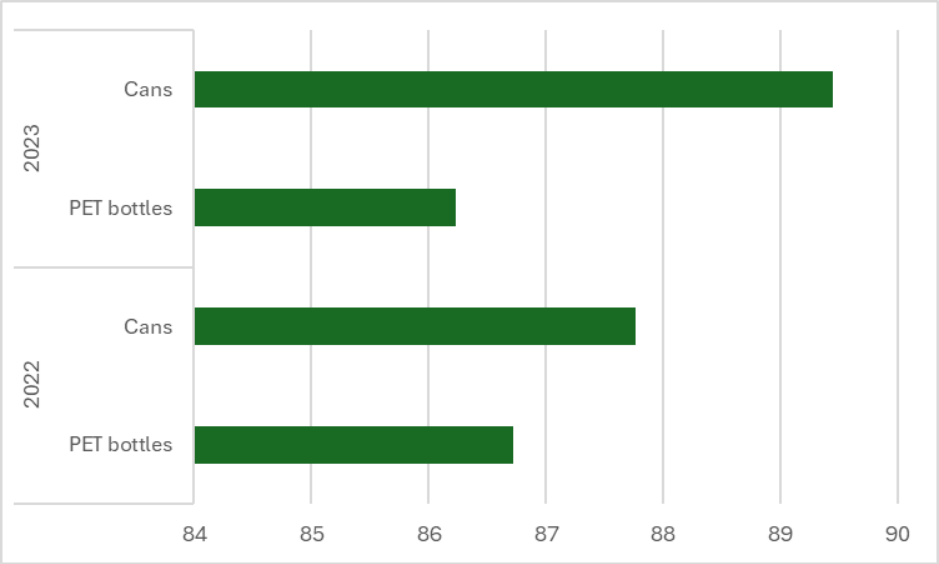

Figure 2: Recycled percentage of used PET bottles and cans in Sweden during 2022 and 2023

Returpack AB (Pantamera) in Sweden has operated the only approved return system for beverage packaging with a deposit since 1984. Every PET bottle and Aluminium can within the parameters specified for Sweden is transported to the facility operated by Returpack AB, situated outside Norrköping. Upon arrival at the facility, a meticulous process ensures, involving the sorting, counting, and compression of the bottles and cans into compact bales. Subsequently, these bales are forwarded to material recycling, constituting the next phase in the sustainable management of PET and Aluminium waste (Naturvårdsverket, 2023). This systematic approach ensures the efficient handling and it contributes to recycling post-consumer plastic PET bottles and cans used in Sweden. According to Returpack AB, during the years 2022 and 2023, there is an increase in the recycling rate of PET bottles and cans used in Sweden, and it is almost close to the national recycling target for bottles and cans in Sweden. (90%)

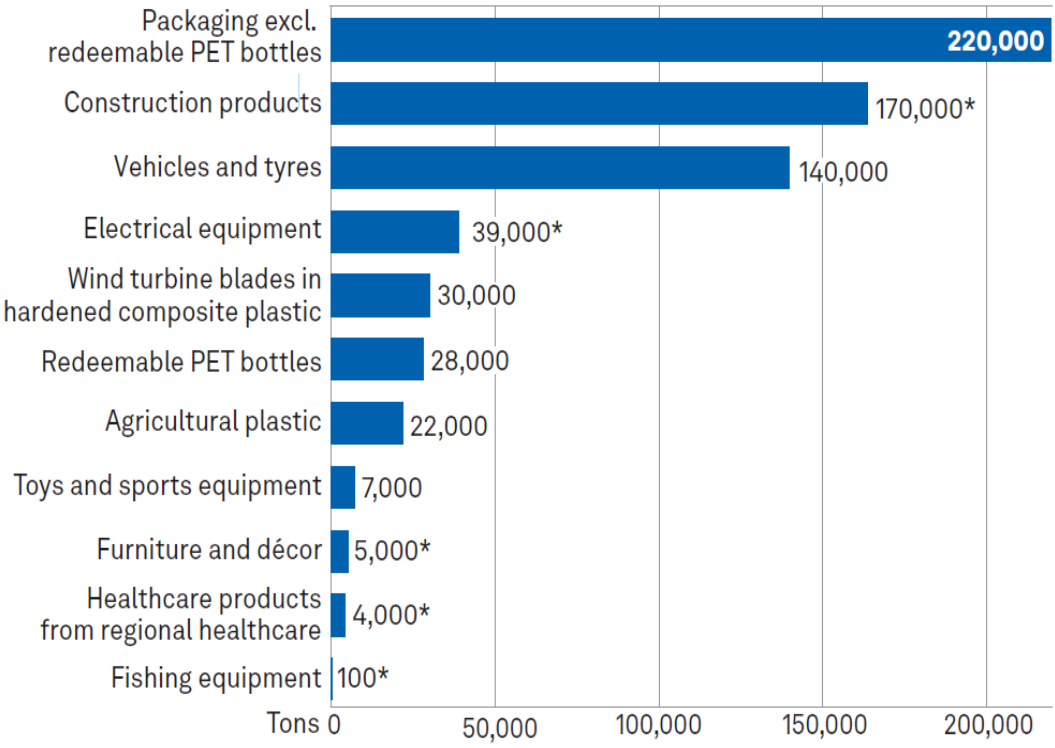

Figure 3 : Plastics entered into the Swedish market in 2019 (tons) (Naturvårdsverket, 2022).

Assuming that all redeemable PET bottles were used for the food packages (in 2019), then more than 28,000 tons of plastic (PET bottles) were allocated for food packaging in Sweden in 2019 (Naturvårdsverket, 2022). Sweden aims to achieve a milestone by 2025 wherein a minimum of 50 percent of all plastic packaging, encompassing redeemable PET bottles, will be directed towards material recycling. Correspondingly, a parallel objective is established within the European Union. However, as of 2020, a mere 34 percent of the plastic packaging introduced into the Swedish market underwent material recycling (Naturvårdsverket, 2022).

Table 1 : Supplied and collected amount (tons) of packaging on the Swedish market in 2022 as well as material recycling (tons) and target fulfilment in weight percentage in 2022 according to regulation 2018:1462 in Sweden (Naturvårdsverket, 2023).

Type of packaging	Supplied amount (tone)	Collected amount (tone)	Material recycling (tone)	Material recycling (percent by weight)	Material recycling goal (percent by weight)
Glass	254,390	227 189	217,823	86#	90
Plastic (incl. PET bottles with deposit)	276 133	151,000	97,970	35#	50
PET bottles with deposit	30,614	26,876	24,749	81#	90
Paper, cardboard, cardboard and corrugated cardboard	662 387	554 906	513 404	78#	85
Ferrous metal (steel) *	34,074	27,474	27,980	**82**	70
Aluminum (incl. deposit cans)	35,984	29,961	29,486	**82**	50
Aluminum deposit cans	27,606	24,542	24,469	89#	90
Wood **	–	–	–	–	15
Total * **	**–**	**–**	**–**	**–**	**65**

* That the material recovery for ferrous metal is higher than the amount collected may be due to stock keeping.

* * Data for wood are too uncertain to report due to missing items.

* * * Total is not reported due to uncertain data for wood.

Red number means that the target was not reached.

Table 1 shows that the recycling goal for plastics, including PET bottles, has not been met. Therefore the producer and the consumer actions are still needed to significantly lessen the environmental impact of plastics in Sweden.

Table 2: Amount of recycled packaging waste and material recycling rate in 2022. The material recycling targets are in accordance with regulation 2018:1462(Naturvårdsverket, 2023).

Type of packaging	Material recycling (tone)	Material recycling rate (percent by weight)	Material recycling target by 2029 (percent by weight)
Glass	217,823	86#	90
Plastic (incl. PET bottles with deposit)	97,970	35#	50
PET bottles with deposit	24,749	81#	90
Paper, cardboard, cardboard and corrugated cardboard	513 404	78#	85
Ferrous metal (steel)	27,980	**82**	70
Aluminum (incl. deposit cans)	29,486	**82**	50
Aluminum deposit cans	24,469	89#	90
Wood *	–	–	25
Total **	**–**	**–**	**65**

* Data for wood are too uncertain to report due to missing items.

* * Total is not reported due to uncertain data for wood.

Red number means that the target was not reached.

According to table 2 , Sweden is far more away from material recycling targets for plastics including PET bottles given by the EU commission in 2022. However, Sweden successfully attained the material recycling targets for ferrous metal (steel) and aluminum packaging.

Table 3 : Supplied and collected quantity (tons) of PET deposit bottles on the Swedish market and material recycling in tonnes and weight percentage in 2021 and 2022 (Naturvårdsverket, 2023).

Year	Added amount (tone)	Amount collected (tone)	Material recycling (tone)	Material recovery rate (percentage by weight)
2022	30,614	26,876	24,749	81#
2021	29,132	25,462	24,011	82#

Red number means that the target was not reached.

In 2022, the material recycling rate for PET bottles with a deposit was 81 percent by weight, which is one percent lower than it was in 2021. Thus, the target of 90% by weight in 2022 was not met. Compared to 2021, both the supplied and collected amount of deposit PET bottles increased in 2022. The amount of material recycled also increased, but not as much as the supplied/collected amount, and thus the material recycling rate dropped somewhat. Consequently, this underscores the necessity for implementing more efficient strategies and measures to attain the material recycling target by 2029.

Table 4 : Supplied and collected quantity(tons) of plastic packaging on the Swedish market as well as material recycling in tonnes and percentage by weight in 2021- 2022 (Naturvårdsverket, 2023).

Year	Added amount (tone)	Amount collected (tone)	Material recycling (tone)	Material recovery rate (percentage by weight)
2022	276 133	151,000	97,970	35#
2021	272,846*	145,720	96,708	35#*

* The amount of plastic packaging supplied for 2021 has been revised, which means that the material recycling rate for 2021 has also been revised.
# Red number means that the target was not reached.

According to table 4, the amount of plastic packages which are sent to other waste management options (incineration, energy recovery) can be estimated.

5.5. International situation associated with plastics

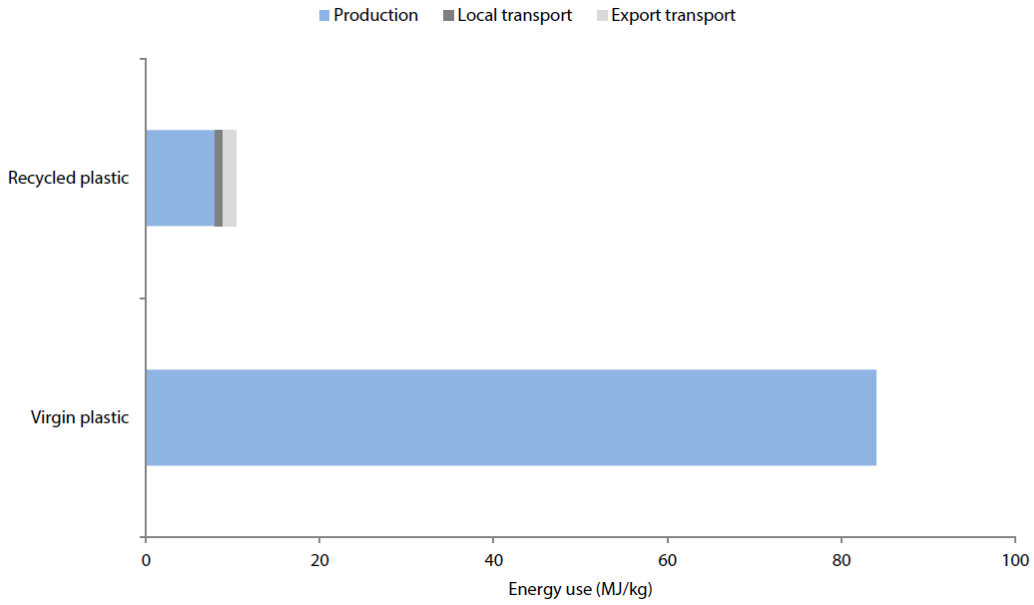

Figure 4 : Energy consumption of producing plastic from fossil fuels (Virgin plastics) and recycled plastics (OECD,2018).

Figure 4 illustrates that the production of plastics from fossil fuels entails a considerably higher energy consumption compared to utilizing plastic scrap. Consequently, this process results in significantly greater energy consumption and CO_2 emissions, thereby exacerbating the negative environmental impact associated with virgin plastics. Hence, it becomes evident that transitioning towards recycling plastics would yield substantial environmental advantages and benefits in contrast to the utilization of virgin plastics.

A recent study of Geyer (2017) revealed that approximately 46 million tonnes of recycled plastics resins are produced per year in the globe and it represents 14%-18% of total plastics at the global level are recycled.

6. Discussion

6.1. Current Legislation regarding FCM from recycled plastics

As of the legislation, Commission Regulation (EU) 2022/1616, recycled plastics for food packaging should always come from decontaminated post-consumer plastic food contact materials. The regulatory framework stipulates that food contact materials must be produced in adherence to Good Manufacturing Practice (GMP), ensuring that these materials do not transfer their constituents to food in quantities that could pose risks to human health or induce undesirable alterations in the food's composition, odour, or taste (Triantafyllou et al.,2002). The detailed specifications for Good Manufacturing Practice concerning food contact materials are outlined in Commission Regulation (EC) No 2023/2006. These regulations extend across the entire supply chain, encompassing the manufacturing, processing, and distribution stages of food contact materials. Compliance with these standards is imperative to guarantee the safety and integrity of recycled plastics employed in items that come into direct contact with food. Plastic legislation; Commission Regulation (EU) No 10/2011 states, plastics for food contact materials need to be manufactured from the chemical substances listed in the legislation and fulfil Specific Migration Limits (SML); the maximum permissible total content that a material may contain (EU Commission,2011).

The interaction between plastic packaging and food has the potential for chemical substances from the packaging to transfer into the food. Mendes, A. & Pedersen, G.,(2021) stated that the migration of substances from plastic to food is a diffusion-controlled process, and it is imperative that such substances adhere to the specified migration limits (SML) stipulated in the Commission Regulation (EU) No 10/2011 (EU Commission, 2011). It is the responsibility of the industry to ensure the material's compliance with the regulation and to document the entire production chain (Mendes, A. & Pedersen, G.,(2021).

6.2. Present situation about FCM from recycled plastics

PET is the most promising polymer for reuse as a food packaging material (Triantafyllou et al.,2002). According to Welle (2023) the use of post-consumer PET into new beverage bottles with up to 100% recyclate content is possible. PET recycling process shows a significant cleaning efficiency as the curbside and deposit PET collection systems are well established all over the Europe. As a consequence, it generates a huge input stream of post-consumer PET bottles. Meantime, PET is a low diffusive polymer so the concentrations of substances absorbed into PET bottles during its first life of the beverage bottle is low. This low input contamination levels together with high cleaning efficiencies make PET ideal for packaging material for a circular economy (Welle,2023). Due to a high diffusivity of PE (Polyethylene) and PP (Polypropylene), contaminants are more effectively absorbed into these polymers (compared to PET) (EFSA, 2015). Therefore, if the input material is not sufficiently decontaminated or recycled in a closed and controlled loop, the risk of chemical migration into food from PE and PP is increased. Thus recycled PP (Polypropylene) and PE (Polyethylene) are hardly used in food contact materials (Mendes, A.C., & Pedersen, G.A.,(2021). EFSA announced that high diffusive polymers like HDPE are completely excluded from being recycled back into food contact at the moment (Welle,2023). Polystyrene (PS) is the next promising candidate worthy of consideration to use recycled PS as a direct food contact material due to its low diffusivity (Welle, 2023). Welle (2023) revealed that recycling of PS back into food contact has not been established to date. Lack of well controlled and sorted input streams and super clean recycling processes on an industrial scale has not been evaluated to date hindered its use today.

6.3. Existent technologies for plastic recycling

According to the findings of this study, the mechanical recycling of plastic food contact materials emerges as the most viable and environmentally friendly mode of plastic recycling, exhibiting a reduced negative environmental footprint. This method yields greater environmental advantages by conserving more energy and emitting lower levels of CO_2 into the atmosphere when contrasted with the chemical recycling of plastics. Consequently, mechanical recycling presents significantly more environmental benefits than chemical recycling. Closed-loop recycling is most viable when the polymer element can be (i) efficiently isolated from contaminants and (ii) stabilized against degradation during reprocessing and subsequent use (Hopewell et al., 2009).

Furthermore, Huysveld et al.(2022) stated that, most of the plastics nowadays are mechanically recycled and chemical recycling is an emerging technology. Close loop recycling and mechanical PET recycling are currently employed in recycling processes for food contact materials composed of plastics, according to the European Food Safety Authority (EFSA). Nevertheless, legislations for the safe mechanical recycling of plastics other than PET into food contact material needs to be implemented in the future (European Commision, 2020). Huysveld et al.(2022) mentioned that Thermo Chemical recycling can be a complementary technology to mechanical recycling, which is the main recycling method in operation today but currently cannot be used for all applications, such as the closed-loop recycling of food packaging, except for PET bottles.

6.4. Environmental benefits of FCM from recycled plastics

It has been estimated that PET bottle recycling gives a net benefit in greenhouse gas emissions of 0.95 tonnes of CO_2-e per tonne of recycled PET (Department of Environment and Conservation (NSW) 2005) as well as reduction in landfill and net energy consumption. An average net reduction of 1.45 tonnes of CO_2-e per tonne of recycled plastic has been estimated as a useful guideline to policy (ACRR 2004), one basis for this value appears to have been a German life-cycle analysis (LCA) study (Patel et al. 2000), which also found that most of the net energy and emission benefits arise from the substitution of virgin polymer production. Another LCA specifically for PET bottle manufacture calculated that use of 100 percent recycled PET instead of 100 percent virgin PET would reduce the full life-cycle emissions from 446 to 327 g CO_2-e per bottle, resulting in a 27 per cent relative reduction in emissions (WRAP , 2008).

When evaluating the environmental impacts of virgin and recycled plastics, it is conspicuous that having recycled plastics for food packaging offers the minimum environmental impact over virgin plastics. Global warming potential, resource depletion potential, acidification potential, eutrophication, photochemical oxidant formation, and water scarcity potential are lower for recycled plastics compared to virgin plastics (Rajendran et al.,2011).

6.5. Present applications of recycled plastics in consumer products

Empower AS (2024) stated that the use of recycled plastics has spread to the fast-food industry, where everyday products such as take-away containers and cups are typically made from recycled plastic components. This application demonstrates the adaptability and long-term potential of recycled plastics in meeting the functional needs of varied food packaging formats. Food packaging made from recycled plastic can be found in a variety of consumer products. Empower AS (2024) pointed out that Nestlé has begun utilizing recycled plastic for its water bottles. Coca-Cola has vowed to use recycled plastic in all of their products by 2030. Take-back and refilling schemes do exist in several European countries, including PET bottles as well as glass (Institute for Local Self-Reliance, 2002). These programs demonstrate how major companies understand the value of using recycled plastic and implementing measures to improve their sustainability. In Spain, recycled plastics are also commonly used as food contact materials in plastic return trays, which are used for the transportation of foods to supermarkets. Re-use of plastic packaging is limited to rigid products, such as trays and crates, used for vegetable and fruit distribution. Once the initial transportation is done, the same plastic trays are used only to transport foods and, after several uses, are sent to be recycled (Abejon et al.,2020). Furthermore, López-Gálvez (2021) mentioned that the handling of fresh fruits and vegetables in reusable plastic crates (RPCs) has the potential to increase the sustainability of packaging in the fresh produce supply chain. This same implication is being done in Sweden supermarkets. Here, the trays can be steam-cleaned between trips, and when worn out, they are often recycled and blended with virgin polymer to produce new trays and crates (Overton, 1994). Magnum has launched new ice cream tubs and lids made from recycled polypropylene which stores under low temperatures as migration of chemicals is really low compared to high temperature conditions. The goal of this company is by 2025, all Magnum tubs will be made with recycled polypropylene and it will be distributed to all European countries. Through this novel approach, this company is expecting to lead the food and refreshment industry towards a sustainable future by paving the way to a circular economy (Unilever, 2020).

Few years ago, Magnum emerged as the first ice cream brand to adopt an innovative recycling technology and to integrate recycled plastic within the ice cream industry. To mitigate the environmental impact of plastic, Magnum has introduced new tubs and lids for its pint range that are fully recyclable and manufactured from recycled polypropylene. This cutting-edge recycling technology transforms previously non-recyclable plastic waste into a valuable resource. The recycled PP waste can be reprocessed indefinitely due to the closed-loop recycling method, which preserves the quality of the material and consequently diminishes the need for virgin plastic (Unilever, 2020).

6.6. Swedish involvement with FCM made from recycled plastics

The official control of food contact material manufacturing companies has just started in Sweden and the competent authority for that in Sweden is the municipalities (Naturvardsverket,2023). On January 1, 2023, a new regulation (2022:1274) regarding extended producer responsibility for packaging came into force. The way packaging is handled in Sweden will change as a result of this regulation. Naturvardsverket (2023) stated that municipalities will be given additional duties as they will take on the operational responsibility of collecting waste from household packaging and offering guidance on preventive measures and sorting. This will lead to increased municipal involvement and responsibility in promoting sustainable packaging management. All municipalities are expected to have a curbside collection of residential packaging materials by January 1, 2027 (Naturvardsverket, 2023).

Together with Lidl Sweden and research institute (RISE), Trioworld has launched the first post-consumer recycled (PCR) plastic film for frozen food packaging of cinnamon buns and cardamom buns (Trioworld, 2022). This groundbreaking new multi-layer packaging is made of 30% recycled PCR and it is 100% recyclable. They have used recycled post-consumer LDPE (Low Density PolyEthylene) for that and to get the film food contact approved the recycled material has sandwiched in between two layers of virgin LDPE. An additional layer of barrier material has been used thus by making a five layer film. Welle (2023) elaborated that the most favourable applications for post-consumer recyclates are foods under refrigerated storage as low temperatures minimized the migrated amount of post-consumer substances into packed food. However, recycled LDPE films are currently not used by Trioworld after the legislation of Commission Regulation (EU) 2022/1616 comes into force. They have published a document of Declaration of Compliance including the results obtained by migration testing and organoleptic testing to reveal recycled LDPE films are still safer to utilize as freezer bags for cinnamon and cardamom buns. They have submitted petitions to EFSA and are awaiting approval for that to continue with recycled LDPE again.

A new study of the Orthex group with the collaboration of SULKI research project has revealed the potential of utilizing recycled plastic in products suitable for food contact (Orthex Group,2023). Recycled material for Orthex freezer containers was tested in that study and it revealed that it's a sustainable choice to use recycled polypropylene as a raw material as it lowers 70% of carbon footprint compared to virgin polypropylene. However, further development of sorting technology is required in order to start the production on a profitable industrial scale.

According to the survey made with some of the food packaging companies in Sweden, some are using food contact materials imported from the EU region. If a plastic food contact material manufacturing company in Sweden is importing the recycled food contact materials outside from European Union, those companies outside in European Union (EU) must also need to be compliance with EU regulation for recycled plastics that intended to contact with food contact materials (Naturvardsverket,2023). Furthermore, every new batch of products coming from outside the EU, needs to have a Declaration of Compliance (DoC) according to Commission Regulation (EU) 2020/1616. As a company, it might be difficult to recognize which regulations and requirements apply to the materials in contact with foods, especially when food contact materials are being imported. Normpack in Sweden assists all the member

companies to cope with all those requirements. This has contributed to increased safety in food packaging in Sweden.

6.7. Barriers and drivers to utilize FCM from recycled plastics

Barriers to utilize recycled plastics as a FCM	**Drivers to utilize recycled plastics as a FCM**
Cost for the decontamination of post-consumer food packages.	The demand for food contact materials create direct and indirect opportunities for recycling companies. (Economic development and job growth)
Prices for the virgin plastics are much lower compared to recycled plastics. (higher economic impact of recycled plastics)	Developing novel technologies and innovations in recycling.
Resource scarcity and a high demanding market could act as a barrier for plastic packaging.	Governmental incentives and regulations to promote the use of recycled plastics as a food contact material.
	Promoting effective communication to consumers regarding recycling and reusing the packaging properly and clear instructions to dispose of packaging waste.
	Eco designing of the packaging.
	Optimizing the packaging processes to minimize direct and indirect expenses
	Research and development on more applicable materials for recycling and to reduce environmental footprints.
	Governments could boost packaging sustainability by favouring innovations.
	Increasing the quality of recycled plastic.

The decontamination of post-consumer plastics poses an extra financial burden in the process of manufacturing food packaging from recycled plastics. This is because it's crucial to ensure that contaminants or residues are thoroughly removed from the collected plastic waste before recycling is occurred (Franz et al.,2022). As a result, a supplementary step in the production process is necessary, requiring comprehensive cleaning and treatment to meet the stringent hygiene and safety standards set for food packaging materials. These additional procedures, while vital, can increase both the time and cost associated with recycling plastics for food-related applications. Consequently, the inclusion of this decontamination step contributes to rise in overall operational expenses of utilizing recycled plastics in food packaging, further

influencing the economic considerations associated with the adoption of sustainable packaging practices.

The price of virgin plastics is generally lower than the recycled plastics, thus making it challenging for companies to justify utilizing recycled plastics. However, as the demand for sustainable packaging is increasing, this cost disparity poses a hurdle for companies seeking to justify the incorporation of recycled plastics into their processes. The price of recycled plastics can also be influenced by supply and the demand as well as the cost of the recycling process (Hopewell et al.,2009). The economic impact of using recycled plastics in food packaging can vary due to several factors; market price developments, cost of recycling and supply and demand. If the Swedish government provides more incentives and regulations to promote the use of recycled plastics for food contact material, the current situation in Sweden might change drastically. The demand for recycled plastics as food contact materials create direct and indirect opportunities for recycling companies; economic development and promoting job growth. Developing novel technologies and innovations in recycling may also create new opportunities for the food packaging recycling industry in Sweden.

Resource scarcity and high market demand can pose significant barriers to plastic packaging. To address this challenge, maintaining a balance between available resources and market needs is crucial. For example, while reducing the thickness of packaging material can decrease resource use, it may also shorten the shelf-life of products. However, enhancing logistics management to ensure rapid delivery of goods to supermarket shelves could mitigate this issue. By optimizing the supply chain and improving distribution efficiency, it is possible to use thinner packaging materials without compromising product quality or shelf-life, thereby addressing both resource constraints and market demands (Mattia et al., 2021).

The utilization of recycled plastics in food packaging assists to reduce the carbon footprint related to plastic production and disposal. Using recycled plastics broadens the packaging industry as it creates opportunities for the recycling companies; economic development and promoting job growth. Developing novel technologies and trends also create new opportunities for the recycling industry. Using recycled plastics in food packaging offers a promising solution to environmental problems; minimizing CO_2 emissions to the environment. Most of the European countries are shifting away from the linear plastic economy and focusing on circular plastic approaches. In many countries, government policies and legislations are in force to empower the use of recycled plastics and government incentives are provided for that. Manufacturing products from recycled material obtains considerably less energy compared to producing them from raw material. Frequent market price fluctuations act as a certain barrier for the increased use of recycled plastics in food packaging. It has become challenging for companies to select recycled plastics over virgin plastics as virgin plastics are lower in price compared to recycled plastics. Furthermore, the price of recycled plastics can also be determined by supply and demand as well as cost of the recycling process.

Packaging producers can incorporate information about recycling and reusing packaging, as well as provide clear instructions for disposing of packaging waste. Effective communication, such as designing labels with straightforward disposal instructions, can significantly contribute to achieving sustainability. Despite various efforts, this aspect has not yet been adequately addressed by the market (Mattia et al., 2021).

When designing packaging, it is crucial to minimize the environmental impacts throughout its entire life cycle, particularly at the end of its life. Therefore, if new packaging projects prioritize

circularity and sustainability in their design, disposal, and end-of-life processes, it would promote sustainable packaging design, which is essential in today's context (Singh et al., 2023).

Optimizing packaging processes to minimize both direct and indirect expenses serves as a key driver for sustainable packaging in the future. By streamlining operations, reducing material usage, and enhancing efficiency, companies can significantly lower production costs and environmental impacts. This approach not only makes sustainable packaging more economically viable but also promotes resource conservation and waste reduction. Implementing advanced technologies and innovative designs can further enhance these efficiencies. For instance, lightweighting packaging materials, utilizing renewable or recycled resources, and improving logistics can collectively reduce carbon footprints and overall environmental burden. Therefore, the strategic optimization of packaging processes is essential for advancing sustainability in the packaging industry (Mattia et al., 2021).

Governments can enhance packaging sustainability by promoting innovations that favour thin, lightweight, and reusable packaging materials. These materials can significantly reduce waste, energy consumption, and the use of raw materials, thereby mitigating environmental pollution. By implementing policies and incentives that support the development and adoption of such sustainable packaging solutions, governments can drive industry-wide shifts toward more environmentally friendly practices. This approach not only aligns with global sustainability goals but also fosters innovation and economic efficiency within the packaging sector (Mattia et al., 2021; Naturvårdsverket, 2022).

Enhancing environmental sustainability by utilizing more feasible recycling materials for packaging is a crucial driver for increasing recycled content in packaging. Future advancements, including technological innovations and marketing research focused on more applicable packaging materials, hold significant promise for minimizing the environmental footprints of plastic packaging. By exploring and implementing new materials that are more easily recyclable and have lower environmental impacts, the packaging industry can move towards more sustainable practices. Additionally, investing in research to improve the recyclability and functionality of packaging materials will contribute to reducing plastic waste and promoting a circular economy (Mattia et al., 2021).

Increasing the quality of recycled plastic involves selecting plastics free from hazardous additives, thereby ensuring that food safety and consumer health are not compromised. By prioritizing the use of safer materials, the recycling process can produce high-quality plastic suitable for food contact and other sensitive applications. This approach not only enhances the overall quality but also the safety of recycled plastics (Naturvårdsverket, 2022).

6.8. Swedish government involvement towards FCM from recycled plastics

Adequate disposal instructions, indication of recyclability of the virgin plastic package or container, and adequate labelling are critical criteria for producing recycled food contact materials from virgin plastics. To facilitate this, virgin plastic food packages should have a clear waste sorting guidance for the consumers (Naturvårdsverket, 2023). The government can put taxes on the use of virgin plastics, thus the consumers are motivated to switch with recycled plastics (Naturvårdsverket, 2023). The most common example of this is obtaining taxes for purchasing plastic carrier bags in supermarkets. Creation of consumer education and awareness campaigns are more crucial (concerning the environmental benefits of recycled plastics) in order to stimulate the demand for products containing recycled plastics (Naturvårdsverket, 2023). The production of supermarket carrier bags from recycled plastics has the potential to offer significant environmental benefits. If these bags are made from recycled materials, it could reduce reliance on fossil fuels, which are typically used to produce virgin plastics. This shift toward recycled plastics not only conserves natural resources but also mitigates the negative environmental impacts associated with the extraction and processing of virgin plastics. By utilizing recycled materials for carrier bags, there is a potential to reduce greenhouse gas emissions and decrease the overall carbon footprint associated with plastic production. Additionally, promoting recycled plastics in this context could help drive circular economy initiatives, encouraging the reuse and recycling of plastic materials, ultimately contributing to a more sustainable plastic life cycle.

Swedish municipalities are the competent authority for FCM manufacturing companies, thus each municipality has the operational responsibility of curbside collection of the residential areas (Naturvardsverket, 2023). If the government could provide incentives to facilitate that process, it will contribute to increase plastic recycling in Sweden. Because, post-consumer waste has a strong influence on the quality of post-consumer recycled polymers (Welle et al.,2023).

6.9. Design considerations for FCM from recycled plastics

Food contact materials crafted from recycled plastics are subject to various limitations, with a notable concern being the potential migration of chemicals from the packaging into the food contents (Etxabide et al., 2022). Elevated temperatures can exacerbate this phenomenon, leading to increased levels of migration of chemicals over time. One of the mitigation measures is to reduce the amount of time the food is stored in order to limit the amount of chemical transfer. Furthermore, compact packaging structures, characterized by a high surface-to-volume ratio, are predisposed to heightened migration levels, prompting the suggestion to refrain from manufacturing small packaging items for use as food contact materials. Particularly, for foods with fatty or acidic attributes, the adoption of inert containers is advisable, given the propensity for chemicals to migrate more extensively under such conditions. These considerations underscore the need for careful assessment and design considerations in the utilization of recycled plastics for food contact materials to ensure the preservation of food safety and regulatory compliance. Welle (2023) stated that low

temperatures minimizes the migrated amount of post-consumer substances into packaged food. Thus recycled polymers are mostly suitable to produce packaging films for frozen foods.

Employing a stratified approach by incorporating insulating layers of both virgin and recycled plastics in the construction of multi-layered food packaging emerges as a practical strategy for creating food contact materials from recycled plastics (Franz et al.,2022). This design entails utilizing virgin plastics for the outer layers of the packaging, while the inner layers are composed of recycled plastics. By adopting this configuration, the migration of chemicals, a potential concern in food packaging, can be effectively mitigated. Franz (2022) stated that the outer layers, comprising virgin plastics, act as a barrier, preventing the migration of potentially harmful substances from the recycled plastic inner layers into the food. This dual-layered structure provides a safeguard against chemical interactions and ensures the integrity of the food contact materials. Consequently, this approach not only facilitates the utilization of recycled plastics in packaging but also addresses the critical issue of chemical migration, thereby enhancing the overall safety and viability of the packaging solution.

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8. Appendix

	Company A	Company B	Company C	Company D	Company E	Company F	Company G
Currently used polymers for food contact materials (types of polymers)	OPP, LDPE	PET for FCM, PS (not for FCM)	PP, Do not use recycled materials for food approved packages.	Recycled PET, recycled LDPE (but nowadays for rec. LDPE, waiting approval from EFSA.)	Recy. PET , near future, will switch to mono materials (only composed of single type of material	Plastic film made from LLDPE (linear low density poly ethylene , recycled PET	Recycled LDPE for freezer storage containers. (not currently)
Are your food contact materials compliant with all relevant food safety regulations and standards(FDA or EU standards, contact material legislation)	Yes	The material used is food approved & compliant with all regulations & standards that exists. Their supplier for foil is in EU area and follows all required regulations.	Yes	Yes	Yes	Yes	Yes

Have you conducted migration tests to confirm that no harmful substances leach into food products?	Yes	Material supplier do the tests	Yes, only for virgin plastics	Material supplier do the testing	Yes	Yes, foil supplier has compliant with that	Yes, material supplier has compliant with that.
Are you conducting an organoleptic testing of packaged foods in order to ensure their attributes like appearance, texture, taste, aroma has been preserved?	Yes	Material supplier do the tests	Yes, only for virgin plastics	Material supplier do the testing	Yes	Yes, foil supplier has compliant with that	Yes, material supplier has compliant with that.

What percentage of your food packaging materials is made from each polymers	30% of recycled content from its total weight	Only use recycled material	Zero as the material is too expensive. But our long term target is to achieve 80% of recycled material.	Up to 40% of recycled material in the foil. (Foil contains 3 different layers of PET. Recycled PET in the middle and virgin on top and bottom just to make sure that it is food approved.	Recycled PET – 90% PS- 50%	Up to 20%-30% recycled material. Sandwich method (rec. PET in the middle and virgin PET on top and bottom of it.	30% of recycled PET and recycled LDPE

Why have you chosen these types of polymers to manufacture food contact materials?(special reason behind the selection; mechanical stability, chemical stability, thermal stability, water resistance, alkaline or acid resistance, price, availability, some barrier properties)	Storage temperature , usage	Produce PET as it is easy to recycle. We recycle the scrap at our factory and send it back to the producer of foil and they make new foil from it.	Quality , price , availability	quality	Recycled PET – Quality Mono materials – easier to recycle, lower energy & resource consumption in the manufacturing process, reduced cost	Quality , easy to recycle, water resistance, price, availability, barrier properties	Alkaline and acid resistance, thermal stability, barrier properties
What types of food packages are you currently using (Laminated packages, metal foil)	Single film plastic, mostly window film in paper bags or bread bags in single OPP or PE	Only produce trays and lids in PET. We don't have any laminate foil. Laminated foil cannot be recycled.	Single film plastic	Plastic liners made from recycled PET, packaging film from recycled PET for frozen foods.	Recycled PET foils for direct food contact.	OPP packaging film	Recyclable multi layered film made from recycled PET and recycled LDPE (but currently not recycled LDPE)

How much polymers/ plastics are used to produce food contact materials on an annual basis?	Maximum 10 tons a year before the legislation of Commission Regulation (EU) 2020/1616	About 60 000 kg PET foil for food packaging during a year.	10 000 tons per year	Approximately 5000-6000 tons per year	Not given	Not given	Nearly 4000 tons per year