

Recyclability by Design for Multilayer Plastic Flexible Packaging

A comparative study of recyclability by design guidelines and alignment among various stakeholders

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Abstract

Various recyclability by design (RBD) guidelines for multilayer plastic flexible packaging (MPFP) were assessed for consistency among parameter values. 9% consistency was observed, which is on the lower end of devised consistency scale. Poly-ethylene and poly-propylene are the two major emerging recycling streams in Danone Nutricia's six key EU market countries. However, a need for consolidated centralized sorting and recycling data at EU level was identified as one of the major hinderance in designing and development of effective recyclable MPFP. Among the countries assessed for recycling efficiency, France was found to be the least MPFP recycling efficient country whereas The Netherlands is the most efficient. A lack of information exchange and collaboration among various stakeholders was also revealed, especially among brands and recyclers. At consumers end, a sense of responsibility towards plastic waste segregation was observed, however a lack of understanding about recyclable MPFP was also revealed through consumer survey. This factor been identified as a marketing opportunity. Majority stakeholders have a gravitation towards mono-material MPFP for recyclable design. This gives an insight into the future of MPFP, its design and recyclability in EU. However, barrier related issues are evident with mono-material MPFP that needs to be taken into consideration. A lack of consideration was observed among stakeholders regarding solvent based MPFP recycling technologies whose categories in mechanical recycling is still a gray area. Mono-material based MPFP is currently more cost intensive than conventional MPFP, hence a comparison in terms of cost, LCA as well as performance is a future study recommendation to assess the viability of both types.

Keywords: Recyclability by design, multilayer flexible packaging, PE, PP, plastic recycling, circular plastic economy

Executive Summary

Introduction

The year 2018 marked an important paradigm shift in plastic packaging industry. The ban on plastic waste import for recycling by China, forced western world to find plastic recycling solutions in a short time. PET, glass and paper industries are relatively developed packaging recycling industries when compared to multilayer flexible plastics. Multilayer plastic flexible packaging (MPFP) type has proven to be one of the most challenging for recycling due to lack of structural standardization, centralized data and clear regulations. The study evaluates the current state of MPFP packaging recyclability by assessing most trusted recyclability by design (RBD) guidelines by comparing them against the sorting and recycling ground realities in EU. ‘Recyclable by Design’ can be interpreted as design of a packaging that fits the sorting and recycling stream in a region. Hence, RBD guidelines are set of instructions for a packaging design that enables it recyclability as per current state of recycling or make it future recycle ready. Various stakeholders like packaging developers, suppliers, recyclers and consumers play important role in MPFP value chain (especially at end of life stage) and hence their views on the topic are important to assess. Current sorting and recycling technologies cannot process MPFP due to non-standardized design parameters like additives, multi-layers materials, barrier layers, etc., which might not be compatible with existing recycling streams and may pollute them on entering. The study explores current state of MPFP recyclability by assessing different guidelines, views of stakeholders and state of sorting and recycling of MPFPs in Danone Nutricia’s major EU market countries. Conclusions are then drawn based on the analysis, about the ideal MPFP structure, brand and producer responsibility as well as recommendations for recyclable MPFP design and future research.

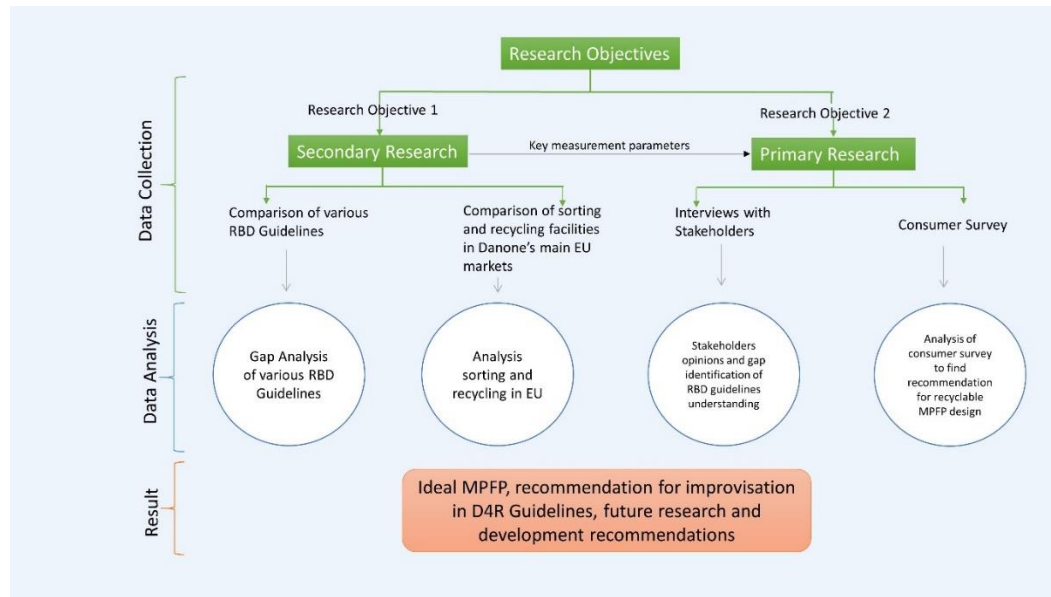
Research Objectives (RO)

RO1: To compare recyclability by design guidelines and sorting and recycling operations with the aim of contributing to Danone’s D4R guideline.

RO2: To compare alignment of thought with respect to current RBD guidelines for MPFP among stakeholders using qualitative and quantitative data with the aim of exposing the factors that hinders effective recyclable MPFP development.

Methodology

The data collection was divided into two parts based on research objectives. RO1 corresponds to secondary data collection i.e. data collected via online research of reports, studies and research journals. RO2 corresponds to primary data collection i.e. data collected directly by author via interviews and online consumer survey. Each RO corresponds further to two data collection steps, which are analyzed separately and eventually devises four analysis. Finally, the result is derived in the form of a recommended RBD guideline, recommendations for improvements in Danone's internal design guideline (D4R) as well as suggestions for future research.



Results and Discussions

The result of the study suggests the scope of improvement in Danone's D4R guideline for MPFP design could be introduction of sub-parameters and specifications for coatings and barriers, additives and labels. A need for consolidated data for MPFP recycling and sorting at EU level was identified. Integration of life cycle assessment tools in D4R guideline (or vice versa) was also stated as one of the scopes. Finally, a need for categorization of all the design data corresponding to each EU market country was identified as one of the major scopes of improvement for D4R. A comparison of various RBD guidelines revealed lack of harmony and missing information in suggested design parameters. This is true for more specific parameters whose percentage use are smaller in MPFP design. Since brands generally refer to these guidelines for developing in-house design guideline, a non-unanimous behavior can cause confusion for a packaging designer/developer and may not present a clear data. All the guidelines that were assessed showed incomplete information for one or other parameter and sub-parameters.

An analysis of sorting and recycling data in Danone Nutricia's major EU markets revealed that poly-ethylene (PE) and poly-propylene (PP) are major developing plastic recycling streams. This information also gives a course about the material MPFP design should aim for, as per the plastic stream in a country. Among the countries that were compared for recycling efficiency, France, though has developing PE recycling stream, is found to be the least recycling efficient, whereas The Netherlands is the most recycling efficient country. The qualitative research (stakeholder interview and consumer online survey) revealed a lack of information exchange among brands, packaging suppliers and recyclers as a major factor for non-recyclable design of current MPFP, which is multi-material layers packaging and generally have a metal barrier for high performance and food safety assurance. 16 stakeholders were interviewed, out of which 70% agreed that metallized layer and a non-uniform material structure should be changed to a non-metallized version with mono-material structure.

One recycler have tested mono-material (PE based) MPFP to be 100% recyclable. However, currently available mono-material (mostly PE and PP based) MPFPs have lower barrier and machine performance than their metallized counterparts. Another differentiating factor is the price. Mono-material based MPFP has a higher raw material cost than conventional MPFP as the technological development of barriers is still at nascent stage. Some stakeholders have argued that the primary purpose of a packaging is to ensure quality and safety of food which is questionable with mono-material based MPFP. Corresponding to this, two chemical based solvent recycling technologies (categorization as chemical recycling is arguable) have successfully recycled post-consumer MPFP with food grade quality and without deteriorating the structural integrity of the polymer. These recycling technologies fulfills the criteria for plastic circular economy but weather it fits the definition can be argued. The online consumer survey revealed that consumers do their part in segregating the MPFP plastic, however, majority thinks that the conventional MPFP is recyclable. Some readers may argue that the ignorance on consumers part does not impact MPFP recyclability, but the consumer awareness have ability to change plastic policies and brand profitability.

Conclusions

A MPFP design guideline with sub-categories for the percentage (amount per gram), recommended value and to avoid values have potential to add clarity for a packaging developer/designer. A strong need of collaboration with recyclers has been identified as a major factor for future recyclable MPFP since recyclers are involved in the ground work. This could be in the form of recycling tests for the MPFP at concept stage. Mono-material packaging based on PE or PP has been identified to be a focus material that has potential to be 100% recyclable in Danone's major EU market. Hence, it is safe to assume that the MPFP packaging portfolio in Early Life Nutrition can focus on PE or PP material to meet their 2025 goal of 100% recyclable packaging.

Recommendation for further research

- LCA comparison of conventional metallized MPFP and mono-material based MPFP in various Danone Nutricia's market can add value to the current research.
- A barrier performance comparison study in tropical vs temperate climate can reveal viability of future implementation of mono-material in Danone Nutricia's Asian market.
- Comparison of environmental footprint of mechanical recycling of mono-material MPFP with 'Newcycling' or 'Creasolv' recycling of metallized (conventional) MPFP.

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Completion of this thesis marks a milestone in my decade long journey of learnings in the field of food technology, science, innovation, teaching and research. Before choosing Lund University for specialization in Food Packaging Design and Logistics in LU Sweden, I considered my educational journey in Food Innovation incomplete. To realize this last mile in my academic voyage, Katrin Molin-Besch, Erik Andersson and Jenny Schelin have played a vital role of mentors, confidants and role models. Thank you for shaping my life and preparing me well for a new direction in my career.

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List of acronyms and abbreviations

AlOx	Aluminum Di-Oxide
APPR	Association of Post-Consumer Plastic Recycling
CEFLEX	Circular Economy for Flexible Packaging
D4R	Design for Recyclability
ELN	Early Life Nutrition
ERP	Extended Producers Responsibility
EU	European Union
EVOH	Ethylene Vinyl Alcohol
FFRG	The Flexible Films Recycling Group
FMCG	Fast Moving Consumer Goods
FPA	Flexible Packaging Association
HDPE	High Density Poly Ethylene
KPM	Key Measurement Parameter
LCA	Life Cycle Assessment
LDPE	Low Density Poly Ethylene
MPF	Multilayer Plastic Flexible
MPFP	Multilayer Plastic Flexible Packaging
MRF	Material Recovery Facility
MRF	Material Recovery Facility
MTB	Mechanical Biological Treatment
NIR	Near Infra-Red
PA	Poly Amide
PD	Packaging Developer
PE	Poly Ethylene
PET	Poly Ethylene Terephthalate
PO	Poly Olefin
PP	Poly Propylene
RBD	Recyclable by design
SiOx	Silicon Di-Oxide

1 Introduction

This chapter introduces the outline of the study conducted in Danone Nutricia Research along with the goals and purpose. This part also states the purpose and defines major research objectives that will benefit the baby nutrition packaging industry and academic multilayer plastic flexible packaging (MPFP) research. This section ends with stating the delimitations of this project.

1.1 Report Outline

This report begins with an overview of current global plastic problem and Danone's long term commitment to make all its packaging recyclable by design by 2025, as a solution. This study however will focus on one of Danone Nutricia's major packaging portfolio type – MPFP, through case of a baby cereal product packaging innovation project example. The introduction of project is followed by exploring the concept of Recyclability by Design (RBD), MPFP as a bigger challenge for recycling, current sorting and recycling scenario of Danone Nutricia's European market and changing trends in recycling. The theory also throws a light on changing consumer behavior towards plastics packaging. This is followed by the methodology, results and discussions and subsequently conclusion and recommendations of future.

1.2 Background

The background of the study can be justified by the current plastic related challenges, especially marine pollution and garbage clusters in oceans. This has encouraged various brands to pledge to change their packaging policies for instance, Danone's packaging policy states making all of their packaging 100% reusable, recyclable or compostable by 2025. Since 2018, concept of recyclability by design has also gained traction.

1.2.1 Plastic problem

Plastic in many ways has become one of the major drivers of 21st century economy. Low cost and unparalleled functional properties has increased its consumption multiple folds in past few decades. While plastic has been playing an imperative role in our lives, its linear economy chain and disposable characteristic has been an overwhelming drawback for environment, especially the oceans in recent times. As of 2017, only 14% of total plastic produced globally is collected for recycling, which is a loss of approximately 100 Billion Euro economic opportunity every year (eea.europe.eu, 2020). National Geographic states that 'We made plastic. We depend on it. Now we are drowning in it' (Nationalgeographic.com, 2020). This is a powerful message and it can be interpreted as the harm being done to ecology. Ellen McArthur's executive summary on New Plastic's Economy 2019 progress report (New Plastics Economy - The Future Of Plastics - New Plastics Economy (en-GB), 2020) states that no change in current rate of dealing with plastic waste can lead more plastics in ocean than fish (by weight) by 2050. This is a significant statement from an organization that is driving innovation strategies in tackling the

plastic waste problem. But one may ask, why the plastic waste problem and finding the solutions for it has gained traction only in recent years? Why didn't we see plastic pollution as a problem earlier? The answer may lie in the January of 2018, when China enacted a policy of banning import of plastic waste from western world. Being the largest importer of plastic waste and major recycling industry till 2018, China's decision had a huge impact on plastic waste management systems worldwide (Huang et al., 2020). This action shook up plastic packaging industry worldwide. This incident corresponded with emerging pictures of plastic straw stuck in sea turtle's nostril, fishes stomach filled with plastic bags and other graphic marine lives entangled in something or the other, made of plastic. The pictures drew huge consumer attention and opposition towards marine plastic pollution. As a result, an immediate need of producer's responsibility emerged among brands. This change has been a background of current panic in plastic industry and recycling organizations around the world. Plastic packaging has been gaining notoriety when images of marine life stuck in plastic are circulated around social media or a brand image is associated with littering. More and more consumers are looking for sustainable lifestyle in recent years and being plastic free is becoming a part of it (Townsend S., 2018). A consistent growth is being observed in sustainable packaging market which is evident from a google trend analysis. Figure 1. is a google trends result for the word 'sustainable packaging' worldwide for past five years (2014-2020). As evident from the figure 1, a consistent growth can be observed with an increase of 150% internet search for the word 'sustainable packaging' between 2014 and 2019.



Figure 1. A worldwide google trend graph for the word 'sustainable packaging' from year 2014-2019 (Google Trends, 2020)

A quick look in the supermarket shelves, compared to few years ago, reveals a shift towards paper or paper looking packaging for the products earlier packed in MPFP. This is either in the form of paper coatings over poly-ethylene terephthalate (PET) or sometimes a matt finish over an MPFP. This is due to the notion among consumers that paper is a better alternative material than plastic for recycling. But what if the most lightweight, low carbon footprint and functional and yet non-recyclable plastic packaging can be made recyclable? It will not only solve the ocean pollution crises but may also help in changing the consumer perception towards plastic packaging. MPFP, single use plastic and other types of plastic based flexibles are most popular type of packaging due to their low cost, especially in

Asia but is also highly unmanaged in terms of waste due to its lower collection, sorting and recycling rates. (Ritchie and Roser, 2020). However, when it comes to recycling plastic packaging (all types) Europe is not the greatest example but is still ahead than most countries worldwide and is moving fast in the right direction. Figure 2. depicts the increase in plastic packaging collection and recycling rates in Europe over a span of 10 years.

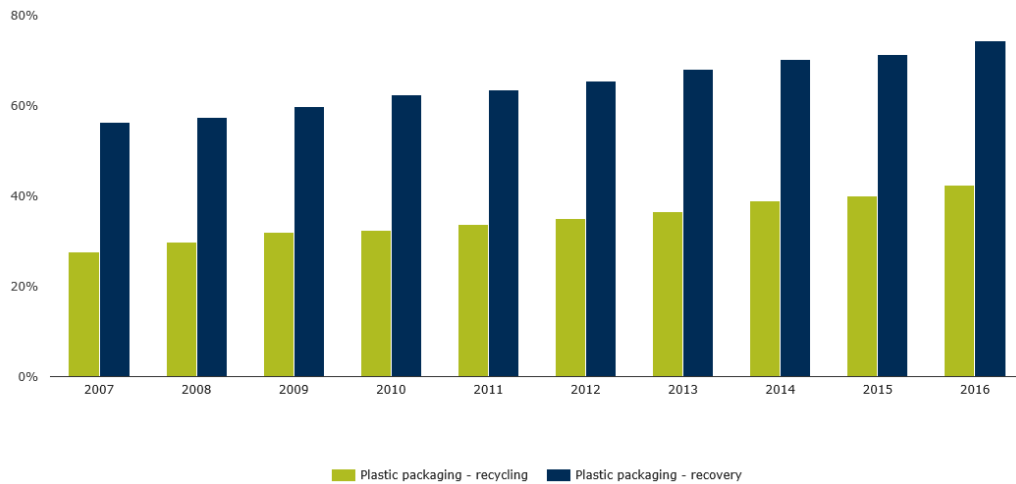


Figure 2. Plastic Packaging Recycling and Recovery, EU 28 (Eurostat.2020)

With an economically rising global population, the extent of packaging waste will surge dramatically, both in terms of volume as well as value. The European Commission has estimated that 5.25 billion euro worth of recyclable materials (including plastics) is sent to landfills every year in Europe (Kliaugaitė, 2013). For plastic packaging, an estimate of 8 million tones is landfilled per annum (PlasticsEurope, 2015).

Keeping in view the current expectations of consumers, what can be done to make MPFP more recyclable? What are the current challenges blocking the path of MPFP to becoming sustainable?; This study aims to answer these questions through a case of the MPFP packaging development project in Danone Nutricia Research, Utrecht. Figure 3. Represents a funnel approach to the study.

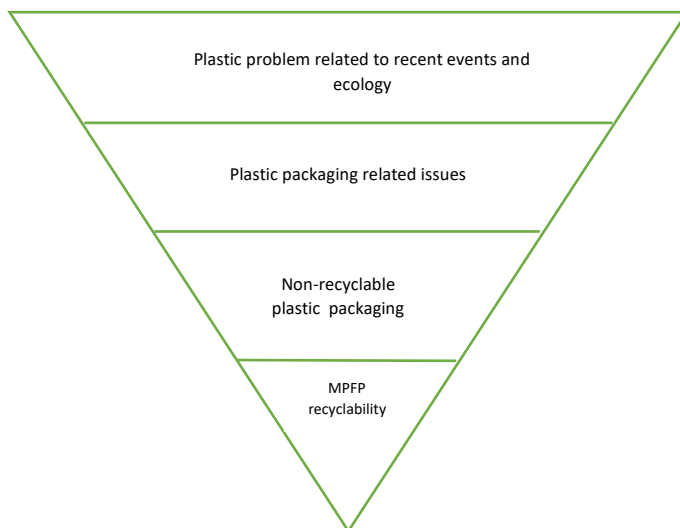


Figure.3. Funnel approach to MPFP recyclability problem as a part of current plastic problem

1.1.2 Danone's 2025 Sustainable Packaging Overview

In October 2018, Danone released its packaging policy of “accelerating the transition towards the circular economy”. It states the need to move away from conventional packaging systems that are unsustainable and the action plan to make all of its packaging circular by 2025. ‘Circular’ here means 100% recyclable, reusable or compostable packaging (see Fig.4.) As of 2017, 77% of Danone’s total plastic packaging is either reusable, recyclable or compostable. Currently, the MPFP portfolio of Danone’s early life nutrition (ELN) is not recyclable and as a part of extended producer’s responsibility (ERP), Danone aims to extend accountability to post consumer stage of product’s life cycle. In 2019, the percentage of the packaging from recycled material went up to 30% from 27% in previous years due to Danone’s commitment towards a sustainable future for its packaging. In its integrated report summary, Danone defines five major goals that will drive innovation in packaging development projects-

- a. Optimization of weight and movement towards 100% circular design,
- b. Zero plastics to landfill from industrial waste,
- c. innovation to ease the life of consumers and engage them to sort and recycle,
- d. use sustainable resources and
- e. create second life for all its plastic packaging. (Danone, 2018)



Figure.4. Danone's guiding principle for 100% circular economy

As a part of short-term strategy of Danone’s sustainable packaging policy is to collaborate with organizations like Loop, Terracycle, Ellas’s UK and Renew Ocean to either handle the waste and recycle it or promote refilling of its products. A very good example is collaboration of Danone’s baby food brand olvarit with an organization called Terracycle. Terracycle collects Olvarit baby food MPFP pouches and turn them into reusable spoons (Figure 5).



Figure.5. Danone’s collaboration with teracycle to convert discarded olvarit pouches to reusable spoons (internal report)

Danone’s internal packaging design guidelines like Design for Recyclability or ‘D4R’ and packaging eco-design life cycle assessment (LCA) software ‘Peter’ are the two most commonly used tools to design a recyclable package and assess its carbon footprint as per current sorting and recycling technologies in most market countries. D4R guidelines will be discussed in subsequent sections. Innovating and re-designing the MPFP to be recyclable has been identified as one of challenging and priority project in Danone. Henceforth, this study aims to contribute towards the bigger packaging innovation goal.

1.1.3 MPFP in Early Life Nutrition Portfolio

Early Life Nutrition (ELN) segment of Danone Nutricia Research’s business makes baby nutrition products. Figure 6 represents the portfolio of types of packaging designs in ELN segment. Out of 14 packaging types, 4 are MPFPs. The range of products packed in MPFPs varies from soft pastes, cereals, milk powders and other powder product variations. As of 2020, none of the MPFPs in ELN is recyclable by design but development of recyclable packaging is an urgent target for Danone Nutricia to achieve.

1. Can 	2. Bag in Box (Flexible) 	3. Sachet (Flexible) 	4. Pouch (Flexible) 	5. Bowl 	6. Cup 	7. Stick (flexible) 
8. Eazy Pack 	9. JewelBox 	10. Stand Alone Pouch (Flexible) 	11. Bottle 	12. Jar 	13. Plastic plate 	14. Brick 

Figure 6. Early Life Nutrition packaging portfolio of Danone Nutricia Research

This study will evaluate the root cause of the challenges associated with designing a recyclable MPFP packaging from various stakeholders’ perspective, current sorting and recycling condition in Danone’s EU Market and future trends. The study inspires to find answers to the non-recyclability issue of MPFP and is motivated by the case of project ‘Green D.’

1.1.4 Project ‘Green D’

In the term ‘Green D’, ‘green’ stands for sustainable and ‘D’ stands for doypack – an industry name for stand-alone pouch with a zip for resealability function (Figure 7). Green D is a sub-project of a larger project called ‘Waffle’, which is a long-term project that aims to convert all the current MPFPs to a recyclable format. The doypack is a primary type packaging and made of Polyolefin (PO) with a barrier film. This combination of materials, makes the current packaging unidentifiable by

existing sorting and recycling systems, sending it to an incinerator or a landfill. The aim of 'Green D' project is to find a recyclable material keeping technological challenges and cost in scope and re-design the packaging to make it 100% recyclable. The current packaging aims to be available in EU market by end of 2021. In brief, the purpose of this study is to present the case of "Green-D" project as challenges associated with application of principle of recyclability by design for a MPFP.



Figure 7. The type of packaging that is referred as 'doypack' in Danone's ELN portfolio.

1.1.5 Concept of Recyclability by Design (RBD)

'Recyclability by design' or 'design for recycling' is an eco-design strategy which is an approach for designing environmental friendly products or in this study an ecofriendly packaging. For a brand that aims to reduce its environmental footprint, the first stage is to review all the process leading to design of the product to find the ambiguities in design. Several strategies can be adopted to make a design recyclable i.e. material choice, material quantity, improvement in process technology, optimization of life cycle or end-of-life usage. (Worrell and Reuter, 2014). European waste framework directive 2008/98/EC that suggests waste hierarchy of reduce, reuse, recycle, recovery and lastly landfill as the steps to follow when designing a product or packaging. The aim of the directive is to lower the amount of waste produced as top priority, followed by using the material repeatedly and safe disposal as a last option. For Danone, the RBD concept is a business designation for their packaging policy. RBD aims to innovate recyclable ready packaging with incremental changes of current packaging solutions and new packaging development that might be implemented in future. (Ferrandiz, 2018)

1.3 Project Purpose and Research Objectives

Our society today is facing immense waste management crises. Pictures of plastic covered beaches in South East Asia, choked up rivers in developing countries, news of plastic bags being recovered from deep points in oceans and sea life crumbled in plastic are a common now a days. This unsettling scenario has developed aversion among consumers towards plastic usage and is pushing them to adapt a lifestyle that can avoid these instances in future. MPFP being one of the cheapest and most functional form of packaging is a popular choice among food producers as well as consumers, especially in growing economies where the rising middle class can afford branded products in smaller quantities without paying the premium. But the environmental pollution due to MPFP is especially evident in developing economies, where the small MPFP satches escape and leach in environment. The reasons are – irresponsible import of plastic waste by SEA countries from developed economies for recycling and then not recycling it, lack of local waste collection systems and littering behavior of general population. However, developed economies like EU are also not currently advanced in recycling of MPFPs. As a packaging developer, the producers can mitigate this problem, at least in EU for time being, where the sorting and recycling capabilities are higher than rest of the world. This leads to the purpose of this study, defined as follows:

To identify loopholes in understanding of recyclability by design principles among various actors involved in value chain of MPFP with the aim of optimizing similar projects in future. To further define and explore the purpose of the project two major research objectives have been identified.

Research Objective 1

Since the import ban of plastic waste to China from western countries, multiple plastic packaging design guidelines have emerged in Europe and North America. These guidelines aim to assist the producers (packaging companies and fast-moving consumer goods (FMCG) companies) in coherent development of recyclable plastic packaging. However, majority of the guidelines are nascent, do not rely on tested data, in-consistent and non-specific in nature. Multiple FMCG companies refer to these guidelines when developing internal guidelines for their packaging development process, for instance, Danone's recyclable packaging development guideline (D4R) refers to Plastic Recyclers Europe, RECOUP, CITEO etc. The question that arises here is how specific are these guidelines? Are they in harmonization with current collection, sorting and recycling technologies? Where are the gaps? To answer these questions, as a part of purpose of the project, research objective (RO) 1, can be defined as follows:

RO1: To compare recyclability by design guidelines and sorting and recycling operations with the aim of contributing to Danone's D4R guideline.

This objective will support in understanding the current state of agreement among various RBD guidelines for plastic packaging. This objective will help in and detect the loopholes in current guidelines by comparison with existing plastic sorting and recycling infrastructure in Danone Nutricia's EU markets. The outcome of this objective also aims to contribute specific knowledge towards Danone's D4R guidelines as well future MPFP RBD projects. Lastly, this objective aims to develop a more comprehensive and specific guideline for recyclable MPFP.

Research Objective 2

Designing a successful recyclable packaging comprises of taking into account the factors that may affect its recyclability at various points in the value chain during its life cycle. The stakeholders in a MPFP value chain are film producer, convertor, packaging developer, designer, recycler, consumer etc. These stakeholders influence the success of close loop recycling of MPFP. Therefore, it is imperative to factor in their perspective and current position on MPFP RBD process and closed loop recycling. This exercise will help in determining the gap in comprehension of RBD principles, improvement in current guidelines and designing a recyclable Green D packaging. Correspondingly, research objective 2 has been is as follows:

RO2: To compare alignment of thought with respect to current RBD guidelines for MPFP among stakeholders using qualitative and quantitative data with the aim of exposing the factors that hinders effective recyclable MPFP packaging development.

This objective aims to ease the future development process of RBD MPFP, give a comprehensive recyclable MPFP guideline recommendation and design a recyclable Green D doypack.

1.4 Delimitations

The study report will not cover the following topics: secondary and tertiary packaging, semi-rigid and rigid packaging, industrial and commercial plastic waste, other packaging materials such as glass, steel, paperboard, paper, bioplastics and bio-degradable packaging process and equipment design solution, generation of LCA data. One of the delimitation of the study has been about choice of RBD guidelines to study the comparison. Several local RBD guidelines which might have been more suitable for the analysis have not been taken into consideration due to their non-availability in English language. The assessment of cost of any RBD packaging is also out of scope of this study.

As I write this study report in the first half of year 2020, the world has been struck with COVID- 19, with no clear direction for future. Like major packaging innovation projects in Danone Nutricia Research, current project has had a minor negative impact on the communication and data collection process. The scope of the study was also to include packaging tests as well as pilot plant trial data. The consumer tests that were originally planned to be a focus group study of product users had been replaced by a simplified online survey to obtain basic insights about consumer behavior towards MPFP recycling. Reaching some stakeholders like suppliers and recyclers have also been a challenge due to increased demand in packaging material. However, all the efforts have been put in place to adapt the methodology to evolving conditions.

2 Theoretical Framework

This chapter forms background for the methodology, results, discussions and recommendations of the study. Beginning with the introduction of MPFP and associated challenges with its usage in current times is followed by brief overview of latest plastic sorting and recycling technologies that are widely used in EU. Later, the report explores the concept of recyclability by design via emergence of circular economy. The chapter ends with the current and future trends in MPFP design and recyclability.

2.1 Flexible Packaging

Flexible packaging, historically has been a paradigm shift for food industry. Its structure, shape, easy availability and multitudes of factors makes it one of the most widely used type of packaging. However, there are major challenges associated with its recyclability.

2.1.1 Brief history

The first flexible packaging was invented by a Swiss textile engineer, Jacques E. Brandenberger in 1908 in the form of cellophane, a thin transparent sheet made of cellulose. By 1912 he improvised the use of cellophane and sealable flexible film used in gas masks. The intellectual property to manufacture cellophane was then obtained by Du Pont, an American chemical company, which started refining the functionality and sealing properties of the film by using various coatings. Application of Polyvinylidene chloride (PVDC) is known to be a breakthrough in flexible films technology as it added the oxygen and moisture barrier to cellophane and this was the first barrier used in flexible packaging of food items. One of the major landmark in flexible film development was invention and refining of polyethylene and application as extruded flexible film. The first commercial production of polymerized bi-axially oriented poly propylene (BOPP) was introduced in 1960s by DuPont in USA. This was a significant development since 1970's marked the widespread use of flexible films like BOPP, PE and PET films in commercial food packaging and other applications. (Wagner, 2016). Figure 8 represents a brief timeline of history of plastic flexible development. Since 1970s, the usage of flexible films and multilayer flexible films for food packaging has revolutionized the food sector and played an important role in food security globally. (Wagner, 2016).

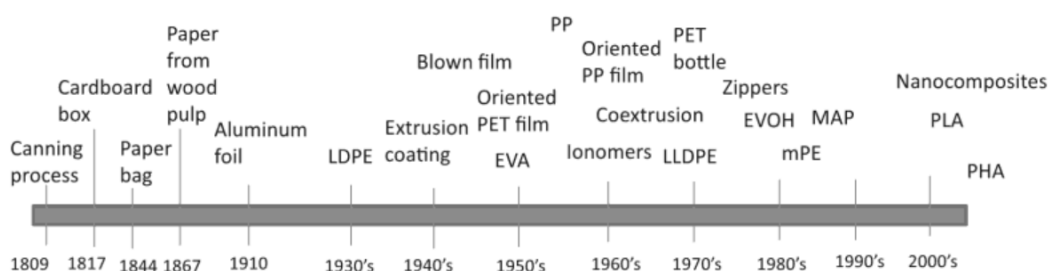


Figure 8. Milestones in flexible packaging history (Morris, 2017)

2.1.2 Structure

MPFP is combination of two or more polymer layers into a composite web that provides protective, functional and printing properties. This is either done through co-extrusion technology or lamination technology. Depending upon the type of application, different types of flexible films can be produced (figure 9). Multilayer films are known to use less material at source, have low cost and smaller carbon foot print during transportation when compared to heavier packaging. (Wagner, 2016).

Flexible packaging shape is not rigid but can be altered easily when filled with a product. Technically, flexible packaging can defined as a material with a thicknesses of up to 250 microns (American Plastics Council, 1996). The structure can be a simple film or multi-layer i.e. it combines thickness from 13 to 75 micrometers of different materials (Glenroy, 2016).

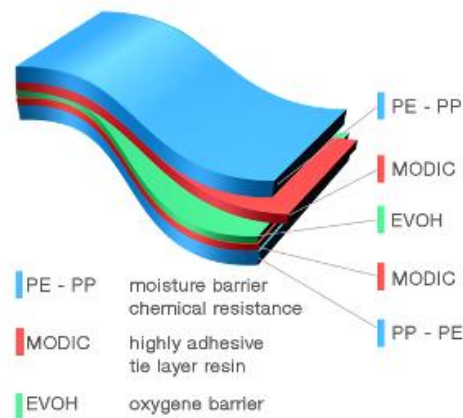


Figure.9 General illustration of structure of a multilayer flexible film commonly used for food packaging (Mcpp-global.com, n.d.)

In addition to reduction in carbon foot print, MPFPs have an advantage of higher product to packaging ratio when compared to other primary packaging. Generally, there are two type of multilayer packaging – supported and unsupported. Supported structure contain plastic and non-plastic layers like paper and aluminum foil, whereas unsupported structure only contains plastic layers with compatible barriers. Three types of MPFP layers, along with their functionality, as seen in Table 1. (plasticpackagingfacts.org, 2020).

Table.1. Functional Properties of the different layers in three layer multiple layer flexible packaging (plasticpackagingfacts.org, 2020)

Layer	Functional Properties	Examples
Exterior	Strength, heat resistance, packaging efficiency, printable surface	PE, PP
Middle	Protection from light, gases and odors	EVOH, Nylon, PVC, PE, PP

Internal	Flexibility, strength, product integrity	LDPE, LLDPE, EVA, PO plastomers, Ionomers
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Currently, no mandatory design standards for MPFPs exists in the EU and therefore the structure can vary from 3 layers to upto 9 layers and in some cases even more. However the material used for food packaging in flexibles is regulated by Regulation EC 1935/2004 of European Food Safety Authority. This legislation includes sub legislation Commission Regulation (EU) No. 10/2011, stating regulation for recycled materials (including recycled plastic packaging) intended to use as food contact material (Legislation - Food Safety - European Commission, n.d.). The composition of a MPFP layers can be identified by conducting polymer identification tests as per European Union Reference Laboratory (JRC Technical Report, 2016).

2.1.3 Market Significant

Though the consumer trend is growing in favor of a plastic free economy especially in Europe, however, multiple market research reports paints a different picture (Mintel, 2020). Global flexible packaging market is expected to cross 170 billion Euros by 2024, with a growth rate of 4% between 2019-2024. A UK based study has reported that plastic flexible films accounts for a total of 17% of total packaging industry globally. (Tartakowski, 2010)

The global volume of consumer flexible packaging is predicted to reach 33.5 million tonnes in 2022. By material segmentation poly ethylene (PE) is still a preferred choice and will remain so in coming years, followed by poly propylene (PP) and poly ethylene terephthalate (PET). Food industry constitutes more than 60% of demand for flexible packaging followed by pharmaceutical and beverage industry. A surge in demand of mini and micro packaging is gaining traction, especially in fast developing economies like China, India and south American. (Smithers Pira, 2017)

Even though the developed economies are trending towards circular and more responsible waste generation, growing economies are yet to catch-up on the trend. The rise of middle class ensures affordability of products which were earlier out of reach for instance ‘sachet’ packaging - a small MPFP packaging is very popular in south Asian countries due to affordability and convenience. It is also extremely hard to recover from environment if the post-consumer plastic is not managed properly. (Gone Adventurin, 2017)

Multiple market research company reports like Grandview Research, Markets and Markets, GM Insights, TechnoVario etc. have predicted a steady and continuous growth in flexible packaging market in coming years. As of April 2020, there are no published academic reports on effect of COVID-19 related situation of flexible packaging market, however, multiple news articles have reported a surge in demand of flexibles in China (Paige, 2020).

2.2 Sustainability of MPFPs

Flexible packaging association (FPA) states that MPFP allows for transport of a higher volume of product for less packaging material. This helps brands to reduce the investment in packaging and logistics owing to MPFPs low transportation cost. MPFP generates lower environmental impact than its rigid counterparts due to less occupation in landfills. For a MPFP stand-alone pouch, material to product ratio is 35 times higher than glass bottles with a metal caps and 21 times higher than aluminum can for same amount of product (see Figure 10). However, the lightweight nature and low cost have been the factors that complicates MPFP's recovery and recycling process. Low material thickness and bulk density causes technical issues like trouble with film layer separation during recycling process, rendering it un-economic to recover. Lighter weight and smaller sizes of MPFPs are separated out during trummel separation to ultimately land in an incinerator or landfill. (Niaounakis, 2020)

Therefore, by design flexible films (including MPFPs) are considered non-recyclable fraction of waste stream and thus sent to landfill or energy recovery (Flexpack.org, 2020).

Life cycle assessment (LCA) tools can also be employed to understand the impact of packaging on environment, but due to low sorting and recycling, few LCA

Beverage Packaging	Product Weight	Packaging Weight	Product-to-Packaging Ratio	Packaging Weight per 100 g Product	Energy Consumption MJ/8 oz	Emissions Kg CO ₂ e /8 oz
Glass Bottle & Metal Cap	8 ounces (236 g)	198.4 g	1:1	83.9 g	3.36	0.29
Plastic PET Bottle & Cap	8 ounces (236 g)	22.7 g	10:1	9.6 g	3.00	0.18
Aluminum Can	8 ounces (236 g)	11.3 g	21:1	4.7 g	0.99	0.08
Stand-up Flexible Pouch	6.75 ounces (199 g)	5.7 g	35:1	2.8 g	0.45	0.02

Figure. 10. Sustainability factors comparisons of various types of packaging (Flexible Packaging Association, n.d.)

studies have been conducted on multilayer plastic flexible (MPF). A study in 2011 was conducted to compare environmental impact of two packaging films composed of low density polyethylene (LDPE) and polyamide (PA) with thickness 70 microns and 90 microns respectively. It was concluded that plastic pellet production from virgin material had a higher environmental footprint than resource recovered material (Siracusa et al. 2011). Another study assessed the impact of several recycling stages like washing, sorting, shredding, extrusion and re-granulation for PE films and found out that extrusion stage has largest impact environmental footprint. Nonetheless, mechanical recycling still has much lower environmental footprint than producing and using virgin plastic for packaging (Gu et al., 2017).

Due to lack of MPFP design and composition standards, its structure can vary from 3 layer to 9 layers and is largely based on the type of product. Risk of biological contamination from food MPFPs in recycling streams makes it less likely for retail to have a deposit system in place for consumers like glass and pet bottles does. Consequently, collection is challenging due to lack of uniform end use market for recycled flexibles (Nonclercq, 2017). Sorting is another challenging facet, since too many resins makes it impossible to correctly identify resin composition and generally due to its lightweight, plastic flexible packaging end up in paper stream or contaminates other low density plastic streams. (Davis, 2015)

Organizations like Flexible Packaging Association (FPA), Circular Economy for Flexible Packaging (CEFLEX), Association of Postconsumer Plastic Recycler (APPR), RECOUP and The Flexible Film Recycling Group (FFRG) are consortium of academics, plastic companies and FMCGs, trying to develop uniform guidelines for recyclable design of flexible packaging. Relevant guidelines will be discussed in subsequent sections.

2.3 Recyclability of plastic based flexible packaging

As mentioned before, MPFPs are generally considered non-recyclable part of the waste plastic (especially post-consumer) stream and a contaminant for other plastic streams due to multi-material structure. In energy recover system, plastic waste is combusted and the energy is used up for electricity production with an efficiency of more than 90%. (Technical University of Denmark, n.d.). Flexible plastic waste is also commonly used in cement industry as a fuel source in many developing countries like India (Al-Salem et al., 2010). But since the definition of circular plastic economy, as will be discussed later, does not support incineration as a principle, energy recovery is not considered a positive usage of plastic waste. Flexible film waste can be of two types depending on its origin– ‘post-consumer waste’ and ‘industrial waste.’ Depending on the type of quality instream, both types of waste can be configured either closed loop or open loop when recycled using a mechanical process. Currently, post-consumer flexible packaging waste is either incinerated, landfilled or have very low open-loop recycling. Generally, the quality of recycled material from closed loop recycling is low, due to degraded structure of polymer as it goes through a number of processing steps like shredding, washing, drying and re-granulating, before co-extrusion. Closed-loop recycling process has high quality of uniform input stream and is generally just extruded before being used to produce packaging. Therefore, the polymer has better structural integrity than open-loop process. The input stream usually consists of uniform plastic but the amount of contaminants (additives, inks etc.) and dirt (organic waste, dust etc.) are higher in post-consumer flexible packaging. Among all the plastic film waste, post-consumer MPFPs are the most challenging to recycle mechanically due to non-standardized structural layers. Hence, post-consumer flexible waste is generally recycled chemically or used for energy recovery. Two main end uses for recycled plastic films are sheet production (43%) and composite lumbar production (44%). (Moore Recycling Associates Inc., 2017).

2.3.1 Market opportunity for mechanically recycled flexible packaging in EU

Nonclercq (2017) assessed the potential market opportunities for mechanically recycled flexible packaging for food contact applications as flexible packaging and rigid packaging and other applications. It was concluded that it is challenging to achieve high quality of recycled flexible from post-consumer waste. The second challenge is securing the supply of raw material. However, injection molded application of recycled flexibles into rigid plastic can be a major market opportunity for recycled flexibles.

Table 2. Summary of potential market opportunity for secondary recycled flexible material (Nonclercq, 2017).

Potential market	Go/No Go	Reasons
Food application → food application	No go	- Demanding food regulation - Barrier between food and recycled material?
Flexible packaging → flexible (packaging)	No go	- Quality issue: impossible to blow films - Cast film?
Flexible packaging → rigid packaging	Go	- Injection moulding applications - Mix with virgin RM
Flexible packaging → other applications	Go	- Downgrading: composite lumber, buckets

For secondary applications, India and Indonesia have been using the flexible packaging waste to build roads and tiles (Gone Adventure, 2017). Table 2 summarizes the potential markets for recycled flexibles.

2.3.2 Plastic flexible film collection and sorting technologies in European Union (EU)

In the EU, kerbside collection differs among member state with low level of uniformity. It varies from schemes like door-to-door collection, bring point, deposit and return system. Currently, France has the lowest gathering of lightweight plastic packaging whereas Austria and Germany has the most comprehensive systems in EU (AMEC and Axion Consulting, 2016). Table 3 summarizes the different collecting schemes of EU member state.

Table. 3 Waste collection schemes and programmes in European countries (Haig et al., 2012; Cimpan et al., 2015; Seyring et al., 2015)

Collection Type		Material	EU Countries	Film Collection
Door-to-door	Single Fraction	Plastic	Austria	Comingled flexible and rigid plastic collection
			Netherlands	Comingled flexible and rigid plastic collection
			Denmark	Not collected
	Co-mingled	Plastic and Metals	Latvia	Not collected
			Germany	Collected with mixed plastics
			France	Some collection with mixed plastics
			Italy	Rigid and film plastic is collected separately
			Hungary	Collected with mixed plastics
			Ireland	Collected with mixed recyclables
			Slovenia	Collected with mixed plastics
Bring Points	Single Fraction	Plastic	Sweden	Collected with mixed plastics
			Spain	Collected with mixed plastics
			Portugal	Collected with mixed plastics
Deposit and Return		Plastics	Netherland	Collected with mixed plastics
		Plastic and Metals	Norway	Collected with mixed plastics
		Plastic, metal and glass	Sweden	Collected with mixed plastics
			Denmark, Germany, Lithuania, Croatia, Estonia, Finland, Iceland	Collected with mixed plastics

Recycling of post-consumer MPFP is a challenging task. The key challenge is removal of contaminants like pigments used as pro-oxidants during film production and prodegeasants (specific types of toxic gases) produced at high temperatures during reprocessing of plastic films. Some of the recycled plastic material may carry a rancid odor. (Drobny, 2007)

Another issue pertains to generation of harmful volatiles from inks used in MPFPs that may end up in secondary reprocessed pellets. Hence, the recovered plastic is usually dark in color and used for lower grade product manufacturing. (Tartakowski, 2010)

The technology for sorting and recycling available in the material recovery facility (MRF) depends upon the type of input stream. Facilities that receives mixed waste

plastics are generally called Mechanical-Biological Treatments (MBT). In countries with advanced sorting facilities, it is carried out using equipment. For instance, tumble or trommel is used for size based sorting whereas magnets and eddy current (uses rotating magnets to remove non-ferrous from ferrous) are used to remove metal contaminants. As most of the flexible packaging is bags, bag-splitters can be employed to open and empty the bag off leftover foods (Haig et. al., 2012). Ballistic separator are used in next stage to separated three dimensional rigid packaging from lighter 2D packages like pouches. The 3D packs begin heavier are pushed down, whereas 2D packs being lighter are pushed to upper end of separator. Air separators are also used for same purpose. Induction sorters use metal detection mechanism and are effective at separating flexible films with metal layer (McKinlay and Morrish, 2016). Near Infra-Red (NIR) system is used after this to identify the type of plastic film through optical wavelength reflection mechanism. NIR though cannot sort films with either thin coatings (like PVdC) or black inked surfaces. Figure 11. is a simple flowchart depicting sorting mechanism for multilayer plastic flexible packaging from a mixed waste stream. Packaging with dimension smaller than 50-70 mm is generally sorted out in the size classification step sent to energy recovery plant. This can be considered the first path of flexible package leakage as smaller packaging like ketchup satches, chocolate wraps etc. are “lost”.

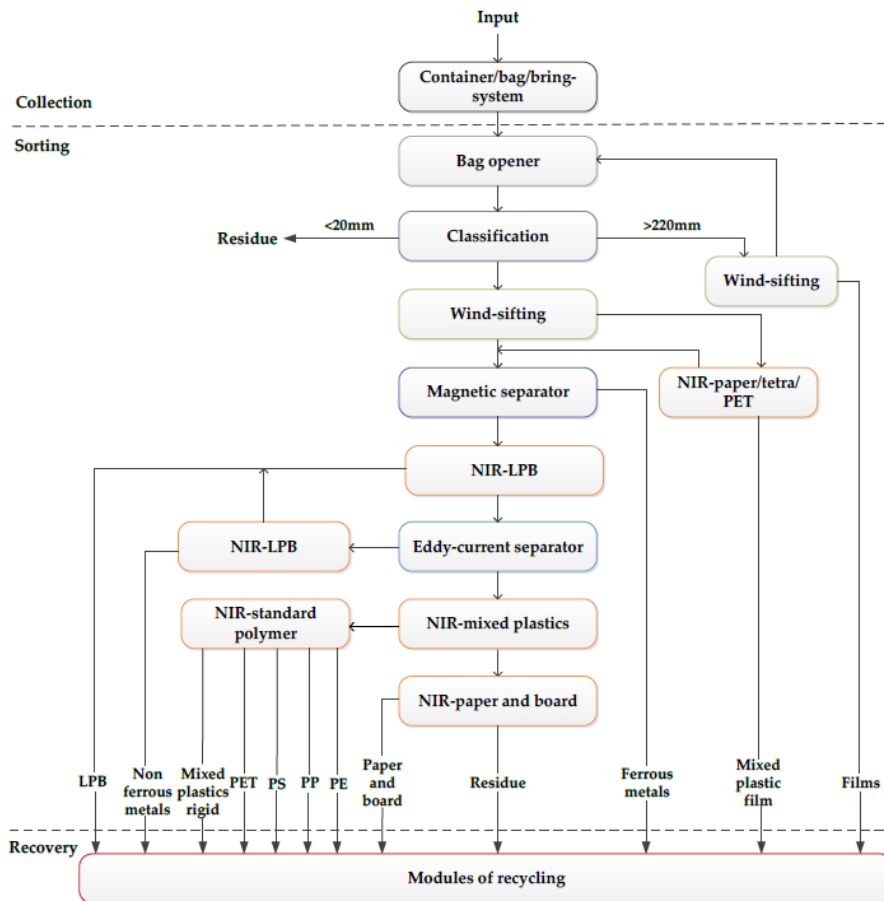


Figure 11. Simple flow chart depicting sorting process for multiplayer plastic flexible film in major EU countries ((Kaiser, Schmid and Schlummer, 2017)

During trommel separation, most light weight MPFPs are extracted from the input. The MPFP fraction containing metallized layer is unlikely to be extracted by eddy current sorting during the metal separation step. Multitudes of parameters influence the eddy current sorting, but it has been extensively reported that the comparatively low aluminum content along with the shape of MPFP prevents it from being separated. The ballistic separation is the ultimate point to isolate residual flexible packaging. It is typically collected with the 2D fraction which is sent to mixed plastics segment. Only a small portion might ultimately end up in the NIR sorting area, which would sort it according to the polymer type of the exposed surface layer visible to NIR and its camera. MPFP recycling demands sophisticated technology to achieve a superior quality downstream that has ability to preserve the mechanical properties of recycled molecule. (Parini, 2015).

2.3.3 Current recycling of MPFP

Compatibilization, delamination and dissolution are the three most widely used current recycling technologies to obtain quality recycled flexibles (including MPFPs in some facilities). Compatibilization is addition of specific additives based on the resin composition of film, in the film mixture during extrusion, to enhance the bonds between different polymers (Wyser et al. 2000). In delamination process, different layers of MPFP are separated by dissolving the adhesive using specific solvent (Favaro et al., 2013). Selective dissolution is another method used to dissolve and precipitate different layers of MPF. After dissolution, the polymer is separated using density difference as principle (Achilias et al., 2007). Table 4. Summarizes various types of recycling agents used using for various type of MPF packaging for mechanical recycling process.

Table 4. Use of recycling agents for MPFP recycling

Process	MPFP film structure	Recycling Components
Compatibilization	PP/PET/SiO _x	Maleic anhydride-grafted polypropylene
	Mix of PE, PA6 and PET	Oxazoline groups, ethylene/acrylic acid copolymer or block copolymer styrene-ethylene/butylene-styrene-grafted-succinic acid
	PET and HDPE Blends	Ethylene glycidyl methacrylate (EGMA) and styrene-ethylenebutylene-styrene grafted with maleic anhydride (SEBS-g-MA)
	PET and PE blends	EGMA and a copolymer of ethylene- α -olefin grafted with maleic anhydride (PE-g-MA)
Delamination	PE/Aluminum/PET	Acetone
	PET/whey protein/PE	Enzymatic detergents containing protease

	PET/EVOH/PE or PET/PE	Alkaline liquor
Dissolution-precipitation	PET/EVOH/PE	Xylene
	PET/PE	Mixture of alcohol with water
	LDPE Structures	Organic Solvents

Presence of inks on the surface of MPF packaging is one of the biggest hurdle in efficient recycling. De-inking processes like degassing and use of chemicals to remove the ink makes the end product loose its physical properties i.e. the polymer chemical bond strength decreases. Currently the technology for non-water based ink removal is not economical, hence most of the recycled MPFP is used for making low grade products like trash-bags, pipes, bags, lumbar etc. Compatibilization, delamination and dissolution are the key steps in current MPFP recycling technology but when viewed from lenses of circular economy (discussed in next section) fails to result in a positive business model and secure supply. (Gecol et al., 2001)

MPFP recycling is currently done at a small scale and not in a circular business model (discussed in next section) due to multiple factors like food contact material regulations restriction on usage of recycled plastic for direct contact with food products. However, emerging new technologies can scale up high quality mechanical recycling of MPFPs.

2.3.4 Emerging technologies for End of Life MPFP recycling

The recycling problem of MPFP waste can be approached from various viewpoints – increase in recycling rates, diversion of flexible packaging from landfills, creation of main stream recovery process, modification of existing sorting systems, designing the packaging recyclability as per existing recycling infrastructure, identification and generation of recycle end-use market (Agro Group International, Newark, 2019). Some of the emerging concepts, solutions and technologies pertaining to MPFPs are as follows:

2.3.4.1 CEFLEX project

CEFLEX is a collaborative consortium project of more than 150 companies and organization representing European flexible packaging value chain. Its aim is to make design of MPFP sustainable, economical and have an end-of-life value in a closed loop recycling, similar to PET bottles value chain. It also aims to increase European collection and recycling of flexibles and develop guidelines for recyclable design of the MPFPs. CEFLEX has developed guidelines for flexible packaging design to maximize collection, sorting and recycling within existing infrastructure. Additionally, a number of new opportunities have been identified to maximize resource efficiency and make recycled MPFPs profitable. CEFLEX ensures that flexible packaging recycle find sustainable end markets to replace virgin materials. (CEFLEX, 2020)

2.3.4.2 Development of single polymer barrier and pouch material

New cost effective mono-material (PO, PE or PP) replacements are being developed by many packaging companies, without a need for changing the

processing line. Many companies are also involved in store drop-off models to enhance collection of their mono-material pouches (Agro Group International, Newark, 2019). Australian packaging giant Amcor's "AmLite Ultra Recyclable" standalone MPFP is a metal free packaging that performs with high barrier (Amcor, 2020). B&K, a German packaging convertor also offers mono-material recyclable options for MPFP with a material recycling rates upto 80% (B&K, 2020). Canadian, Nova Chemicals "I-Beam" have expertise in high oxygen barrier manufacturing that is compatible with mono-material structures (NOVA Chemicals (International) S.A, 2020). Dow "RecycleReady" technology using HDPE and EVOH barrier offers a high stiffness that tear-resistant PET and PE structures (Dow Inc., 2020).

2.3.5.3 Compatibilizer development for recycling of MPFPs

Compatibilizers are molecules with different functional groups to aid recovery of non-compatible polymers in packaging film systems and mixed plastics. "Retain" technology from Dow Chemicals has manufactured a MPFP with PE-ethylene vinyl alcohol (EVOH) barrier compatible with PE layer and can be recycled in PE stream. Compatibilizer is incorporated into the PE layer which disperses EVOH in the PE during recycling and loses its ability of providing barrier. (Dow Inc., 2020)

2.3.5.4 Development of barrier coatings and Adhesives to replace polymer layers

Barrier layers and adhesives are one major challenge for recycling of MPFPs as they interfere with mechanical recycling. Silicone-di-Oxide (SiOx) and Aluminium-di-oxide (AlOx) are the two major types of barriers being used in MPFPs. Currently, light and mixed barriers with carbon-nanocoated PO and polyesters as well as PA are being developed. A good example is Amcor's "Ceramics" line (Amcor, 2020). Nano-clay composite-coated, acrylate-coated polymer films, nano-fibrillated and nanocrystalline cellulose coatings are being developed for recyclable MPFP (Cooper, T, 2019).

2.3.5.5 Selective Extraction Processes

As the name suggests, selective extraction refers to a process of targeting polymers selectively to dissolve from a mixture of different plastic molecules. APK AG "Newcycling" chemical dissolution as Fraunhofer's "CreaSolv" process has been front runners in selective extraction. Both the technologies use same principle of separate proprietary solvents to dissolve the target polymer. This step is followed by precipitation, removal of contamination, purification of extracted molecule and palletization for next use. (Fraunhofer IVV, 2020) (APK AG, 2020). The flow chart of the process can be found in appendix A. Selective extraction process is debated as a mechanical recycling process. Hindustan Uniliver Ltd. (Unilever India) has embraced the CreaSolv technology to tackle the 'satche' related waste generation in India (Hindustan Unilever, 2020).

2.3.5.6 Oxidative process for PE

Biocellation Inc, an USA based firm, has developed an oxidation process recycling for all kinds of PE molecules. This process takes shredded contaminated plastics as input, followed by selective oxidative decomposition of PE using catalyst. This converts plastic polymer into oligomers and dibasic acids. Dibasic acids are separated from catalysis, collected in a vessel and crystallized into solids.

(Innovation — BioCellection, 2020). The process flowchart can be found in appendix B.

2.3.5.7 Pyrolytic Process and Gasification

Pyrolytic and gasification process uses same principle of obtaining downstream chemical components from mixed waste flexible plastic. Controlled oxygen content or anaerobic thermal gasification is employed to produce smaller molecules. (Eniscuola, 2020)

Enval technology (see appendix C) is solution for recycling of plastic aluminum laminates using microwaves to induce pyrolysis. This process uses anaerobic microwaves to induce pyrolysis in shredded laminates over a carbon bed with a temperature of over 1000 °C to recover 100% clean aluminium. The plastic components are converted into fuel gas to power microwave and to alkane liquids that is used as diesel fuel. (Enval | Plastic aluminium laminate recycling, 2020)

2.3.5.8 Digimarc

‘Digimarc’ technology uses invisible to naked eye watermark on the plastic packaging that is easily identified by NIR or other optical auto identification technology for sorting into different streams in a recycling facility. Digimarcs facilitates consumer to find out right recycling bin for their packaging by pointing the packaging at camera for an interactive experience through the ‘invisible barcode.’ (Digimarc Barcode, 2020) This technology is currently at a trial stage with some of the major European food brands and Ellen MacArthur Foundation (BBC News, 2020).

2.4 Recyclability by Design

Recyclability of any object is not just dependent on the availability of a recycling stream for its material but also on its design. The principle of recyclability by design is core of circular plastic economy concept, which states the importance of holistic approach for a packaging design, keeping its whole value chain under view.

2.4.1 Circular Economy – Concept, need, emergence

Coining the term ‘circular economy’ and its concept is not attributed to a single author, rather it’s an amalgamation of notions from thought leaders from late 1970s onwards. Walter Stahel, an architect and industrial analyst, in 1976 coined the concept of ‘Performance economy’. In his report submitted to European commission, he envisioned economy in loops and its impact on waste prevention, job creation, economic competitiveness and resource saving. (The Product-Life Institute, n.d.). Later, German chemist Michael Braungart and American architect Bill McDonough developed the concept of ‘Cradle to Cradle’ in 1990s. The system focuses on achieving effectiveness through design, elimination of waste, power generation through renewable energy and efficiency through respecting natural systems. (Home - Cradle to Cradle Products Innovation Institute, n.d.).

‘Blue economy’, ‘Regenerative Design’, ‘Natural Capitalism’, ‘Industrial Ecology’ and ‘Bio-mimicry’ are sub-concepts of circular economy with a basis of three core meta principles- a. preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows by regenerating, virtualizing and exchanging; b. Optimizing resource yields by circulating products, components and materials in use at the highest utility at all times in both technical and biological cycles by regenerating, sharing, optimizing and looping; and c. foster system effectiveness by revealing and designing out negative externalities. In short, circular economy seeks to build capital by ensuring flows of goods and services in a sustainable manner that creates a value for each business. (Ellenmacarthurfoundation.org, 2020). Circular economy does not identify waste as waste, rather a useful input to generate the product in a circular feedback loop (Ellenmacarthurfoundation.org, 2020). ‘Repair-reuse-recycle’ has been a slogan from circular economy model released by European Parliament (European Parliament, n.d.).

An example of circular economy is business of ‘Loopstore’ that is built on idea of reusable packaging that aims to reduce the use of single use plastic. Loop provides home delivery of daily use items in reusable packaging that can be returned by partnering with major FMCG brands. Loop has optimized its supply chain and the LCA studies conducted in comparison to conventional retail store, shows a lower Global Warming potential (Loopstore.com, 2020). Ellen McArthur foundation has been a driving force in rethinking the world’s plastic problem. Its initiative of ‘New Plastic Economy’ is focused around ‘reuse and recycling’ of plastics as a core concept. Its report on reuse of plastics states the potential of recycled plastic as a \$150 Billion untapped industry. As part of the commitment towards circular economy, 400 major business including companies representing 20% of all plastic packaging produced globally, have signed commitment to make their plastic packaging ‘recyclable by design’ in coming years (Newplasticseconomy.org, 2020).

The New Plastic Economy report of 2016 suggests following steps to achieve a fully circular functioning plastic economy (appendix D):

- Creation of an effective after-use plastic economy
- Reduction of the leakage of plastics into natural systems
- Decoupling plastics from fossil feedstocks
- Establishment of global plastics protocol and Co-ordination of large scale pilots and demonstration projects
- Development of insights and building an economic and scientific evidence based recycling solutions
- Engagement of policymakers
- Co-ordination and communication among stakeholders.

New plastics economy concept encourages the closed loop mechanical recycling of plastics as shown in Figure 12.



Figure 12. Plastic packaging value chain in a circular economy (Newplasticseconomy, 2016)

‘Rethinking the case for plastics, starting with packaging’ is one of the initial steps to circular plastic economy and the concept of recyclability by design (RBD) is highly integrated into this idea. Currently, only 14% of the total plastics is recycled and 95% of the value of a plastic packaging is lost after one use. To sort this problem, designing the packaging that is for reuse or a higher value recyclability is one of the solutions. ‘Recyclability by design (RBD)’ defines concept of a packaging that is designed in synchronization with available recycling technologies, such that its 100% recyclable. A packaging designed using recyclability principles can be easily recycled and used in closed loop. For instance, a PET bottle with a high density poly ethylene (HDPE) cap and low density poly ethylene (LDPE) sleeve can be recyclable in one country, but may not be recyclable in other depending upon the plastic recycling technologies available locally. Hence, it is imperative to understand the market that packaging will cater to. The origins of the concept are unknown but it has been gaining momentum with introduction of circular economy in amalgamation with a paradigm shift of sustainable economy

Ellen McArthur's 'New Plastic Economy' chapter is solely dedicated to understanding the principles for a circular plastic economy and is a good source to understand recyclability by design concept. Nonetheless, there are several guidelines that are specific to type of packaging and material used, as will be discussed in next section.

2.4.2 'Recyclability by Design' Guidelines in Europe

Many countries in collaboration with academic institutes, brands and academia have released their own RBD guidelines (discussed in detail under results & discussion chapter) for plastic packaging design suited for local sorting and recycling technologies. 'RECOUP', a UK based guideline has been a front runner and one of the first detailed guideline for recyclable design for major kinds of plastic packaging, however, the guidelines are mostly material specific. European Union based 'CEFLEX' has specific guideline for MPFP and flexible packaging. Austria based 'Circular Packaging Design Guideline', Plastic Recyclers Europe's 'Design for recycling guidelines', and The Association of Plastic Recycler's APR 'Design Guide for Plastic Recyclability' are some of the most comprehensive guidelines for designing plastic recyclable packaging. These guidelines give design recommendations and material combinations that must be used for a circular and sustainable packaging that are either recycle ready or recyclable in future. For instance, 'Circular Packaging Design Guideline' from FH Campus Vienna, suggests following general recommendation for recyclable plastic packaging:

- Use the most common types of material (e.g. PO, PET)
- Only use new material if they are compatible with collection and recovery facilities.
- Avoid additives and high print ratio
- Choose transparent designs
- Use inks that will not contaminate recycling streams
- Avoid using smaller parts that can be removed by consumers

'CEFLEX', as mentioned earlier, is a collaborative initiative by consortium of major FMCG and plastic packaging European companies and research organizations representing value chain of flexible packaging (CEFLEX, 2019). CEFLEX aims to establish collection, sorting and reprocessing infrastructure for post-consumer flexible packaging in Europe by 2025. Figure 13. is brief description of key principle for recyclable design for flexible packaging.

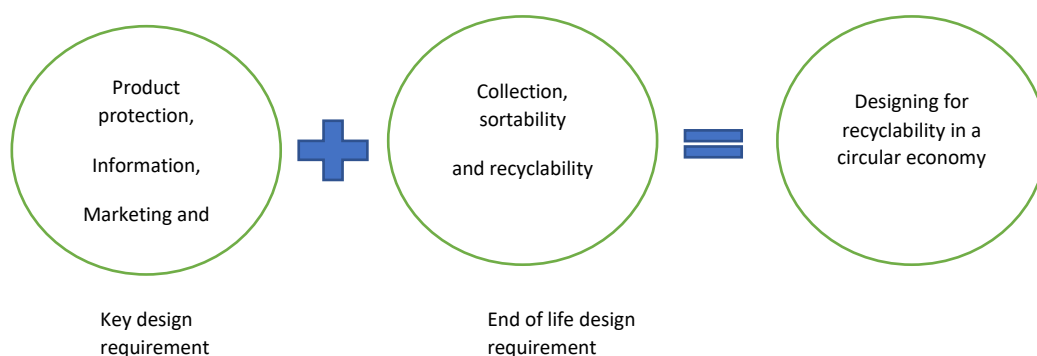


Figure. 13. Flexible packaging design requirement (CEFLEX, 2020)

CEFLEX's phase 1 guidelines (to be published in 2020) provide information of RBD for PO based structures that can be sorted and recycled using existing infrastructure and processes. As per the guidelines, PE based monomaterial flexible packaging is the most suitable material since recycling stream already exists in most European countries along with market application, followed by mono-PP streams and mixed PO streams. As per the guidelines, monomaterial is preferable choice and a flexible packaging can be called monomaterial only when more than 90% of it is monomaterial, as this kind of design will not affect the yield of recycling process. As of 2020, CEFLEX guidelines are the most comprehensive guidelines for MPFP recyclable packaging design.

3 Methodology

This chapter highlights the methodological tactic used for data collection to fulfill the purpose of the project along with data collection process and its motivation. The section begins with explanation of study approach, followed by data collection and ends with data analysis methodology.

3.1. Study Approach

The study approach has been developed by first identifying the major purpose. To achieve the purpose, two research objectives have been identified (see 1.3). The research objectives are fulfilled using primary and secondary data collection, which corresponds further to four types of data collection methods, as can be seen in figure 14. The data collections correspond to four data analysis, which eventually results in:

- Gaps in current RBD guidelines (which can be useful to clear confusion and see which parameters to pay attention to while MPFP development).
- Clarity about MPFP sorting and recycling situation in Danone's EU market, which will help packaging developers to cater the recyclable MPFP need of a particular market.
- Perspectives of various stakeholders about current scenario of MPFP development, recyclability, current and future trends. This will help in identification gaps with respect to understanding and preference of RBD guidelines and views about MPFPs future in EU.
- Lastly, the consumer survey is conducted to understand the consumer perception about recyclability of MPFP and how it can be communicated effectively to consumers.

Further, all the above analysis and results is used to develop an ideal MPFP recyclability by design guideline and to make recommendations for Danone's internal Design for Recyclability (D4R) guidelines.

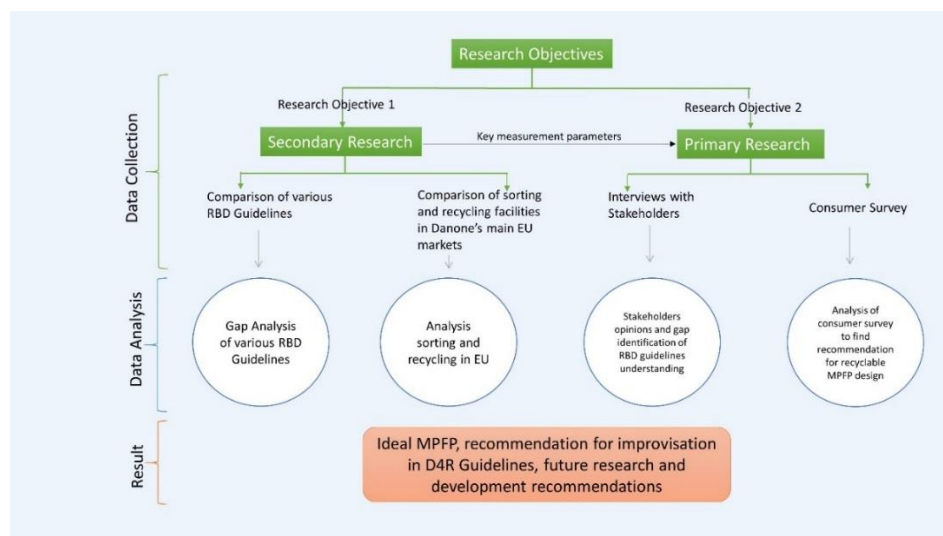


Figure 14. Study approach split into three parts – data collection, data analysis and result

3.2 Data Collection

Primary and secondary data have been collected in this study with the purpose of fulfilling the data collection needs to justify research objectives. The study started with collection of secondary data before primary data with the purpose of establishing key measurement parameters as depicted in figure 14.

3.2.1 Secondary Data

The research started with collection of secondary data for exploring research objective 1 which is associated with various recyclability by design guidelines. This data collection strategy was limited to internet research using various websites, RBD reports, academic journals and books.

3.2.1.1 RBD Guidelines data collection

Web screening was done to find out the relevant plastic packaging guidelines pertinent to Danone Nutricia's EU market and Nordic. Since very few guidelines are specific enough for MPFP design for recyclability, only 5 most comprehensive guidelines were chosen based on following criteria: a. the guidelines can be compared using same parameters, and b. the guidelines are applicable for MPFPs. The studies were compared on key measurement parameters (see 3.2.2.1) for most common recyclability by design parameters.

Danone's D4R guideline was also included as a part of comparison to understand its similarity or dis-similarity with the most relevant RBD guidelines. It is significant to understand the variance among different guidelines because multiple brands and researchers follow these guidelines to design recyclable packaging or develop brand's internal guideline. A low variation for the parameters reflects consensus among stakeholders, whereas a high variance reflects confusion and lack of clear guidance and a need for it thereof. Another purpose was to understand the scope of improvement in the D4R.

Following guidelines were chosen for comparative study:

- Danone's Design for Recycling (D4R)
- CEFLEX phase 1 guideline (unpublished)
- Plastic Recyclers Europe
- FH Campus Wein
- RECOUP UK
- Nordic Council of Ministers

It should be noted that all Nordic countries are not the part of EU or forms Danone Nutricia's major markets but since many countries like Sweden have a more established recycling regulations and uniformity, Nordic design guidelines form basis for an interesting comparison. It should also be noted that many well know plastic organizations have published recyclability by design guidelines for instance, Association of Plastic Recyclers have one of the most comprehensive guidelines but is material specific and hence cannot be used for comparison. Lastly, when this study was begun, United Kingdom was still a part of the EU and hence the study will consider data from The UK as a part of EU.

3.2.1.2 Sorting and Recycling in Danone's major EU market countries

The sorting and recycling data have been collected from Danone's internal research documents as well as web search. The sorting and recycling data are collected from following countries:

- United Kingdom
- France
- Spain
- Portugal
- Germany
- The Netherlands

Above six countries form the major markets of Danone in EU. This means that a single product is sold in these countries with the same packaging. In this study's case its 'Bledine' baby food product sold in same packaging format. Assessing the current situation of sorting and recycling of MPFP in these countries will help in understanding the need for modification in the packaging as well as assessing the current recycling streams for recyclability by design for MPFP packaging.

Following parameters were chosen to compare the sorting and recycling data:

- Collection of MPFP
- Sorting of MPFO
- Recycling rates
- Total plastic packaging recycling
- Total energy recovery
- Landfill
- Major sorting technologies employed

The above parameters were chosen primarily due to data availability for all the selected countries. The purpose of this data collection was to understand the gap between current recycling and sorting technologies employed and the RBD guidelines.

3.2.2 Primary Data

Primary data is reflective of research objective 2 which is related to understanding the agreement among various stakeholders involved in MPFP development project (many of whom are involved in Green-D project) regarding RBD principles. Primary data collection is based on the key measurement parameters derived from secondary data in secondary data collection step. It consists of qualitative data collection and quantitative data collection.

3.2.2.1 Defining key measurement parameters

One of the purposes of primary research is to define key measurement parameters (KMP) on the basis of which primary research could be done. The KMP forms the backbone for primary data collection and is stated after analyzing the secondary data.

3.2.2.2 Interview with stakeholders – Qualitative data collection

The sample population chosen for primary data collection are a mix of internal and external stakeholders of Danone. Internal stakeholders include employees of Danone Nutricia Research involved directly and indirectly in Green D project, mainly from packaging development department, marketing, supply chain and operations. The external stake holders include major MPFP material suppliers of

Danone Nutricia and recyclers in various market countries for Green D project product.

The qualitative data collection is the first step in primary data collection, which is the research strategy that highlights the thought process of the sample population. This data collection includes ‘one on one’ interview process with the stakeholders via ‘WebEx’ video calling software. The interview questions are based on the key parameters observed in secondary research process. The interviews are conducted in a semi-structured process which is a technique that enables respondent’s perspective on the subject matter and elicit depth of information (Boyce and Neale, 2006). The type of questions are open-ended semi-structured based on the following parameter:

- Factors influencing sortability of MPFP for consumers
- Factors influencing MPFP for current collection, sorting and recycling technologies
- Factors influencing development of recyclable MPFP with respect to current guidelines.

An interview of semi-structured nature allows investigator to have valuable conversation with the interviewee. Table 5 is the list of people who were interviewed for this data collection process. A total of 30 people were contacted for the interview consisting of: 10 Danone (internal) employees, 10 suppliers and 10 recyclers. The choice of stakeholders for the interview was based on the criteria presented in Table 5:

Table 5. Stakeholders category chosen for the interview and the criteria

Stakeholder category	Criteria
Danone (internal)	· People who are currently involved in MPFP packaging development projects or have worked in similar projects in past. · People who are aware of current flexible recycling issues · People who work in plastic packaging sustainability department
Suppliers	· Suppliers who are at forefront of developing recyclable packaging and already have some recyclable MPFP in market. The suppliers are also Danone Nutricia’s contacts.
Recyclers (recycling technology companies/recycling organizations/recycling research organizations)	· Recyclers who are carrying out MPFP recycling at a large scale · Recycling technology companies who have gained popularity in recent times · Organizations that are testing new methodology for recycling of MPFP

A global perspective was tried to be obtained by interviewing people from all aspects of a MPFP packaging value chain. The total number of respondents were 16 as can be seen in Table 6.

Table 6. List of stakeholders interviewed for primary data collection

Company	Function	Name	Department/Position
Danone	Packaging Research & Development	Benoit Piette	Senior Packaging Technologist
		Anne-Sophie Jue	Senior Packaging Technologist
		Karina Lopes	Senior Packaging Technologist
		Cerdiera	
		Luis Vasquez	Senior Packaging Technologist
	Supply	Lopes Artem	Global Senior Buyer
	PMTC	Naydenov	
		Jesus Maza Lisa	Flexible end of use packaging manager
	Packaging Sustainability	Adiamuick Matuez	Global Circular Economy Manager
	Packaging Sustainability	Frederic Chivrac	Global Packaging Design Innovation Manager
	Packaging Sustainability	Manon Lisiecki	Recyclability Junior Manager
Packagig Material Supplier	Bischof & Klein	Frank Hoeft	
	Schur Flexibles Folienprint	Catala Vincent	
	Gualapack	Matrin Leucke	
		Marrone Michelle	
Recycles	Tomra	Charlotte Glassneck	Recycling of MPFP
	CITEO	Vincent Collard	Mechanical Recycling research
	APK ag	Kristy Barbara Lange	‘Newcycling’ technology

The type of questions asked were open ended: conversation type (see Table 7). The objective of asking open ended questions was to get as much information and perspective from the interviewee with minimum interruption. An example of the conversation style is as follows – The interviewer is ready with 6 questions to ask from the interview and after asking question no.1, the interviewee has expressed her/his opinion on a subject matter that answers question no.2,3 and 4; the interviewer will not be asking them the question no.2,3,4 again and they are considered being answered with answer no.1.

Table 7. Questionnaire for the stakeholder interview

Stakeholder	Questions
Danone	Q1. Which recyclability by design guideline do you follow for MPFP development projects? Why? Q2. Which RBD guideline is more trustable according to you and why? Q3. What are the challenges observed during an MPFP development project? What will ease the process of MPFP development? Q4. What is the scope of improvement in D4R guidelines? Q5. What factors hinder an effective recyclable MPFP development? Q6. What could be future trends in MPFP design?
Suppliers	Q1. Which recyclability by design guideline do you follow for MPFP development projects? Why? Q2. What are the current challenges in development of recyclable packaging? Q3. How closely do you work with recyclers? Q4. What factors hinders an effective recyclable packaging development for you in current scenario? Q5. What changes do you wish to see in RBD guidelines and MPFP recycling? Why? Q6. What could be the future of MPFP design?
Recyclers	Q1. What are some observable changes in MPFP sorting and recycling? Q2. What RBD guidelines are you aware of? Which is most trustable and why? Q3. What could be done as a brand to ease MPFP recycling? Q4. What is an ideal MPFP design according to you? Q5. What could be the future of MPFP recycling? Q6. What changes do you wish to see in MPFP design and recyclability?

3.2.2.3 Consumer survey – Quantitative data

The purpose of collection of consumer based data is to understand the following:

- Whether consumers see MPFP as a recyclable packaging or not
- What minimum can be done to educate consumer on recyclability of MPFP
- What is the current understanding of recyclability of MPFPs

Table 8. Questions asked for the online consumer survey

Number	Questions	Multiple Choice Options
1	Which age group do you fall in?	18-24; 25-34; 35-44; 45-54; 55-64; 65+
2	Multilayer packaging (like a potato chips/crisps bag) is recyclable.	True; False; Maybe/not sure
3	I buy a product only if its plastic package is recyclable.	True; False; I don't pay attention
4	Chasing arrow symbol on a package means its recyclable	True; False; Not sure
5	After I put my chips/crisps bag in trash can, this is what most likely happens with it	It is taken to a recycling center; It is sent to some other country; Incinerated; Landfilled; I am not sure

6	When home, I put my chips/crisps bag in the following trash bin	I use a single trash bin for all the waste; I put it in a 'only for plastics' bin; I put it in a 'only for dry trash' bin; I put it in a 'only for plastic bags' bin; Other
7	I live in the following region	Western Europe/Scandinavia; Asia; Americas; Australia; Other
8	How do you think the message of 'this is a recyclable plastic chips/crisps bag' be communicated through packaging?	

Originally, a focus group of 'Bledine' baby food product users was decided to be conducted, with a projective and choice ordering technique. But due to the COVID-19 situation early in Spring 2020, this process was not possible. Hence, an online survey with 100 participants was decided to be done as a replacement for focus group. Through a small personal research with friends and family (about 20 subjects) it was found the most easily identifiable type of MPFP that can be found in market is a potato crisps/wafers/chips packaging and hence this was the choice of packaging that the consumer survey questions were based on. Seven multiple choice questions and one open question were asked, as depicted in table 8.

3.3 Data Analysis

The data analysis was done corresponding to the data collection values and were used to synthesis the recommended guideline, draw conclusions and recommendations for future research.

3.3.1 Gap Analysis of various RBD Guidelines

Different recyclability by design guidelines were thoroughly read and common design parameters were chosen to be compared. It was made sure that all the parameters are available in chosen guideline. The data used for this section was obtained from secondary data collection for RBD guidelines. Followings are design parameters against which the guidelines were compared:

- Material
- Barriers and coatings
- Packaging size
- Density of the material
- Adhesive
- Polymer colour
- Additives
- Ink colour/varnish
- Printing Surface
- Label
- Additional features

A scale was developed to analyze the variance among the design parameter values of the guidelines as follows: if more than 50% of the guidelines suggests the same value for a parameter, its considered to be low on variance; whereas less than 30% is considered a medium on variance scale; lastly less than 10% is a high variance score. The cut offs were established using Angoff cut off method (Mills, 1983). a It should be noted that few RBD guidelines do not provide any information on some parameters, in this case the values have been interpreted to be a difference. This is justified by the fact that a lack of information as well as varying information, both adds to confusion equally. However, this analysis can be interpreted differently by different readers. Figure 15 is the scale representation.

Colour	Variance	Cut off
	High	10%
	Medium	30%
	Low	50%
	Low information	x

Figure 15. Colour variation for variance among RBD guidelines and cut off

The consistency among the guidelines were calculated using the formula below:

$$\text{Consistency (in \%)} = (\text{No. of parameters with low variance} / \text{total number of parameters}) * 100 \text{ (eq.1)}$$

A value of less than 50% reflects a high consistency, whereas a value less than 50% represents low consistency as can be seen in figure 16.

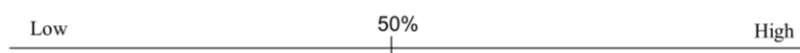


Figure 16. Scale representation for consistency for RBD guidelines parameters

A low consistency value corresponds guidelines suggesting different parameter for different packaging features. On the other hand, a high consistency value suggests the opposite.

3.3.2 Analysis of sorting and recycling facilities in Danone's EU markets

The sorting and recycling data were collected as a part of secondary data collection to primarily answer the following:

- What are the major recycling streams in a particular country?
- What are the major sorting and recycling rates?
- What are the major technologies used in these countries?
- Which countries need a major improvement in its recycling?

Firstly, answers to above questions will help in understanding the packaging material requirement (according to EU closed loop recycling standard) for the Green D project and improvement in D4R Guidelines. Secondly, this data will be used to cross check the compatibility with the RBD Guidelines pertaining to that country (if available) or the RBD Guideline most standard to EU. The most common RBD Guideline in EU will be determined by stakeholder interview which is a part of primary data collection.

The last question is answered using recycling rate/energy recover ratio and recycling rate/landfill ratio. A value of less than 1 is considered unfavorable in both the cases which means energy recovery and landfill are higher than recycling of MPFP; whereas a higher value is desirable since, it reflects a higher recyclability.

3.3.3 Analysis of gap in RBD concept and recommendations from stakeholders for MPFP packaging

Individual assessment of each stakeholder was done in the form of suggestions based on multiple points, as shown in table 9.

Table 9. Assessment points for stakeholder interview

Stakeholder	Assessment points
Danone (internal)	· Most common RBD guidelines · Most trustable guidelines · Challenges with D4R guidelines · Improvement in D4R guidelines · Current challenges in recyclable packaging development projects · Recommendations
Supplier	· Collaboration with recyclers · RBD Guidelines · Current packaging development challenges · Future Trends · Recommendations

Recycler	· Collaboration with brands and packaging suppliers/convertors · RBD Guidelines · MPFP recycling challenges · Future trends · Recommendations
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The interview transcripts were analyzed using inductive method of thematic content analysis. Nine interviewees were interviewed for data collection from Danone. Questions were asked to the participants based on assessment points mentioned in table 9. The most reoccurring answers were assigned a code and their reoccurrence was evaluated. The purpose of assigning number to reoccurrences is to measure the reoccurrence of same opinion from other stakeholders. In this analysis the transcripts are first thoroughly read and marked for reoccurring words, themes, opinions in the form of ‘codes’. The codes could be a number, phrase or an alphabet. The relevancy of an opinion is established if the codes related to a particular topic, question or opinion repeats several times in the transcript. The relevancy of a code can also be based on something similar being stated in previously published reports or scientific articles. A score is then given to the code based on the repetition in the answers of the interviewees with respect to each assessment point. Since the number of interviewees are lower for suppliers and recyclers, the coding was not possible. Instead, common phrases assessment. No preconceived theory was used to assess the transcript and the author/interviewer kept an open mind to remove any bias. (Vaismoradi, Turunen and Bondas, 2013).

The most common and repetitive suggestions were then collected as individual data points for discussions and future recommendations for analysis of the gap in agreement among stakeholders regarding RBD guidelines, concept and trends. The result from the analysis is then used in improvement suggestions for D4R guideline.

3.3.4 Consumer survey analysis for recyclable MPFP design

The consumers survey was done online through an unpaid registration with surveymonkey.com. 100 responses were collected online by posting the survey link on following platforms- author’s LinkedIn profile and a Facebook group called ‘Dissertation Survey Exchange.’ About half of the responses were collected through friends located in the EU.

Surveymonkey.com represents the collected data automatically in the form of charts and tables. The data was analyzed to find out the factors mentioned in section 3.2.2.3. The information was analyzed used to confirm or reject the hypothesis that ‘consumers are unaware about the state recyclability of MPFP’. The information was also used to deduce the factors that may increase the awareness about recyclability of a recyclable MPFP and to find out the way this message can be put across the packaging. This data is specifically useful to reach the recyclable by design message from MPFP to consumers. It should be noted that the consumers here are not the users of infant nutrition packaging (section 1.1.4), rather respondents at various web platforms as mentioned above.

4 Results & Discussions

This chapter presents results and discussion in the form of analyzation of collected data as well as author's views. This chapter is divided in five parts – part one and two are the analysis of secondary data whereas part three and four are analysis of primary data. Every part consists of details of the data, analysis, result and author's opinion

4.1 RBD Guidelines

Table 10 is an outline of the premise of the recyclability by design guidelines chosen for the comparison purpose:

Table 10. Premise of the recyclability by design guidelines chosen for gap assessment

RBD Guideline	Premise
D4R	· Differentiating components of a packaging with different colors corresponding to recyclability of those components. This can land a packaging into a lower or a higher recycling category even if the major component of the packaging is 100% recyclable. · Highly dependent on just the major recycling streams availability in EU · Not country specific · Considers PLA, PS and Multi-material pouches and satches non-recyclable
CEFLEX	· Takes into consideration collection, sortability and recyclability of the zone/region before designing a packaging. · Follows closed loop mechanical recyclability of packaging as a theory for circular plastic economy · Considers a MPFP recyclable if more than 95% of the package material is mono-material
Plastic Recyclers EU	· Guidelines for PE and PP based films (coloured and colourless) only · Based on three categories of compatibility with existing EU sorting and recycling infrastructure
Nordic Council of Minister*	· Design recommendations based on the tested methodology for post-consumer plastic waste mix
RECOUP	· One of the earliest UK based plastic packaging design guidelines similar to Plastic Recyclers EU · Highly material specific · Compatibility of the packaging design divided in three colour zone depending on recycling stream availability in the UK
FH Campus Wien	· General recommendations for design of all kinds of plastic packaging · Based on the most commonly employed sorting and recycling technologies in western Europe

*(Briedis and Syversen, 2019)

4.1.1 Comparison of packaging parameters

It is significant to understand the comparison of various RBD guidelines along the major parameters to find out the gaps. As can be observed in table 11, majority of the guidelines specifies PE and/or PP as their preferred choice for recyclable MPFP. Some guidelines also suggest the materials that should be avoided in MPFP design. Another observation is the usage of word ‘mono-material.’ For barriers and coatings, two guidelines suggests using vapor deposited coating layer which ensures low thickness i.e, less than 100 microns, while others specify EVOH is preferable. EVOH as a preferred barrier layer in MPFP has also been validated by one of the stakeholders (in qualitative data collection) through mechanical recycling tests when used in PE and PP mono-material packaging. Metal layers have found to interfere with mechanical recycling and hence should be avoided. The recommendation of packaging size in majority of the RBD guidelines corresponds with the theoretical research (see section 2.3.3). Since majority of the EU countries uses trommel separator for sorting plastic packaging/waste at recycling centers, larger packaging size has a better chance of getting recycled as it will not seep through the separator mesh size or openings. A consistent result was obtained about density of the packaging. A density of less than 1g/cm^3 has been the major recommendation from majority of RBD guidelines. This density value corresponds to the density of PE and PP as packaging material and is true for the guidelines that only recommends the density and does not specify the packaging material. For the polymer colour, inks and varnished, majority of the guidelines recommends light and pale colours. This fact has also been validated by all the recyclers interviewed as a part of stakeholder interview (primary data collection). An inconsistency was observed for additive usage with no specified additive. Printing surface is one of the most important aspect to consider when designing any kind of packaging for recycling. Direct printing causes the ink to leach during recycling and decreased the quality of recycle and hence should be avoided. For label recommendations, two types of values were observed during comparison- a. percentage of surface with label and b. material of the label.

Table 11. Various parameters and their values from different RBD guidelines

Parameter Guideline	Material	Barriers And Coatings	Pack Size	Density	Adhesive	Polymer Colour	Additives	Ink Colour/ Varnish	Printing Surface	Label	Additional Features
D4R	PE, PET, PP preferred Avoid PS, PLA, Mixed plastic. PVDC, PCDV, OXO degradable material banned	Not specified	Avg 50 mm	<1g/cm ³	Not Specified	Not specified	Not specified	Lighter colors (dark colors can also have high recyclability based on polymer thickness)	Not specified	Not specified	Not specified
CEFLEX	Mono-material (>90% of total package) PE, PP, PET (depends on available recycling stream)	Thin vapor deposited layer preferable	>20mmX20mm	<1g/cm ³	Maximum 5% of overall weight, use non-stick additive Water soluble preferred	Clear, natural, pale	Minimum (not more than 5%)	Paler (not more than 5%)	Surface print Reverse print	Same material as pack structure	Same material as pack structure Avoid RFID tags
Plastic Recyclers EU	Monomaterial- prefer LLDPE, LDPE	EVOH preferable. PA, PVDC, PVC, metallized, foaming agents are prohibited	Not specified	<1g/cm ³	Water soluble (at 40-60 degree Celsius)	Light, transparent	Should not exceed 0.97g/cm ³	Avoid -use non-toxic, non-bleeding	Laser marking < than 50% printed surface No direct printing	PE only and conditionally PP	Closures made of HDPE
Nordic Council of Ministers	HDPE, LDPE, PP	PVC, Al and metal should be avoided	Not specified	Not specified	Not specified	Light	Not specified	Carbon Balck to be avoided	Avoid direct printing	Material should be same as main packaging	Material should be same as main packaging
RECOUP	Mono-materials	Thin vapor deposited <less than 100 micron	Not specified	Not specified	Water soluble or dispersible at 60-80 degree	Light, transparent	Non-stick	light	Avoid direct printing	Should not cover more than 60% of surface	Avoid, if present use same material as package Avoid RFID
FH Campus Wien	PE, PET, PP preferred Avoid PS, PLA, Mixed plastic. PVDC, PCDV, OXO degradable material banned	Not specified	Avg 50 mm	<1g/cm ³	Not specified	Lighter colour (in conjunction with less thickness)	Not specified	Lighter colors (dark colors can also have high recyclability based on polymer thickness)	Not specified	Not specified	Not specified

4.1.2 Result from analysis of parameters

As explained in the methodology chapter, various guidelines are analyzed using a variance scale. Figure 17 shows the result of analysis:

Packaging Component/parameter	Variance
Barriers & Coatings	
Additives	
Density	
Adhesives	
Additional Features	
Ink	
Materials	
Label	
Polymer Colour	
Printing	
Packaging size	

Figure 17. Packaging component and variance for various RBD guideline

Calculation for consistency:

$$\begin{aligned}
 \text{Consistency (in \%)} &= (\text{No. of parameters with low variance} / \text{total number of parameters}) * 10 \\
 &= (1/11) * 100 \\
 &= 9.09\%
 \end{aligned}
 \tag{eq.2}$$

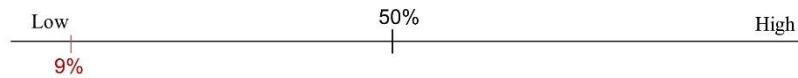


Figure 18. Consistency representation for RBD guideline parameter comparison

As can be observed from figure 18, only one out of total eleven parameters that were compared, have low variance value among all the guidelines. This can be interpreted as- more than 50% of the total guidelines in this study suggests that polymer colour should be 'light'. Six out of eleven parameters have medium variance value and this means that about 30% of the guidelines suggests same value for the parameter or packaging component. Two parameters have a high variance i.e. less than 10% of the total guidelines agree for same value for the same parameters. It should be noted that 'not specified' value in the parameter is considered a variance factor (as mentioned in section 3) since a lack of value is thought to add confusion for the packaging developer. If the 'not specified' value is interpreted as 'no conflict' value i.e. the value is not considered to be a variation factor, the consistency may increase.

To find out the consistency value as a representative value for the overall consistency in values for eleven parameters that RBD guidelines were compared for, equation 1 and equation 2 are used. 9% consistency is a very low value since the cut off for high consistency is 50% (see figure 18).

4.1.3 Discussion

‘Mono-material’, ‘PP’ and ‘PE’ were the most common values under packaging material parameter for majority of the guidelines hence it can be inferred that recyclability of MPFP is strongly associated with MPFP that is fully made up of only one material, including attachments and labels (if any). There has been a strong consistency for the same thought in Chapter 2 as well as stakeholder interview (section 4.3). None of the guidelines mention using metalized layer for barrier in MPFP, which is generally the design of conventional MPFP with high barrier properties. This is true due to the fact that NIR and optical technologies used in sorting centers are not able to detect the MPFP packaging’s material if the barrier is metallized (section 2.3.3). Hence, it is safe to assume that metal barrier layers shall definitely not be a part of recyclable MPFP design. However, when assessing the values of parameters for barriers and coatings, a very low consistency was detected among the guidelines. Some guidelines suggests the thickness of barriers/coating but do not specify the type that should be used and vice-versa, while others only specify the barriers/coatings that should not be used. In author’s opinion, barriers and coatings should be considered separate parameters and can be more specific about the recommendations, thickness value and avoidance. Table 12 is a recommended representation of the values for barriers and coatings parameters. The values have not been added intentionally as table 12 is an example.

Table 12. A recommendation for representation of barrier and coating values for RBD guidelines for MPFP

Parameter	Thickness	Recommended	Avoid
Barriers			
Coatings			

Packaging size is one of the main factors contributing to non-recyclability of MPFP packaging. ‘Sachets’ formats like ketchup packs are non-recyclable even though the material is recyclable with no metal barrier and unacceptable coatings. The reason is because of its small size. A MPFP size smaller than 20 mm (in some countries it is 50mm, may also depend on recycling center) is either sent to landfill or incinerated. Smaller packaging also has a higher chance of seeping in the environment. Hence, the size parameter should be strictly followed for a recyclable MPFP by identifying the sorting capability of the region where MPFP is to be sold. Density value is fairly consistent. A value of less than 1g/cm^3 corresponds to value of density of PP and PE, and hence it can be inferred that a suggestion to keep the density below this value automatically corresponds to packaging material specification i.e. PE or PP. However, some guidelines like D4R suggested the density value to be kept below 1g/cm^3 along with material suggestion of PET for MPFP design. This may lead to confusion because for a PET material based MPFP, density cannot be less than 1g/cm^3 , as this density value corresponds to PE and PP as the material value. Usage of adhesive parameter can also be categorized into – a. maximum percentage, b. water soluble or solvent soluble and temperature, c. recommendations and d. to avoid categories. A similar representation can be done for additives (see table 13).

Table 13. A recommendation for representation of adhesive and additives parameters for RBD guidelines for MPFP

Param-eters	Max %age	Solvent & temp.	Recommend	Avoi-d

One of the major flaws identified in all guidelines were the non-distinction between sub-parameters- ‘what should be used and its recommended value in the form of percentage’, ‘recommended options’ and ‘what should be avoided’. Either the guideline had one or two of the three but none of the guidelines suggested values for all three sub-parameters.

The results from the analysis of parameters are high in variances and low in consistency. The values reflect a high disagreement among various RBD guidelines. Generally, brands (like Danone Nutricia) develop their internal packaging design guideline relying on the most comprehensive and common guidelines and some brands rely on one or two guidelines (more about this will be discussed under section 4.3). The reliance on current existing RBD guidelines hence can be mis-leading for a packaging designer/developer due to conflicting information.

4.2 Sorting and Recycling in Danone Nutricia’s major EU Markets

Table 14 is the depiction of comparison of various sorting and recycling data of EU countries. The collection, sorting and recycling of MPFP signify the total MPFP collection, sorting and recycling data from post-consumer waste in the mentioned countries respectively. Collection of MPFP signifies the type of MPFP waste collection system in different countries. As can be observed in the table 14, MPFP is generally collected with all other plastic packaging. Only Spain employs the option to collect flexibles separately, as well as co-mingled with other plastics. ‘Sorting of MPFP’ and ‘Recycling of MPFP’ signifies the major plastic sorting and recycling streams available in the respective countries with an emphasis on type for MPFP preference. For instance, France has PE as sorting of MPFP value, which indicates a preference for PE recycling stream in France. This value may not necessarily signify the current MPFP sorting technology availability but just a gravitation of certain country towards a certain sorting and recycling stream with respect to future.. It should be noted that the recycling technology data in numbers has not been taken into account since the information is largely sporadic, varying and due to emergence of new MPFP recycling technologies are being implemented on experimental scale in various countries across EU.

Table 14. Comparison of various sorting and recycling data of EU countries.

Data	UK	France	Spain	Portugal	Germany	Netherlands	Italy
Collection of MPFP*	All flexibles Door to door collection of co-mingled flexible with rigid plastic	Door to door co- mingled collection (plastic + metals collected together)	All flexibles -bring point collection, co- mingled plastic and metal	All flexibles -bring point collection, co- mingled plastic and metal flexible	All flexibles door to door co- mingled collection (plastic + metals collected together)	All flexibles Door to door collection of co-mingled flexible with rigid plastic	All flexibles door to door co- mingled collection (plastic + metals collected together)
Sorting of MPFP*	PE focused	PE	Mixed PO	Mixed PO	PE, Mixed PO	PE, Mixed PO	PE, mixed PO (not everywhere in Italy though)
Recycling of MPFP*	Exported	PE	PE	PE	Clear and coloured PE, Mixed PO	Clear and coloured PE, Mixed PO	PE, Mixed PO (depending on the market)
Recycling% **	32	25	44	32	38	37	30
Energy Recovery%***	46	42	20	30	57	63	38
Landfill%***	22	33	36	38	5	0	32
Sorting Technology**	Turbosorters, NIR	Trummel, NIR, Visible Spectrum	Manual, Trummel, NIR	Manual, Trummel, NIR	Trummel, NIR, Optical	Trummel, NIR, Optical	Manual, Trummel, NIR

*Danone's Internal Flexible packaging report

**Plasticeurope 'Plastic Report 2019'

As explained in Chapter 3 (methodology), the recycling rate vs energy recover vs landfill rate values can be used to estimate the plastic recycling efficiency (that includes data for MPFP recycling as well) of various EU countries. This data can be used to identify the major recyclable MPFP market needs, plastic recycling policy change requirements and to understand progression of certain countries in this area and replicate the models in countries that are lagging. Table 14. is the result of recycling rate vs energy recovery vs landfill data.

Table 15. Recycling rate vs Energy Recovery vs Landfill in various EU countries

Country	Recycling rate/Energy Recovery (approximation)	Recycling rate/Landfill (approximation)	Total (recycling efficacy)
UK	0.7	1.5	2.2
France	0.6	0.8	1.4
Spain	2.2	1.2	3.4
Portugal	1	0.8	1.8
Germany	0.7	7.6	8.3
Netherlands	1	X	Highest
Italy	1	0.9	1.9

‘Recycling%’, ‘energy recovery%’ and ‘landfill%’ are the representation of data for current total plastic packaging recycling rate (approximation) in stated countries which includes the data for MPFP as well. As observed in table 15, Spain has a higher ratio for recycling vs energy recover followed by Portugal, Netherlands and Italy, whereas Germany has a very high recycling vs. Landfill ratio. It should be noted that since Netherlands has no landfill, it is the best example among all the countries. UK and Spain also have a lower landfill rates when compared to their recycling rates. As depicted from the total score depicts the total recycling efficiency of a country. Netherlands holds the highest rank (due to 0% landfill), followed by Germany. Whereas Portugal, Italy and France are the least MPFP recyclable efficient countries with France holding the last position.

4.2.1 Discussion

It is evident from table 14, that PE is the most sorted plastic packaging material and most recycled stream in most countries that were taken into account. Hence, PE can be a good option for future MPFP packaging design to be taken into consideration when developing a monomaterial. However, the packaging material should be chosen with careful consideration for the sorting and recycling technologies of the countries. From table 14, it is evident that PE, PP and mixed PO are generally acceptable material types for MPFP. From a packaging developer perspective, it can also be analyzed as the choice of material to focus on while developing a packaging for certain market. This gravitation towards PP, PE and PO as major streams is due to awareness about non-recyclability of MPFP packaging in past two years due to plastic trash import ban by China.

The average recycling rate of plastics, including MPFP is 37% which is still on the lower end but a better number from five years ago (Plastic Recycler Europe, 2019). One of the main principles of circular plastic economy is elimination of landfill and reduction of energy recovery. So far only The Netherlands have been able to achieve the goal of zero landfill. A general consensus is observed about packaging material choice by comparison between RBD guidelines and sorting and recycling data for MPFP i.e. PE and PO. Hence, in future it will not be surprising if major

brands in EU are using PE or PP based monomaterial packaging for their MPFP packed products.

4.3 Interview with stakeholders

4.3.1 Danone Nutricia Research

The most common guideline referred to by Danone stakeholders or packaging developers (PDs) is D4R, which is the Danone's internal recyclable packaging design guideline. For MPFP packaging development CEFLEX guidelines were found to be the most preferred guideline due to its detailed orientation to specific parameters. Two PDs also referred to Recyclclass guidelines for MPFP recyclability design assessment. All PDs stated that D4R guidelines is the most trustable however has presents following challenges – a. lack of specificity towards packaging parameters like additives, barrier layers etc.; b. lack of integration of Peter tool (LCA assessment tool); and c. presents misleading or confusing information and not clear enough.

With respect to the challenges in comprehension of RBD guidelines (other than CEFLEX), the PDs suggested that excessive information, lack of scientific data and un-specificity to country's recycling and sorting data, are major factors. Lack of data was also mentioned as one of the major challenges in recyclable MPFP development projects, followed by lack of key performance measurement indicators and lack of access to pilot plant. One PD also mentioned lack of clear marketing brief as a hinderance factor in major MPFP development projects. Apart from the assessment points data, other insights were also collected from the Danone interviewees. For instance, some of the major factors that hinders effective recyclable MPFP development and application in current times is lack of recyclable material availability from suppliers (like mono-material for MPFPs), high cost of raw material, low barrier properties and low machinability when compared to non-recyclable MPFP. Another interesting answer was 'fitting recycling requirements for all countries in one packaging'. One of the respondents suggested that pressure on recycling streams and government policy change can be more effective than putting pressure of the brands. One reoccurring comment from PDs was lack of alliance among stake holders and waste management systems and low data to overview MPFP value chain. Without data, it is difficult to make design decisions. When asked about the changes that packaging developers would want to see in current recyclable MPFP value chain, that major response was a clear regulation for MPFP at EU level that will bring harmonization among current sporadic standards. With respect to the specifics packaging design parameter, a strong gravitation was observed towards 'monomaterial' being the focus. Only one respondent spoke about the lack of understanding from consumer about 'which trash bag to put MPFP in'. Pertaining to the current situation with COVID-19, one question was asked about the impact on ongoing projects. From procurement and production perspective, there is currently no impact with an increased demand for baby food products. However, majority of the renovation and innovation project are either delayed or halted until the situation is better to restart.

4.3.2 Suppliers

A variety of questions were asked to suppliers around the assessment points mentioned in methodology. Three out of four suppliers said that they are aware of CEFLEX and find it to be the most trustable RBD guideline. Other RBD guidelines that were mentioned are from Plastic Recyclers Europe. When asked about the major reason supplier trust CEFLEX guideline – three out four who follow the guideline said that it is technically feasible to produce a PE and PP based mono-material MPFP and recycle it. One supplier has been successful in conducting the test. All four suppliers who were interviewed said that they perform in-house recycling tests. However, only two confirmed working directly with the recycling companies and that too only locally and not with other countries even if they are producing packaging for other countries. One supplier preferred doing recycling tests with consumers and the other did not work end-to-end with recyclers.

When asked about the major challenges faced while developing a recyclable MPFP, three out of four suppliers mentioned the technical challenges that comes with development of a recyclable MPFP. The major challenge is with sealing the packaging. It should be noted here that three out of four suppliers consider recyclable MPFP as ‘mono-material’. Development of a mono-material MPFP is challenging since the sealing temperature window of the packaging machine has to be altered. One of the supplier mentioned -‘In the process you must not affect the appearance of outside layer. Outside layer must not deform. Melting points are different in multi-material. In monomaterial you for example if you have triple PP layer, you need to choose different types of PP. You have specific PP outside and inside to be able to seal the inside. This gap is very small and this is the main challenge. Mechanical performance is another challenge- aluminum, PET laminates are much stronger and resists better to puncturing. This is one of the areas of improvement we are working on. A mono-Poly Olefin will necessarily have low performance. Thirdly it is the barrier. Al has fantastic barrier to light and oxygen- we have to substitute al with something that resist hot sealing, light, heat etc. because without barrier you do not have shelf life.’

When asked about the opinion on future trend for MPFP packaging two out of four suppliers were optimistic about mono-material packaging. The other two suppliers were not confident in the willingness of brands to pay the higher price for a mono-material MPFP and its ability to protect the food product quality which is highly critical for baby food products. The major recommendations from suppliers were for brands to increase the collaboration with them.

Pertaining to the COVID-19 situation, the suppliers are observing an increase in packaging material orders but there has been delays in supply due to closed borders in several countries.

4.3.3 Recyclers

Two out of three recyclers suggested CEFLEX to be the MPFP guideline that they follow and trust, however one recycler suggested that it is un-necessary to use CEFLEX when the technology to recycle conventional MPFP is available. All three recyclers mentioned their close collaboration with brands and local communities to understand the recycling needs and take feedback. However, lack of information exchange among brands and recyclers that is essential for upgrading the recycling systems was mentioned as huge drawback to achieving successful recycling. It was also mentioned that brand owners have prioritized marketing needs above recycling

needs when it comes to MPFP packaging. One of the recyclers also stated that mono-material approach is a ‘status-quo’ and brands may feel pressured to use this type of packaging since the scientific data has not been promising when it comes to barrier properties and closed loop recycling.

For the future trends, two recyclers mentioned that mono-material is the future of MPFP packaging and should be developed future but one recycler completely disagreed with this point of view. The recycler who disagreed with monomaterial as a solution of MPFP recycling problem, suggested use of their solvent technology that produces high quality of recycle with no change to polymer integration at molecular level and is food grade.

For recommendations to other stakeholders, it was suggested to promote the idea of recyclable MPFP among consumers since most consumers are unaware about the mono-material development. It has also been suggested by one recycler to have a free exchange of information among suppliers and recyclers, which currently is very low. Two recyclers agreed that design of the packaging should be simple and as clean as possible, while one recycler was indifferent. One of the interesting answers to the most observable challenging in flexible recycling was this – ‘NIR machines does not detect every single layer. For example, outer layer is very thick sometimes and do not know if its multilayer. This mis-identification pollutes the recycling stream. But if it is really thin, machine doesn’t pick up the signal and sees the second layer. And when middle layer is super thin, NIR only reads outer layer and inner layer and doesn’t understand what multilayer is made of. Producers (everyone who has this information- suppliers, FMCGs) are not willing to share the recipe of the flexibles and there are no standard design guideline. However, NIR is getting better over time to make it possible to detect every multilayer.’

Pertaining to COVID-19 situation recyclers are observing an increase in the generation of MPFP and plastic recycling in-stream. One of the reasons that surfaced for this phenomenon is the sudden surge in market demand for packed food, more cooking at home and hence increased generation of plastic packaging in recycling centers.

4.3.4 Discussion

All nine interviewees from Danone (PDs) agreed that D4R is the most trustable and comprehensive guideline. After D4R, CEFLEX is the guideline that majority of PDs refer to for MPFP design. Major criticism of the D4R was lack of specificity for sub parameters like labels, adhesives and inks. D4R guideline needs a specific separate section for MPFP design for a better understanding of parameters that should be used. A suggestion to the D4R guideline can refer to, be found under section 4.5. Seven out of nine PD interviewees agreed that mono-material is the future of MPFP packaging but two suggested that it might not be an easy transition and needs a faster development to achieve Danone’s 2025 recyclable packaging targets (see section 1.2.2). It is observed that one out of three suppliers were not convinced that mono-material was a good option from perspective of product safety and barrier properties. Co-incidentally the same supplier did not mention following CEFLEX guidelines. This can be due to following factors- either the supplier is not aware and have not explored the CEFLEX guideline, might be inclined to a recycling technology like ‘Creasolv’ or ‘Newcycling’(see 2.3.5) or just thinks from

a product safety perspective. A lack of structure and vagueness was observed among suppliers when enquired about working directly with recyclers to test recyclability of their packaging. All four suppliers were consistent about lack of knowledge about recycling information in countries other than where they are based. This can be one of the main gaps for lack of agreement among stakeholders for a thorough RBD guideline. Three out of four mentioned the lack of barrier properties, expensive raw material and sealing challenges with a mono-material based but recyclable MPFP. This in author's point of view is the biggest tradeoff. But the question that arise here is whether the product quality should be compromised for a recyclable packaging and is it possible to use a mono-material MPFP everywhere in the world?

In author's opinion, recyclers should be a central stakeholder in development of RBD guidelines since they do the groundwork and may understand the reality of recycling MPFP better than other stakeholders. In the interview, idea of mono-material recyclability was highlighted but when asked about the validity of CEFLEX guideline, only one recycler could fully confirm it. One out of three recycler completely rejected the idea of mono-materials since their technology can fully recycle the current multi-material MPFP with ability to produce food grade output, which is not possible with current mechanical recycling technology. Though the cost comparison of mechanical recycling versus non-mechanical recycling is not clear. Also, the recycler does not acknowledge their technology in chemical recycling categorization. The technology is based on solubilizing polymer using chemicals and its acceptability as mechanical recycling is arguable, since, closed loop recycling do not recognize use of chemicals in mechanical recycling. However, the opinion around this concept is divided. About 70% of the total stakeholders, agreed with mono-material MPFP being recyclable for future. In author's opinion it could be due to the definition of circular plastic economy by EllenMcArthur Foundation that has been a leading figure in circular economy reports in recent times. Non-mechanical recycling does not fit the circular plastic economy's definition and since only mono-materials could be recycled mechanically, the gravitation of stakeholders to mono-material is self-explanatory.

One of the major gaps identified that demotes alignment on single concept of RBD guideline here has been lack of information exchange among suppliers, brands and stakeholders. The reason is not clear. This could be due to the fact that information exchange may potentially hamper the supplier's profitability.

One of the recyclers was representing the technology that can recycle conventional MPFP with high energy efficiency and low chemical use argued that mono-material is not the answer to the MPFP recyclability. The arguments presented against mono-material were – lack of barrier properties, lack of sealability, high cost and low scientific evidence about mechanical recyclability. In author's view this is a valid argument but may not be as effective in European context which has temperate climatic conditions. The argument is more convincing in tropical climatic conditions context. Overall, the role of suppliers and recyclers was observed to be larger than brand owners when assessing the ground reality of MPFP packaging. A lack of collaboration was observed among suppliers and recyclers but a good collaboration was observed among brand owners and suppliers. However, among all three, brand owners were observed to have a higher impact ability to influence the trend of recyclable MPFP due to direct communication through consumers and higher visibility.

An interesting perspective was brought about by one of the recyclers about the definition of closed loop recycling, and of future recyclable MPFP. It was observed that the majority of the stakeholders did not mention MPFP recycling technologies like 'CreaSolv' and 'Newcycling' either due to lack of awareness or blurry categorization among recycling technologies. But, it is important to acknowledge this technology as it does remove the need for investment in new packaging material and technology which cannot perform at par with current MPFPs. The idea about chemical-mechanical recycling should not be rejected. It can especially be useful in tropical countries where barrier properties of mono-material MPFP might not have good performance. It was also observed that a wide acceptance to 'recyclable MPFP' is synonym with 'mono-material'. This is generally true for the stakeholders who accept CEFLEX as the most trustable guideline for RBD for MPFP.

4.4 Online consumer survey

The graphical representation and full results of the online consumer survey results can be found in appendix E.

4.4.1 Results

Out of 100 respondents, 92 belonged to an age group of 10-34 with 66 respondents between 25-34 age group. 75% of the total respondents belonged to Western Europe/Scandinavia region. 35 respondents agreed that multi-layer packaging is non-recyclable, whereas a close 33 respondents agreed that it is recyclable, whereas the rest said that they are 'not sure'. The question about the chasing arrow symbol being representative of a package's recyclability had 74 respondents agreeing to the statement, whereas only 10 disagreed with the validity of the statement. 41 respondents believed that their packaging is taken to a recycling facility, whereas 21 respondents did not know what actually happens to a packaging. Half of the total respondents put their MPFP in a 'only for plastics' bin, whereas 18% and 13% put it in a single trash bin and only for dry trash bin respectively.

On asking about how the message of 'this is a recyclable plastic chips/crisps bag' be communicated through packaging? The major suggestions were as follows:

- "The package should say in bold letters THIS IS RECYCLABLE"
- "With chasing arrows symbol"
- "Big text"
- "With a green symbol or green dot"
- "Color coding and separately collecting recyclable plastic on particular day of week"

4.4.2 Discussion

Since the online survey was posted on Facebook survey collection groups and on LinkedIn, majority of respondents are thus in an age group of 25-34. Incidentally, this is the age group that has been reported to be more environmentally conscious than other age groups (NYpost.com, 2018). A confusion was observed about whether an MPFP is recyclable or not. Hence, it cannot be estimated clearly whether majority thinks if an MPFP is recycled or not. Thus, it is important to communicate to consumer about the recyclability of the package. This can also be a good marketing strategy. Majority agreed that they do not pay attention to whether a packaging is recyclable or not. This can be due to a lack of interest or ignorance. A partial reason could be lack of communication of recyclability message on the packaging. It is author's opinion that a clear visible message on the package can generate some interest in consumer about recycling their MPFP. One of the important revelations was the lack of information about recyclability of MPFPs among consumers. Majority revealed that MPFP is recyclable. This is a major inconsistency with the current available data on MPFP recyclability in the EU (PlasticsEurope, 2019). The confusion probably arises from the chasing arrow symbol or any other symbol that might be confused for 'this packaging is recycled', as was mentioned in one of the survey comments. A chasing arrow symbol does not signify that the packaging is definitely recycled. It means that the material, the packaging is made up of is recyclable (Oceana.org, 2020). The question about home level MPFP disposing behavior revealed that majority respondents put their MPFP

in trash bag that is dedicated only to plastics. This is good news for sorting centers since it is easier to separate the segregated trash than non-segregated ones.

Overall, consumer survey revealed a lack of information at end consumers about recyclability of the MPFP but a strong behavior towards responsible plastic trash segregation. Hence, in author's view it is brand's responsibility to communicate, since consumers are doing their part in waste segregation. A clear symbol or a phrase on bold letters should be used. It is author's strong opinion that a clear recycling information should be mandatory on the packaging like a nutritional label. The survey also revealed that if in future, an MPFP waste segregation category is recommended to consumers at home level, they will probably be willing to do so. A question may arise here that if consumers are segregating their MPFPs, which is ultimately sorted in sorting centers, what is the need for awareness about recyclable MPFP? The answer to this could be— a marketing opportunity from brand's perspective and general increase in awareness among environmentally conscious consumers. The increase in awareness may result in increased demand for recyclable material (ultimately increasing competition among suppliers and bringing the cost down) and also change in packaging legislations.

4.5 Major gaps in RBD guidelines & sorting and recycling system incongruency

Following are the major identified gaps from the stakeholder interview and online consumer survey that contributes to lack of uniform understanding of RBD concept among stakeholders:

4.5.1 Reliance on multiple RBD guidelines

It was observed that some stakeholders refer to multiple guidelines for their packaging development projects. This was especially true for suppliers. As was evident from primary data analysis, the congruency among various guidelines for MPFP design is very low and this factor can cause confusion among stakeholders. Hence, it is better to either do the groundwork of understanding the sorting and recycling in the area stakeholder aims to sell their MPFP in or refer to a single trustable guideline.

4.5.2 Lack of exchange of information

Lack of exchange of information has come up as one of the major grievances from the recyclers towards brand owners. It was a general consensus among recyclers to have more information about packaging design as it helps them improve their technology. A lack of information about the recipe of the packaging has potential to pollute the downstream.

4.5.3 Lack of centralized data (on collection and sorting at EU level)

Lack of consensus, standard design and agreement among different stakeholders was also identified as one of the major barriers to effective MPFP recycling. Whether an MPFP should be 3 layer or 10 layer or even more, there is no EU level legislation that dictates this factor as of 2020. Though there is a push towards recyclability, it often came up in interviews that this push is without a clear roadmap.

4.5.4 Lack of awareness among consumers

A majority of the online consumer survey respondents believed that their current MPFP packaging is recyclable. Now, this could also be an error at author's end due to lack of knowledge about availability of recyclable MPFP in some markets (since respondents were from five continents with majority from the EU), but as per Plastic Recyclers Europe's 2019 report, MPFP are categorized non-recyclables. Hence, this can be best explained as lack of awareness about recyclable plastic among consumers. This reflects that consumers cannot differentiate a recyclable MPFP from a non-recyclable MPFP. Hence, brands may not feel the need to change their packaging design.

4.6 Recommended RBD guideline for MPFP

A RBD design guideline for MPFP was developed using the gap analysis result of various RBD guidelines (section 4.1), inputs about RBD guidelines from stakeholder interview (section 4.3) and indicators from online consumer survey. The data from RBD guideline analysis with low and medium variance was taken into consideration. For instance, parameters like packaging material, barriers and coatings, density, additives, adhesives, inks and labels. Inputs from stakeholder interview is also incorporated in the form of comments and recommendations for instances.

Table 16. Recommended guideline for recyclable MPFP design based on primary and secondary data

Packaging Characteristics	Recommendation	Thickness	Avoid	Comments
Material	PP or PE	x	PLA Mixed Plastic	If selecting monomaterial design the material should be mono-material but different layers can use different orientations.
Barrier/Coating	EVOH	less than 100 micron thickness.	Metallized layer like Al PVC, PVDC Foaming agents	Does not interfere with the downstream used when used in a quantity such that the overall density of the package remains less than 1g/cm ³
Packaging Size	50 mm x 50 mm minimum	x	Smaller than 20mm X20 mm	Most trammel separators have a 50x50 mm screens, some may have smaller screens as well, but this is a safe option
Density	<1g/cm ³	x	x	Since the density of PE and PP is less than 1g/cm ³ , the density of the whole packaging (including inks, adhesives, barriers) should be less than 1g/cm ³

Adhesive	Water soluble (40-80 °C)	x	Solvent soluble	Most mechanical recycling operation uses hot water to clean the incoming stream after shredding the MPFP
Polymer Colour	Transparent, pale, light yellow - green colour spectrum	x	Dark colours	Darker colour impacts the colour and price of downstream
Additives	Avoid	x	x	
Inks/Varnish	Pale or minimum	x	Dark colours	Darker inks impacts the colour and price of downstream
Printing Surface	No direct printing	x	x	Direct printing risk of leaching of inks
Label	Same material as packaging; should not occupy more than 50% of total surface area of the MPFP	x	x	Same material maintains the density of package less than 1g/cm ³ , and less surface area occupation facilitates NIR readability for sorting
Additional Features	Zips, Spouts etc. should be of same material as package	x	x	Same material maintains the density of package less than 1g/cm ³

The major difference between the recommended guideline and the RBD guidelines assessed is the incorporation of comments from the stakeholders and addition of the sub parameters like recommended values and values to avoid. It should be noted that the measurement of barrier properties of any packaging using a RBD guideline is only possible through shelf life (or accelerated shelf life) studies with product inside the packaging. As per the stakeholders the current cost of the mono-material (future recycle ready) PE-PP based packaging is 20 to 35% higher than current metallized MPFP packaging.

5 Conclusion and Recommendations

This chapter answers the question that were posed in the beginning of the study in the form of conclusion and gives recommendations for future research.

5.1 Conclusions

5.1.1 Compatibility and gaps of the current RBD Guidelines with current MPFP sorting and recycling in EU

The process of analysis of current RBG guidelines revealed other related important information that can be utilized to optimize the future MPFP development projects in Danone Nutricia Research, as well as can benefit the future of MPFP industry. The study also showed that major MPFP guidelines have low consistency which means that each guideline may suggest different parameter for different packaging feature. Some of the most important differences observed were about packaging size, barriers and coatings, adhesives and additives. These sub parameters constitute a smaller percentage in the packaging. Non-uniformity of sorting and recycling technologies has been obliterated as the reason for low consistency among RBD guidelines since it was evident from sorting and recycling data that majority of the countries employ similar technologies.

Among all Danone Nutricia Research's market countries, France has the lowest recycling rates, whereas Netherlands has the highest recycling rates. It is important to know this to estimate the level of responsibility a brand has towards sustainable disposal and recycling of its packaging. The online survey revealed a grim picture of understanding of recyclable packaging among consumers. Majority of the respondents in the EU believe that current MPFP is recyclable which is not the case as per Plastic Recyclers Europe's 2019 report.

5.1.2 Improvement in Danone's D4R guidelines and suggestions

The D4R guidelines, Danone's internal packaging design guideline also have been analyzed as a part of RBD guidelines analysis. It was found that the D4R, though, presents a good insight for the basic packaging material parameter, still fails to address the specifics or sub-parameters of MPFPs like labelling, inks, adhesives etc. The MPFP section in D4R is not up to date and the mono-material based suggestions can be included (see section 4.6). Only two out of nine Danone interviewees suggested the use of a LCA study tool called 'Peter's tool' along with the D4R guidelines for a realistic assessment of carbon footprint of the packaging. This suggests that majority of the interviewees may not be aware about the usage of the LCA tool or do not give it consideration. It was also suggested that analysis with D4R guidelines should be a mandatory step before starting any packaging development project to be able to achieve Danone's 2025 sustainability packaging sustainability goals.

5.1.3 Stakeholders overview about MPFP recyclability and future trends

Overall, a uniform agreement regarding understanding of current recyclability issues was observed among various Danone's MPFP PDs. Majority of developers are in favor of mono-material MPFP as a plastic flexible packaging option. This is also validated by the suppliers, who are currently observing an increase in demand of mono-materials MPFP from various brands. Changing regulations and voluntary sustainable packaging agenda has been internal goal of every supplier. This shows a determined attitude of suppliers and brands to fulfill the larger circular plastic economy goal. However, the analysis of gaps in RBD guidelines suggests that a roadmap to reach the objective might still not be clear due to lack of standardization of MPFP packaging design and lack of related EU level regulations. A strong discordance was observed among the stakeholders with respect to exchange of data and information. This was a major input from the recyclers towards brands. A low collaboration was observed among suppliers and recyclers which is a fundamental obstacle to development of a recyclable MPFP since many suppliers are also members of various RBD guidelines drafting committees like CEFLEX. An absence of acknowledgement was observed among stakeholders towards technologies like 'Newcycling' and 'Creasolv' which has a cleaner food grade recycled output without the need of changing conventional MPFP structure. This could possibly be due to an unclear categorization of these technologies under chemical recycling. It is safe to assume that there is a direct co-relation between mono-material MPFP with mechanical recycling and metallized (conventional) MPFP with solvent based recycling technologies like 'Creasolv' and 'Newcycling.' In author's opinion it is important to follow both the recycling strategies, depending upon the barrier requirement of the product. Baby food products, pharmaceutical as well the general food products in high humid-high temperature areas require high barrier properties. Here, the question arise, has mono-material MPFP development reached the barrier level of conventional metallized MPFP? As per the current development in mono-material MPFP barrier properties, it should only be used for products with low barrier requirement and markets with suitable climatic conditions. For tropical climatic condition markets (like Spain and Portugal), investment in 'Creasolv' or 'Newcycling' technology could be a consideration.

5.1.4 Ideal design guideline project Green-D and optimization of similar future research

After thorough analysis of the most common sorting and recycling technologies in Danone Nutricia's major EU market, suggestions from the stakeholders and online consumer survey, it is evident that PE or PP based mono-material would be the best option for a recyclable MPFP. Some recyclers have tested the mechanical recycling of mono-material based MPFP with 100% success rate. However, currently the conventional MPFP with high barrier property is a hard match for mono-material based MPFP due to lower barrier and machinability. Products like Bledine (cereal based dry baby food), might have a stable shelf life in a monomaterial MPFP in temperate climates like North-Western Europe. Though, for future, technological advancement in mono-material strength, barrier properties and machinability is strongly predicted by majority of the stakeholders. As per this study an ideal packaging design for Green-D project would be a PP or PE based packaging material with pale colour, compatible material zipper (as additional component) and a 'chasing arrow' sign with the material name written on it (see figure 19).

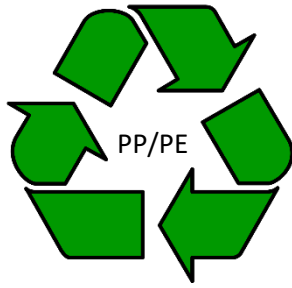


Figure 19. An example of the symbol that can be used in the front labelling of MPFP packaging for Green-D project

5.2 Further research recommendations

For further research it is suggested to use the information from the study and apply it to the Green-D project or a similar MPFP development project. Packaging tests can be done to compare the current MPFP format with the mono-material counterpart. It is also suggested that the recommendations for ideal MPFP design guideline be incorporated in the D4R. To get a deeper view of the same topic it is suggested to interview more recyclers, suppliers as well as users of the product that is packed in MPFP. The consumer focus group data collection was an important part of the study that was not carried out due to unprecedented situation. Lastly, it could be interesting to compare the carbon-footprint of monomaterial recyclability with other MPFP recycling technologies like 'Newcycling' and 'Creasolv'.

6 References

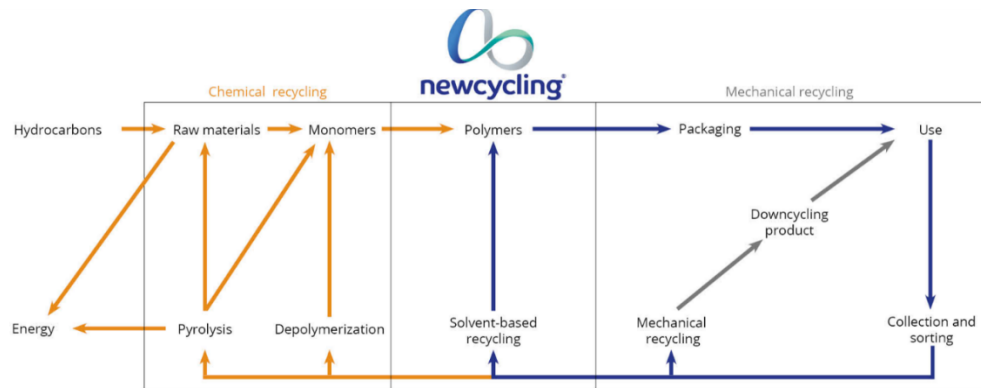
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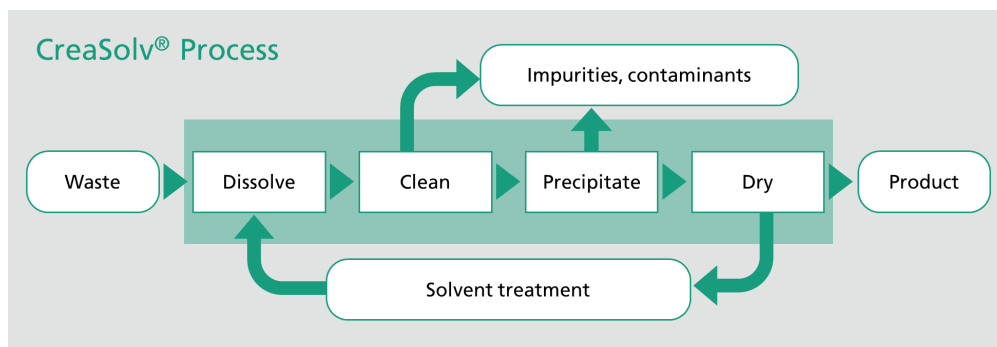
APPENDIX A

APK 'Newcycling' MPFP recycling technology



Source: APK-AG

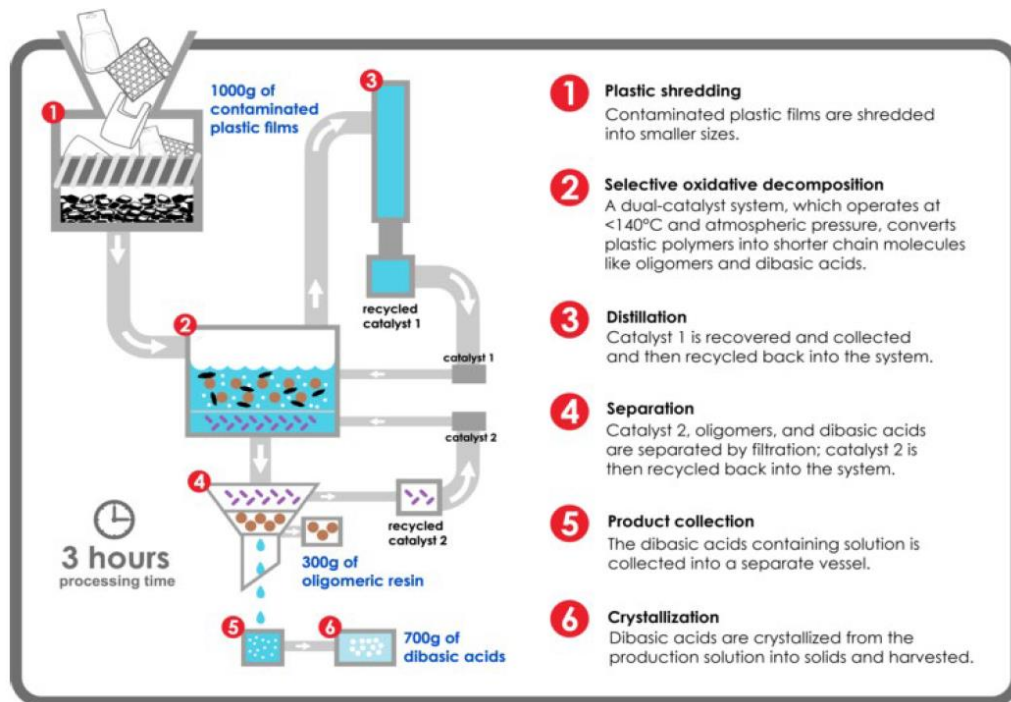
Fraunhofer 'CreaSolv' MPFP recycling technology



Source: Fraunhofer IVV

APPENDIX B

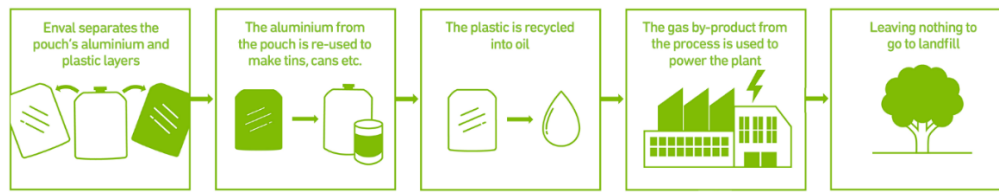
Biocellation's Accelerated Thermal Oxidative Degradation (ATOD) for plastics



Source: Biocellation

APPENDIX C

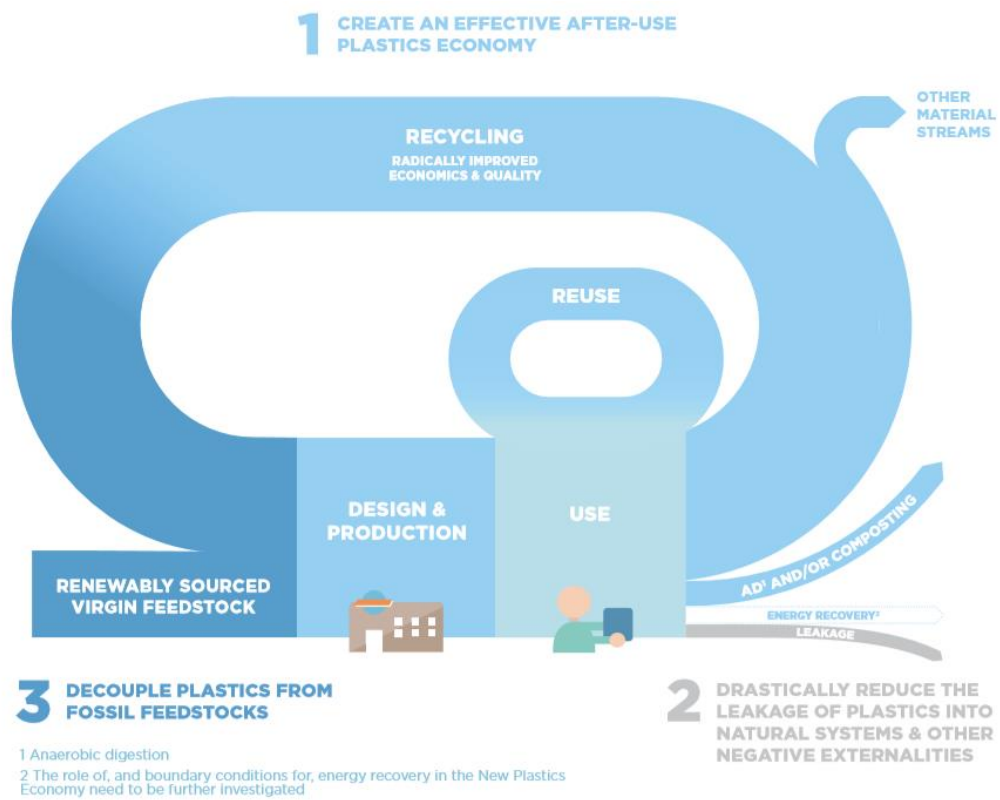
Enval's Plastics Aluminium Recycling Technology



Source: Enval

APPENDIX D

New Plastics Circular Economy



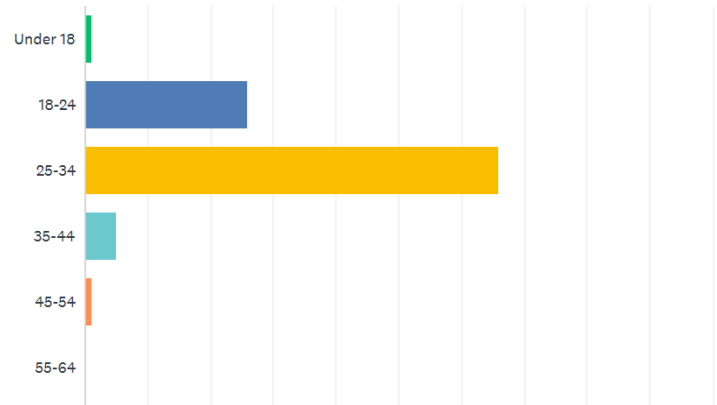
Source: Ellen McArthur 2019

APPENDIX E

Online Consumer Survey Result *(source: surveymonkey.com)*

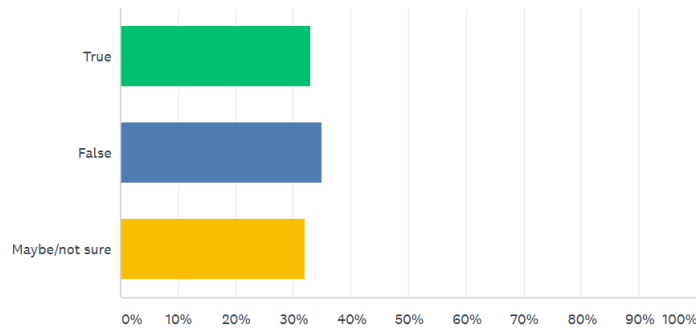
Which age group range do you fall in?

Answered: 100 Skipped: 0



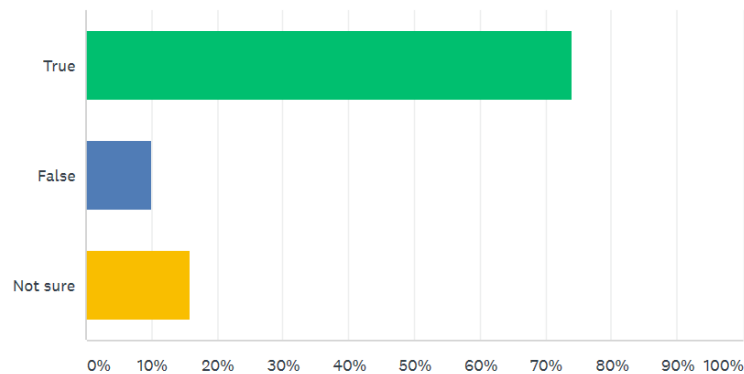
Multi-layer packaging (like a potato chips/crisps bag) is recyclable.

Answered: 100 Skipped: 0



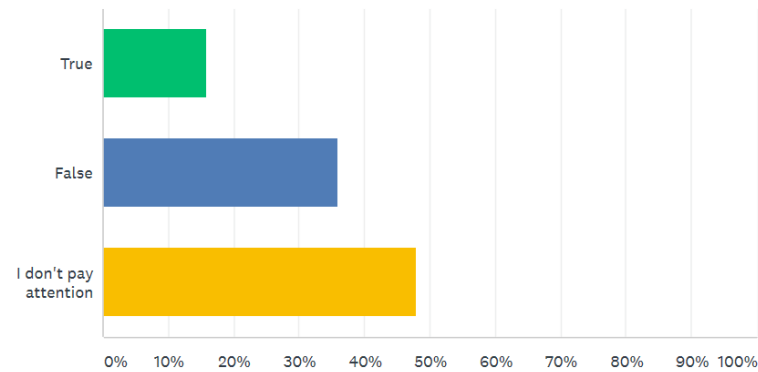
Chasing arrow symbol on a package means its recyclable.

Answered: 100 Skipped: 0



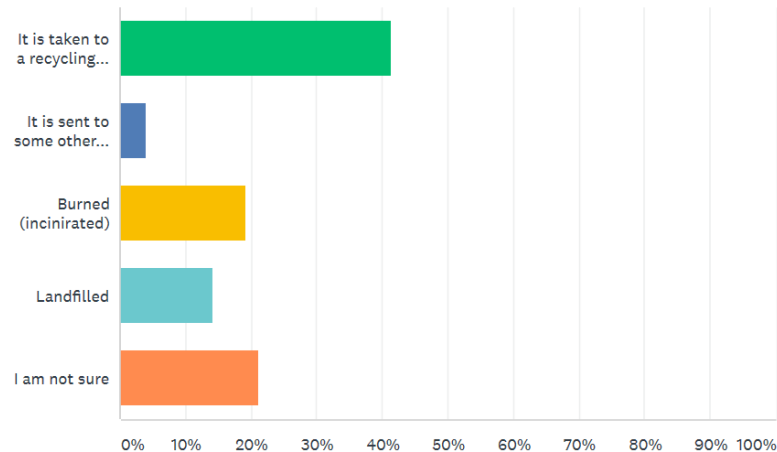
I buy a product only if its plastic package is recyclable.

Answered: 100 Skipped: 0



After I put my plastic bag in a trash can, this is what most likely happens with it:

Answered: 99 Skipped: 1



When home, I put my chips/crisps plastic bag in the following trash bin:

Answered: 100 Skipped: 0

