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Increasing the circularity of high barrier flexible plastic packaging

Results from WP1: Market analysis

Hanna Unsbo, Emma Strömberg, Alexandra Maria Almasi

Author: Hanna Unsbo, Emma Strömberg, Alexandra Maria Almasi
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IVL Swedish Environmental Research Institute Ltd.
P.O Box 210 60, S-100 31 Stockholm, Sweden
Phone +46-(0)10-7886500 // www.ivl.se

This report has been reviewed and approved in accordance with IVL's audited and approved management system.

Preface

This report summarises the results obtained in the first work package (WP1) in the project *Increasing the circularity of high barrier flexible plastic packaging*. The project is financed by Vinnova and lead by RISE.

IVL would like to take the opportunity to thank all project partners who participated and contributed with information and knowledge on the subject. A special thank you would like to be conveyed to Karin Lindqvist (RISE), Mattias Andersson (RISE), Einar Ahlström (FTI) and Rickard Jansson (Swedish Plastic Recycling) who supported the process and contributed to the completion of WP1.

The project group at IVL Swedish Environmental Research Institute

Hanna Unsbo, Junior expert waste and resource flows
hanna.unsbo@ivl.se

Emma Strömberg, Expert Polymeric materials
emma.stromberg@ivl.se

Alexandra Maria Almasi, Expert waste and resource flows
alexandra.almasi@ivl.se

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Acronyms and abbreviations

AlOx	Aluminium oxide
BOPE	Biaxially-orientated polyethylene
BOPP	Biaxially-orientated polypropylene
EAA	Ethylene acrylic acid copolymer
EMAA	Ethylene methacrylic acid copolymer
EVOH	Ethylene vinyl alcohol copolymer
FTI	Förpackningsinsamlingen
HDPE	High density polyethylene
LDPE	Low density polyethylene
LLDPE	Linear low-density polyethylene
MA-g-PE	Maleic anhydride grafted polyethylene
MA-g-PP	Maleic anhydride grafted polypropylene
MMLs	Multi-material laminates (multi-layered structure made up of multiple materials)
MOLs	Mono-material laminates (multi-layered structure made up of a mono material
NIR	Near-infrared
OPP	Oriented polypropylene
PA	Polyamide (nylon)
PE	Polyethylene
PET	Polyethylene terephthalate
PO	Polyolefin
PP	Polypropylene
PUR	Polyurethane
PVdC	Polyvinylidene chloride
Recyclate	Recycled material
SiOx	Silicon dioxide
SPR	Swedish Plastic Recycling

Summary

Plastic packaging constitutes a large part of the total plastic use in Sweden. However, only a limited fraction of all packaging put on the Swedish market each year is recycled. One of the reasons for this is the complex design of many plastic packages, which contributes to challenges when sorting, disassembling, and recycling the collected material into high-value applications. Flexible plastic packaging, namely films, used for packaging groceries/food are especially challenging when it comes to mechanical recycling. This category includes countless multi-layered film structures which often include, for example, barriers and adhesives that may affect the sorting and recycling of the material. In addition, the films often consist of combinations of different types of plastic materials denoted as MMLs in this study, which makes it difficult or prevents the packaging from being recycled into high-quality materials. Preferable to MMLs could be mono-materials, denoted as MoLs in this study, that may provide a higher quality recyclate.

The aim of WP1 was to conduct an initial market analysis to map and quantify the current and future use of complex high barrier MMLs and MoLs on the Swedish market. The market analysis was carried out by studying available literature, both scientific and grey literature, as well as through interviews with relevant stakeholders.

In summary, the following recommendations and conclusions were made. Due to lack of data, the current and future amount of high barrier flexible food packaging that is put on the Swedish market every year could not be estimated. However, a number of suitable MoLs for further study in the following work packages were selected. The suggestions include plastic films of both PE and PP in combination with EVOH, metallisation, SiOx, and AlOx as a barrier. In addition, suggestions are given for both adhesive laminated and co-extruded flexible films.

Keywords: Food packaging, flexible plastic packaging, multi-layered film structures

1 Introduction

Plastic packaging constitutes about 30% of the total plastic use in Sweden (Fråne et al., 2022). Their durability and barrier properties contribute to societal value as they provide protection to the products they enclose. Despite the priorities in the waste hierarchy and the concept of circular economy, most plastic packaging waste is sent to incineration after a very short life cycle instead of, for example, being recycled or reused. In 2021, the recycling rate of consumer plastic packaging put on the market by producers affiliated to Förpackningsinsamlingen (FTI) and Swedish Plastic Recycling (SPR) in Motala[1], was 18.1%. This despite the fact that about 50% of the consumer plastic packaging waste was source separated by the consumers and collected by FTI in 2021 (Swedish Plastic Recycling, 2022). Consequently, almost 82% of the plastic packaging put on the market was either lost or treated by, for example, incineration. One of the reasons for this is the complex design of many plastic packages, which contributes to challenges when sorting, disassembling, and recycling the collected material into high-value applications.

Flexible plastic packaging, namely films, used for packaging groceries/food are especially challenging when it comes to mechanical recycling. This category of plastic packaging includes multi-layered film structures made from multiple materials in several separate layers (here denoted multi material laminates MML). The combination of different materials provides desirable properties such as effective barrier functions and wear-resistance. However, they are incompatible with mechanical recycling. The recycling process remelts the plastic and all the included polymers and/or additives and other materials will end up in the recycled material (recyclate). The mixture of different materials often affects the mechanical properties, stability, and the visual appearance of the recyclate. Mono-material[2] is therefore desirable to achieve a high quality recyclate for use in high-value applications and to meet market demands.

A transition to mono-material often requires several layers of the mono-material with an addition of a very thin barrier layer, for example silicone dioxide (SiOx) or aluminium oxide (AlOx), denoted in this project as a mono-material laminate (MoL). To obtain a good adhesion between the layers, an adhesive is often needed. Another alternative to adhesive lamination is to coextrude a film of several layers, where one layer can act as a barrier. For example, ethylene vinyl alcohol copolymer (EVOH) between two layers of low-density polyethylene (LDPE). Barrier layers as well as adhesives can have a negative impact on the recyclate received from mechanical recycling; however, only few studies have been conducted on what are the impacts and there is a need for more knowledge on the subject. This lack of knowledge is a major obstacle to the industries' conversion to more recyclable and circular plastic packaging. A transition to MoLs, without sufficient knowledge, could lead to sub-optimisation and even worsen the recycling possibilities.

Organizations and actors working towards more circular plastic packaging have proposed that MML structures should be replaced by MoL as they contain limited amounts of barriers and additional constituents. Design-for-recycling guidelines have been published by many of these organisations, such as by FTI. Their guidelines are based on the available infrastructure i.e., what types of packaging designs that are compatible with the existing sorting and recycling processes. The goal is to design packaging that enables high quality sorting at SPR in Motala. The packaging

[1] According to information from FTI and SPR provide extended producer responsibility (EPR) services to the majority of packaging producers in Sweden.

[2] A mono-material is made from a single type of material which for flexible food packaging includes plastic films including a thin barrier layer.

fees producers pay to FTI and SPR are differentiated based on their recyclability according to the design-for-recycling guidelines. Consequently, having well-updated guidelines for flexible food packaging is thus of great interest for the concerned stakeholders.

1.1 Aim and objectives

The overall aim of this project is to increase recycling of plastic food packaging in Sweden. The project is divided into five separate work packages (WPs) with different focus areas. The aim of WP1 is to conduct an initial market analysis to map and quantify the current and future use of complex high barrier MMLs and MoLs on the Swedish market. In addition, WP1 also intends to study the current developments, trends, and design for recycling guidelines for such packaging. The following objectives are considered:

1. Map the current use of complex MMLs and MoLs for flexible food packaging on the Swedish market, including to which extent MoLs are replacing MML to increase recyclability.
2. Investigate the quantity of MMLs and MoLs placed on the Swedish market as well as how the quantities are expected to change in three to five years' time.
3. Investigate current development trends and design for recycling guidelines for such packaging.

The results from WP1 will serve as input to the selection of MoL to be used in WP2 (sorting) and WP3 (recyclability), and as background information to the development and updating of FTI's and SPR's design-for-recycling guidelines in WP4. Within the scope of the study was to investigate the largest volumes of flexible food packaging placed on the Swedish market. The study was limited to explore the impact of certain barriers and adhesives in consideration while other aspects, such as coatings and lacquers, where excluded.

2 Methodology

WP1 is based on a *literature survey* as well as an *interview study* conducted between November 2021 and September 2022.

2.1 Literature survey

A literature review of both scientific and grey literature on market trends and the use of MMLs and MoLs as well as current design-for-recycling guidelines was conducted. The literature was obtained both from other project partners as well as through a systematic review of relevant studies utilising Google Scholar. Search words included *'flexible packaging'*, *'flexible films'*, *'high barrier'*, *'EVOH'*, *'plastic films'*, *'design-for-recycling'* as well as various combinations and phrases including the aforementioned words. Information has also been retrieved from companies' websites linked to, for example, guidelines for design-for-recycling.

2.2 Interview study

Interviews and other types of dialogue was conducted with relevant stakeholders such as producers of plastic films and packaging, fillers/brand owners as well as producers of adhesives and EVOH. Actors active on both the Swedish and international market were consulted, as well as European forums such as RecyClass and the packaging group within Circular Plastics Alliance. Interviews were conducted with all project partners in early 2022 between January and April, see list of partners in Appendix I. Additional interviews were also conducted with other stakeholders such as material suppliers, for example Maag GmbH and Schur.

Depending on the type of stakeholder, questions were developed adapted to the organisation's area of work. A summary of selected example questions asked during the interviews can be found in Appendix II. Organisations were roughly divided according to the different types of stakeholders presented in Figure 1, to ensure that similar companies received similar questions.

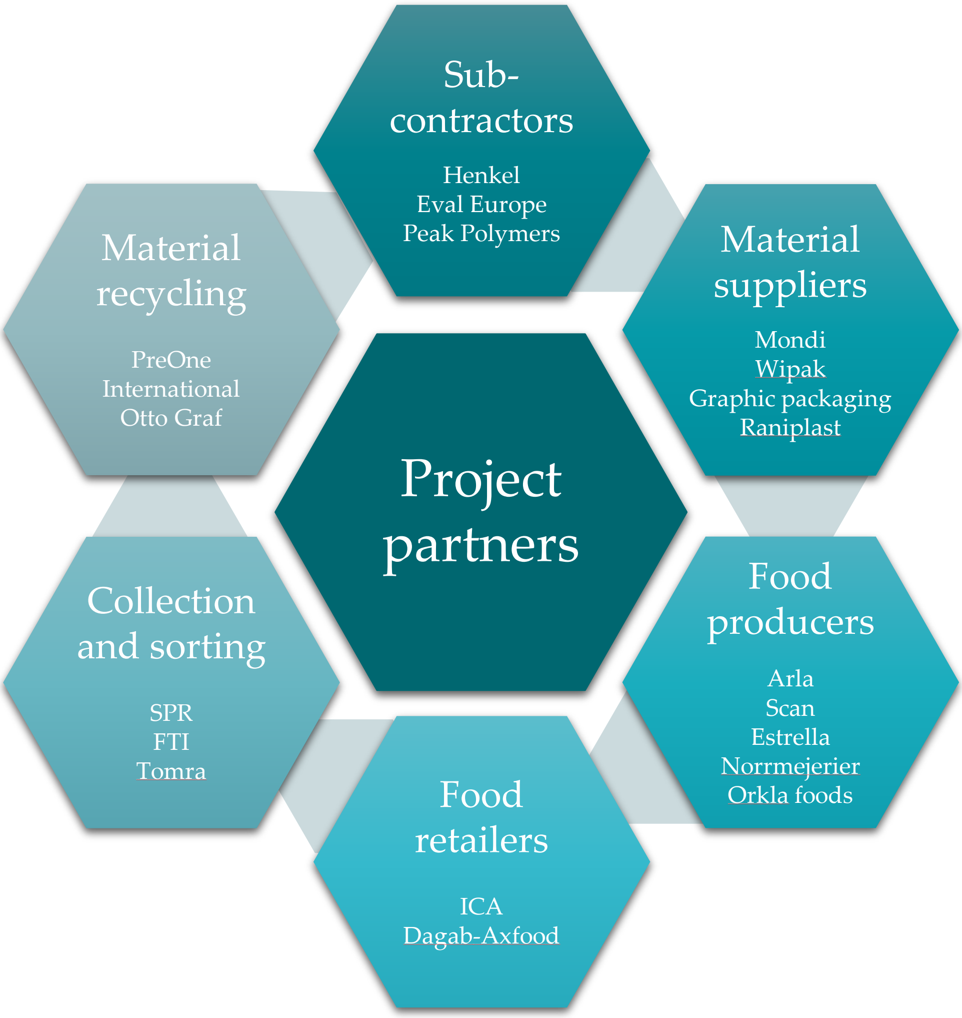

Figure 1: Illustration of all project partners as well as the categorisation of different stakeholders.

3 Results

The results chapter is divided into four main sections. Firstly, the general structure of multi-layered flexible food packaging is presented. Secondly, the current situation in Sweden and future trends are presented followed by a summary of different design-for-recycling guidelines. Finally, the MoLs that are proposed for further study in WP2 (sorting) and WP3 (recyclability) are presented.

3.1 Composition of multi-layered flexible plastic packaging

Multi-layered flexible plastic films are available in a broad number of combinations with different thicknesses, number of layers and barrier materials. Based on the interviews, the thickness is generally 30 to 100 microns for flexible plastic packaging. In addition, the number of layers varies significantly between different structures, which largely depends on the function that is required. This section describes the common materials found in flexible food packaging, relevant barriers, common methods for adhering the layers of the multi-layered structure, and a summary of the information gathered connected to coatings, lacquers, and printing.

3.1.1 Common plastic polymers and layers in food packaging

Flexible high barrier plastic food packaging generally consists of combinations of PE and PP as well as other polymers that contribute with the required barrier properties. In Table 1, commonly used polymers and barrier materials as well as their function are presented.

Table 1: Common plastic polymers and layers in flexible food packaging as well as their respective functions in a multi-layered packaging structure. In addition, common packaging applications for each of the materials. The information is based on technical report by Ceflex (2020a), Mieth et al (2016) and information obtained from the conducted interviews.

Barrier	Functions in a multi-layered structure	Examples of packaging applications
AlOx	Gas barrier	In products that require an excellent gas barrier
Aluminium foil	Gas/aroma barrier, moisture barrier, UV light barrier	Chips, snacks, coffee, powders
EVOH	Gas/aroma barrier	In many different products requiring a good gas/aroma barrier such as cheese and meat
Metallisation (aluminium vapour coating)	Gas/aroma barrier, moisture barrier, UV light barrier	In products that require a very good gas barrier such as chips and snacks

Polyamide (PA)	Provides mechanical strength, puncture resistance, heat resistance, limited gas/aroma barrier	Packaging used for dairy products (e.g., cheese) and meat
Polyethylene (PE)	Heat sealable layer that may be in contact with the food, moisture barrier, combined with other polymers	Groceries/food products
Polyethylene terephthalate (PET)	Aroma barrier, moisture barrier, provides mechanical strength, heat resistance	Meat trays, take away packaging, cheese and ready meals
Polypropylene (PP)	Moisture barrier, mechanical strength, combined with other polymers	Groceries/food products
Polyvinylidene chloride (PVdC)	Gas/aroma barrier, moisture barrier, protecting the surface from e.g., scratches	Currently very limited use
SiOx	Gas barrier	In products that require an excellent gas barrier

Relevant barriers for this project

Barriers are necessary to achieve the function, shelf life as well as to secure the food safety that is required. In this study, the following barriers are considered relevant for further studies in WP2 (sorting) and WP3 (recyclability). These are considered relevant as they were identified to be fully compatible or to have a limited impact on mechanical recycling and allows a high quality recyclate.

- EVOH
- Metallisation
- SiOx
- AlOx

According to the information that was provided by the stakeholders during the interviews, the thickness of a layer of EVOH is about 1 to 3 microns and it generally constitutes around 5% of the total weight of the flexible plastic film. EVOH is used for many different types of groceries/food products and is one of the most widely used barrier materials. Moreover, there are different grades of EVOH on the market that are used in high barrier multi-layered food packaging. Metallisation is often used for products such as snacks and chips, which is required for products that may otherwise be adversely affected by UV light. The vacuum deposited aluminium layer is usually a couple of nanometres thick (Netherlands Institute for Sustainable Packaging (KIDV), 2021). SiOx and AlOx are used in some grocery/food products. These barrier materials provide a god gas/aroma barrier and as well as against moisture. The layers of SiOx and AlOx are relatively thin, compared to for example EVOH, as the layer is applied to the structure through vacuum deposition (APR, n.d.). However, based on the conducted interviews in this study, these barrier materials ae not used to the same extent as, for example, EVOH as they are relatively expensive.

Oriented flexible packaging films

The concept of oriented films refers to thermoplastic films that were stretched during the productions process, either in a uniaxial or biaxial direction. For example, oriented PP (OPP), biaxially-orientated PP (BOPP) and biaxially-orientated PE (BOPE). Orientation changes the properties of a material. Orientation of thermoplastics can improve optical and barrier properties, increases clarity, facilitate the materials ability to shrink when heated and increase the toughness of the material (Ajji and Zhang, 2002; Plastic Recyclers Europe, 2020).

3.1.2 Bonding/adhesion between layers

Multi-layered flexible packaging is produced in one of two different processes, either through co-extrusion or by lamination with adhesives.

Co-extrusion

A multi-layered structure can be achieved through co-extrusion by simultaneous extrusion of hot-melts. The continuous process allows a combination of one or more materials to be combined (Vynckier et al., 2014). Each material requires a separate extruder, and the layers are adhered by tie-layers. A tie-layer allows dissimilar materials to be adhered despite of their differences and chemical resistances towards each other (Biomerics, n.d.). Based on the interviews, examples of commonly used tie-layers are ethylene acrylic acid copolymer (EAA), ethylene methacrylic acid copolymer (EMAA), maleic anhydride grafted polyethylene (MA-g-PE) as well as maleic anhydride grafted polypropylene (MA-g-PP).

Adhesive lamination

Adhesion lamination where adhesives are used, two or more plastic films are adhered together in a multi-layered structure. During the course of the project, it has become clear that the concepts of "*laminate*" and a "*multi-layered structure*" must be distinguished. According to a number of interviewed stakeholders, a “*laminate*” specifically refers to an adhesion laminated flexible film. A “*multi-layered structure”* refers to a plastic film made up of two or more distinctive layers. In this report, the distinction between the two concepts is made and the definition applied.

Based on the interviews, each layer of adhesive is about 1-3 microns thick and consists largely of polyurethane (PUR) based adhesives. Adhesive used for flexible packaging structures can either be solvent-based or solvent-free. In addition, there are two types of adhesives aromatic and aliphatic. The latter can be favourable for the material recyclability of a flexible food packaging as it does not affect the colour of the recyclate as much as an aromatic adhesive. However, aliphatic adhesives are much more expensive than an aromatic adhesive. Consequently, aromatic adhesives are more commonly used for food packaging at this time. During the mapping, it was found that there is limited knowledge of the impact that adhesives have on the recyclability of flexible food packaging. Moreover, there are different grades of adhesives on the market and different adhesives have different properties. Some of the technical properties that are important for an adhesive is the behaviour when exposed to heat, the behaviour when a plastic film is rolled up as well as chemical content.

3.1.3 Coatings, lacquers, and printing

This study does not consider coatings, lacquers, and printing when proposing MoLs for further study of the impact on the sorting and recycling of high barrier flexible food packaging. However, some information and knowledge were gathered under WP1 which is presented below.

- Multiple stakeholders are interested in further studying lacquers to establish the impact on sortability and recyclability. The lacquers are often required to counteract that the printing is damaged.

- According to some of the contacted stakeholders, new varnishes are being developed that, in addition to protecting the outermost layer and printing, may act as a barrier. The hope for a surface varnish with a barrier function is that it will lead to reduced impact on recycling. However, there are no studies or tests that demonstrate this as it is an innovative solution.
- When recycling, especially PP film, the binder in the paint can cause major problems. This mainly includes nitrous cellulose binders as this cause the recyclate to burn when the material is heated up which adversely affects the quality of the recyclate.

3.2 Current use of high barrier flexible food packaging in Sweden

Relevant data for estimating the amount of high barrier flexible food packaging put on the market in Sweden was difficult to access. Data that could have contributed to more precise estimations of the quantities are, for example, sales data, data on production of flexible plastic films or other relevant information. In this study, rough approximations have been made based on information from a Swedish food retailer and SPR. Unless otherwise stated, the information used in the following chapter was provided by SPR or the Swedish food retailer. It was only possible to estimate the total amount MMLs and MoLs put on the market in Sweden, amounts for specific high barrier plastic food packaging was not possible.

According to the official packaging statistics, 221 000 tonnes of plastic packaging were put on the Swedish market in 2020, of which 131 800 tonnes were consumer packaging that is mainly used by households (Fråne et al., 2022). The collection rate was slightly more than 50% of plastic packaging put on the market in 2021. Consequently, almost half of the plastic packaging is not collected for recycling but rather the packaging ends up in another waste stream (e.g., mixed municipal waste). The collection rate presented above represents household plastic packaging excluding PET bottles that are treated in a separate system. Based on sorting efforts done by hand of a limited amount of collected materials sent to SPR in 2022, the collected material contained by weight about 54% rigid and 46% flexible plastic[3]. An analysis of the distribution between different types of flexible plastic is presented in Appendix IV, which is based on the aforementioned sorting efforts.

A majority of the producers of household plastic packaging in Sweden are affiliated with the producer responsibility (EPR) scheme provided by SPR and FTI. When an affiliated producer of plastic packaging sets products on the market, they are required according to *Directive (EU) 2019/904 on the reduction of the impact of certain plastic products on the environment* to report to the Swedish Environmental Protection Agency which is done through the producer responsibility organisation. The producers are, however, not required to report the type of plastic or if it is flexible or rigid packaging. The producers can in general be divided into three categories – convenience/grocery goods, specialty/shopping goods, and other. Based on the different segments, the share of flexible packaging put on the market was estimated. Convenience/grocery goods is the largest group with an estimated share of 61% of the flexible plastic packaging being put on the market, see Figure 2.

[3] Jansson, Rickard. Development engineer at SPR. Email 23rd of August 2022.

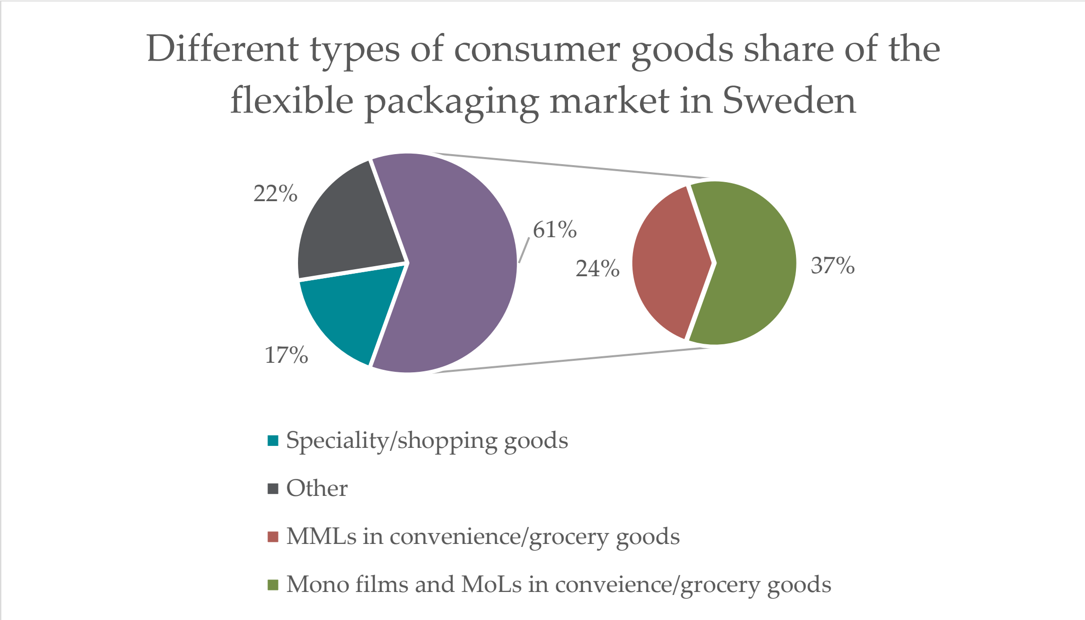

Figure 2: Share of the flexible packaging market in Sweden for different segments of consumer goods as well as the share of MMLs and MoLs in convenience/grocery goods[4]. The total share of convenience/grocery goods accounts for 61%, marked with purple in the figure, of the total share of the flexible packaging market.

To enable estimations of the amount of flexible food packaging put on the Swedish market each year, data provided by the Swedish food retailer was used as a basis for further assumptions and calculations. The provided data was used as proxy-data for all grocery goods sold in Sweden. Out of the estimated 61% convenience/grocery goods, about 24% of the total share is estimated to be MMLs and 43% mono films and MoLs (see Figure 2). This is based on the assumption that MMLs are only used within the segment convenience/grocery goods. Out of the plastic films used for convenience/grocery products, it is assumed that MMLs constitutes 39% of the total usage and mono films and MMLs 61%.

In this study, it was estimated that about 22 600 tonnes mono films and MoLs and 14 400 tonnes of MMLs were introduced to the Swedish market as flexible packaging for convenience/grocery goods in 2020 (see Table 2). A summary of the main assumptions is presented below:

- 46% of the 131 800 tonnes of consumer plastic packaging put on the Swedish market is assumed to be flexible packaging
- 61% of the flexible consumer packaging is assumed to be used for convenience/grocery goods
- 39% of the flexible convenience/grocery packaging is assumed to consist of MMLs and 61% MoLs and mono materials

3.3 Future prospect of high barrier flexible food packaging in Sweden

Complex high barrier flexible plastic packaging is an important asset for the protection and preservation of food. There are no other suitable materials on the market that can substitute flexible

[4] Jansson, Rickard. Development engineer at SPR. Email 23rd of August 2022.

multi-layered plastic films today. Flexible food packaging is thus necessary, and the materials are continuously evolving with new discoveries, technological developments, and other aspects such as the transition to a circular economy. In this study, it was not possible to quantify the change in usage of MMLs and MoLs over the coming years. Instead, a summary of the identified trends is presented in Table 3. Unless otherwise stated, the basis of the presented information was obtained from the conducted interviews with relevant stakeholders and project partners.

Table 2: Current and future trends connected to flexible plastic food packaging.

Trend	Description
Recyclability (e.g., design-for-recycling guidelines)	Today, there is a focus on increased recycling of flexible plastic packaging. To increase recycling, reports such as the ones from Plastic Recyclers Europe (2020, 2019) as well the conducted interviews suggest that one of the most important aspects is design-for-recycling. Designing packaging to facilitate recycling and entail that the material can be used in high-value applications is considered an efficient approach to increase the recycling rate. According to Plastic Recyclers Europe (2019), one of the challenges limiting the recycling of PE-films is specifically a lack of design-for-recycling.
Down gauging	Down gauging - reducing the thickness of plastic films has been a trend in later years. The amount of plastic required for each package has thus been reduced, resulting in more efficient material use. Down gauging remains an important development and trend when it comes to multi-layered flexible packaging.
Biobased alternatives	There are indications that the share of biobased plastics will increase on the European market in the future. For example, European Bioplastics presents numbers demonstrating that the global production might triple in the coming five years (European Bioplastics, n.d.). However, fossil-based alternatives will continue to account for the majority of the market even if the production of bio-based plastics increases.
Mixed materials	Some stakeholders have observed an increased use of packaging utilising a mix of different materials such as combinations of plastics and paper. Combinations like these can cause issues during recycling due to, for example, the packaging not being separated correctly by consumers.
Innovation and new technology	The field of flexible food packaging is continuously undergoing major changes and new discoveries are taking place all the time. There are several factors that contribute to the constant development such as new legislation and regulations, competition between material suppliers, and changes in consumer behaviour and perception. Innovative solutions, materials, and technology are a major part of the development of the packaging industry and many stakeholders mention this as one of the future trends.
Increased use of flexible packaging	Multiple stakeholders expressed that the demand for flexible plastic packaging is increasing within Europe. This is supported, at least for PE-based flexible films, by a report presented by Plastic Recyclers Europe (2020). In addition, the Ellen MacArthur Foundation recognises flexible packaging as the fastest growing packaging category (Ellen Macarthur Foundation, n.d.)
Increased MoLs	With the focus on increased recyclability and design-for-recycling within the industry of flexible plastic packaging, the proportion of MoLs is

	predicted to increase. According to several of the guidelines presented in both Sweden and the EU, a summary is presented in chapter 3.4, flexible packaging with a mono-material structure is preferred. Many of the companies that were interviewed specified that they try to develop packaging that can be recycled according to the guidelines that applies for different market.
Increased use of PP	According to several of the stakeholders, the use of PP is expected to increase in the coming years. The material can be used in applications where certain mechanical properties, such as rigidity, are sought which PE-based films cannot achieve. In addition, some of the stakeholders pointed out that PP recyclate can be used in a larger number of products compared to PE, which may influence the use of the material as high value recycling might be facilitated.
Increased use of oriented films	Oriented PP and PE films contribute to a change in the properties of the materials. When moving towards MoLs, the use of these films is predicted to increase to meet the product requirements of the flexible plastic packaging.

Increased use of MoLs and the transition from MMLs is one of the identified trends. However, there are obstacles that affect and complicate this transition. Some of the common hurdles limiting the transition to MoLs are described below.

Food safety and functionality of the material

The main concern of plastic film manufacturers, food/grocery producers as well as the retailers is that the material retains the functionality required to ensure food safety. Transitioning the food packaging industry from MMLs to MoLs is only possible if this does not adversely affect food safety. The different layers of a multi-layered plastic film have an intended function, such as barriers, which can be difficult to mimic or achieve with a mono-material. For example, PA contributes with puncture resistance that is difficult to replicate, which makes the polymer difficult to replace. The introduction and use of MoLs is thus not always possible as the functionality cannot be achieved. Cheese, nuts, and coffee are some of the products with great demands on the function of the packaging where MoLs may not always be suitable.

Shelf life

The shelf life of various groceries and types of food is profoundly affected by its packaging. To prevent products from being spoiled, advanced flexible plastic packaging has been developed specifically for different product requirements. When shifting to a new packaging, it is often a requirement from the food producers and retailers that the new innovative material can meet the required shelf life. This means that new materials must undergo comprehensive testing to ensure food safety and the required shelf life. The longer shelf life a product has, the longer the testing will take as the material will have to go through full scaled tests under real life conditions to be approved. In conclusion, the total time required for the implementation of new packaging varies depending on the products.

Currently used machinery production rate

The packaging process of groceries and food requires complicated and expensive machinery and technology. Many of the companies have been developing their technology for a long time and have specialized their processes to increase production speed and reduce waste. According to several stakeholders, new materials cannot be replaced without major changes to the process and settings on the machines. In addition, in some cases completely new machines may be required which is costly. Transitioning from MMLs to MoLs will entail a lot of work and investments by relevant stakeholder. This contributes to a need for changes to be able to be justified. For example, one way of justifying the change is that the new material is recyclable and approved by producer responsibility organisations like FTI resulting in a lower packaging fee. However, there is generally a requirement that the production rate is not significantly affected by the adoption of an innovative material. If fewer products can be produced per hour, revenues are reduced, which generally does not motivate a change of material, including a switch from MMLs to MOLs.

Developing new packaging is time consuming and costly

As already mentioned, the process of introducing new flexible food packaging is time consuming due to the comprehensive testing that is required. In addition, the innovative processes of developing, marketing, and testing of new flexible multi-layered films are costly for the related stakeholders. It requires large investments of resources, great knowledge in innovative technologies and materials as well as research to develop the new materials.

3.4 Design-for-recycling guidelines

There are many different guidelines developed to provide guidance to packaging producers and designers on how to design recyclable packaging. A summary of a selection of different design-for-recycling guidelines is presented in Table 4. In addition, in Appendix IV an assortment of relevant criteria has been summarised for each of these guidelines. Some of the guidelines, such as FTI's and Citeo's, are connected to EPR schemes. The guidelines act as a basis for the differentiated fees producers have to pay EPR organisations for collection, sorting and recycling of packaging that the producers put on the market. Others, such as RecyClass and Ceflex, have been developed as international guidance by either non-for-profit companies or industry collaborations.

Table 3: A summary of a selection of design-for-recycling guidelines.

Organisation	Region	Includes criteria directed towards flexible packaging	Comment
FTI	Sweden	Yes	Concerns both PE and PP flexibles
RecyClass	Europe	Yes	Concerns both PE and PP flexibles
Ceflex	Europe	Yes	Concerns both PE and PP flexibles
Citeo	France	No*	No guidelines were found for flexible packaging. However, they do have a fee modulation that includes flexible PE.
Cyclos-HTTP	Europe	No*	No guidelines for flexible packaging were found
COTREP	France	Yes	One set of criteria specifically for PE-flexibles as well as

			another one for other flexibles
APR	Europe	Yes	One specifically for PE and one for PP, however, the latter does not cover only flexible PP
RECOUP	Europe	Yes	Follows the criteria presented by RecyClass
Efficient Consumer Response (ECR)	Global	Yes	Concerns both PE and PP flexibles
Der Grüne Punkt	Germany	Yes	Includes a set of guidelines for films made of LDPE, LLDPE and HDPE as well as one for mixed plastics/mixed PO (which does not only refer to flexible plastic)
Netherlands Institute for Sustainable Packaging (KIDV)	The Netherlands	No*	The guide includes a decision tree which enables the user to answer (yes or no) to a set of questions to determine the recyclability

*No guidelines were found that contained specific criteria connected to flexible plastic packaging. However, the guidelines provide relevant information in regard to recyclability of flexible plastic packaging.

According to interviewed stakeholders, they usually follow the guidelines from RecyClass or Ceflex. In addition, FTI's criteria differ in some respects significantly compared to other guidelines. This has been stated as an issue as many food producers and retailers are putting products on multiple markets in different countries. Developing flexible packaging that are recyclable according to multiple guidelines, especially those that differ significantly from many of the others, can act as an obstacle when developing recyclable packaging. Harmonisation between different guidelines may be preferable but a challenging topic.

3.4.1 Sorting possibilities at SPR based on current technology

At the Swedish sorting facility in Motala, SPR handles post-consumer plastic food packaging. At present, one flexible plastic fraction is sorted out consisting of flexible PE. Upon introduction of SiteZero, the number of fractions will be expanded to include two flexible fractions, one for PE and one for PP. The sorting machines at SPR's facility were developed by Tomra and the machines utilise a combination of near-infrared (NIR) technology and visual light-technology. The NIR-technology allows different types of polymers to be sorted due to the inherent and individual wavelength. Visual light-technology contributes to the ability to sort out different colours.

In theory, the technology provided by Tomra can sort out all different types of plastic as all of them have individual wavelengths. The detector identifies a materials spectrum, and the materials are separated accordingly. However, one machine can only sort out one targeted plastic fraction at a time depending on the settings of the machine. If multiple fractions are to be sorted out a combination of multiple machines is required. In general, the plastic fractions they sort out are based on the markets and the customers' demands. Some of the fractions that are currently sorted out using Tomra's technology around the world are PET of different shapes (bottles and trays) as well as colours, PS, XPS flexible PE and ABS. The machines are equipped to separate multi-layered structures consisting of several materials from the homogeneous material stream. As all plastics have specific wavelengths, a combination of different plastic materials will also contribute to a unique spectrum. However, the machine needs to be able to identify the specific spectrum to enable the material to be sorted out correctly.

Aspects that impact the sorting

There are various aspects and problems that impact the sorting. The ones that were presented by Tomra are:

- Material such as plastics coloured with carbon black as well as materials that they do not have a dataset for are nondetectable. Both these examples impact the ability to detect and separate the material correctly by the machines.
- The shape, weight and size of the plastic can affect how well it can be sorted. For example, if the plastic is too small the machine will not be able to detect it.
- The thickness of the outer layer impacts the sorting of different materials. For example, if the outer layer is thick, the inner layers will not be identified, and the material may be wrongfully discarded or separated into an unsuitable fraction. The maximum depth the machine may identify the individual wavelength is about 50 micrometres; however, it depends on the material.

Obstacles for developing the NIR-technology and the transition towards MoLs

Due to increased use of high barrier MoLs there is a need for further development of the NIR-technology used for sorting plastic waste. The transition towards new materials is affected by various obstacles.

- New multi-layered plastic food packaging requires new datasets to be developed, to enable the material to be detected. Each of the plastic food packaging put on the market needs a specific dataset to enable the packaging to be detected and separated correctly.
- The large number of flexible food packaging contributes to a large number of datasets to be required. Each flexible plastic film and the corresponding dataset needs to be classified to enable the material to be sorted corrected. For example, a PE based structure containing EVOH must be classified as either recyclable if the percentage of the barrier is less than the limit or as residual waste if the EVOH content is too high. The process of classifying a dataset to a specific plastic fraction is difficult, especially for multi-layered plastic packaging. The risk of mistakes being made increases with the number of datasets.
- There is a lack of knowledge about the composition of different flexible packaging. Without in-depth information about different plastic films, the development of needed datasets is haltered.

4 Recommendations and conclusion

During the study, it was identified that, in accordance with similar reports and perceptions by stakeholders, that there is a lack of relevant and available data sources to be able to estimate the amount of high barrier flexible plastic food packaging put on the market each year. Data that could have been of interest are, for example, sales or production data of flexible plastic films, however, this information has not been obtainable. Even though some data could have been provided by a few stakeholders, it is not possible to scale up the obtained data to be representative for the Swedish market as a whole. This due to the large number of stakeholders associated with the production, use and recycling of flexible plastic food packaging and not all have been consulted in this study. In conclusion, it has thus not been possible to estimate the amount of the most common flexible plastic films used for food packaging in Sweden today or expected changes in a three to five years' time. However, a number of suggestions for suitable plastic films for further studies within this project have been developed based on the literature survey and conducted interviews.

The MoLs that are suggested as relevant to be studied further in WP2 (sorting) and WP3 (recyclability) are presented in Table 5. The proposed flexible plastic films are based on the conclusions from the interviews and knowledge obtained within this WP. These suggestions were discussed and developed in consultation with other project partners, such as RISE, SPR and FTI and material suppliers.

Table 4: A summary of the suggested MoLs for further tests in WP2 and WP3.

Main polymer	Laminated/ co-extruded	Composition of MoL	Comment (including a description and rationale of the suggestion)
PRIMARY SUGGESTIONS			
PE	Co-extruded	PE/EVOH/PE/EVOH/PE	A co-extruded multi-layered structure made of PE and EVOH. Allowing the impact of EVOH on the recyclability to be studied.
PE	Co-extruded	PE/EVOH/PE	A co-extruded multi-layered structure made of PE and EVOH. Allowing the impact of EVOH on the recyclability to be studied.
PE	Laminated	BOPE/Adh/PE/EVOH/PE	An adhesive laminated flexible film where a BOPE-film and a co-extruded film containing PE and EVOH have been adhered. Allowing the impact of a combination of EVOH and adhesives on the recyclability to be studied.
PP	Co-extruded	PP/EVOH/PP	A co-extruded multi-layered structure made of PP and EVOH. Allowing the impact of EVOH on the recyclability to be studied.
PP	Laminated	OPP/Adh/PP/EVOH/PP	An adhesive laminated flexible film where an OPP-film and a co-extruded film containing PP and EVOH have been adhered. Allowing the impact of a combination of EVOH and adhesives on the recyclability to be studied.
PP	Laminated	OPP/Adh/Metallisation/OPP	An adhesive laminated flexible film where an OPP-film and metallised OPP have been adhered. Allowing the impact of a combination of metallisation and adhesives on the recyclability to be studied.
SECONDARY SUGGESTIONS			
PE	Laminated	BOPE/Adh/PE	An adhesive laminated flexible film where a BOPE-film and a PE-film have been adhered. Allowing the impact of adhesives on the recyclability to be studied.
PP	Laminated	OPP/Adh/PP	An adhesive laminated flexible film where an OPP-film and a PP-film have been adhered. Allowing the impact of adhesives on the recyclability to be studied.
*N/S**	*N/S**	*N/S**	A flexible film containing either SiOx or AlOx. Allowing the impact of either SiOx or AlOx on the recyclability to be studied.

*N/S (not specified) entails that a specific structure has not been determined for this suggestion. However, the barrier is considered to be of interest for WP3.

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Appendix I – List of project partners

Organisation	Role in project
RISE IVF AB	Project manager, research, and lead of WP 3
IVL Swedish Environmental Institute	Research, lead of WP 1
FTI AB	Responsible for collection of plastic packaging
Mondi	Material supplier, film experts
Eval Europe	Expert EvOH
Peak Polymers	Swedish representative for Eval Europe
Wipak	Material supplier, Film experts
AR Packaging	Material supplier, Film experts
Estrella	Snacks producer, packaging requirements
Orkla Foods	Food producer, functionality tests
Scan	Meat products, packaging requirements, functionality test
Arla	Dairy products, requirements
Normejerier	Dairy product producer requirements on packages
ICA	Grocery supplier; sustainability strategies
Axfood	Grocery supplier; sustainability strategies
Swedsih Plastic Recycling	Sorting plant, lead WP2
Tomra	Expert in NIR technology
PreOne International	Supplier of washing plants, recycler
Raniplast	Plastic film producer, recipient of recyclate
Otto Graf GmbH	Plastic film producer, Recipient of recyclate
Henkel	Adhesive producer & expert

Appendix II – Example questions for interviews

- Which multi-layered plastic films are most common in your packaging today? For which products are they used?
- Which of your products requires the most complex packaging? Why?
- How much of the different types of multi-layered plastic films do you buy/use annually?
- How well do you know the details of the multi-layered plastic films you use? For example, the number of layers, the thickness and type of adhesive/tie layer used.
- Do you have packages where the ink is placed underneath one of the top layers of the multi-layered plastic films instead of on the surface of the plastic film?
- What barriers do you use in your packaging? For what products?
- Have you seen any changes or identified any future trends connected to flexible packaging?
- Can you see any problems connected to the transition towards MoLs?
- Are there situations where MMLs are more favourable than MoLs?
- Do you consider any design-for-recycling guidelines when developing/choosing your packaging?
- Are you familiar with FTIs design-for-recycling guidelines? Is there anything in their guidelines that you consider unclear?
- Do you know how recyclable your packaging is?

Appendix III – Material distribution of flexible packaging based on data from SPR

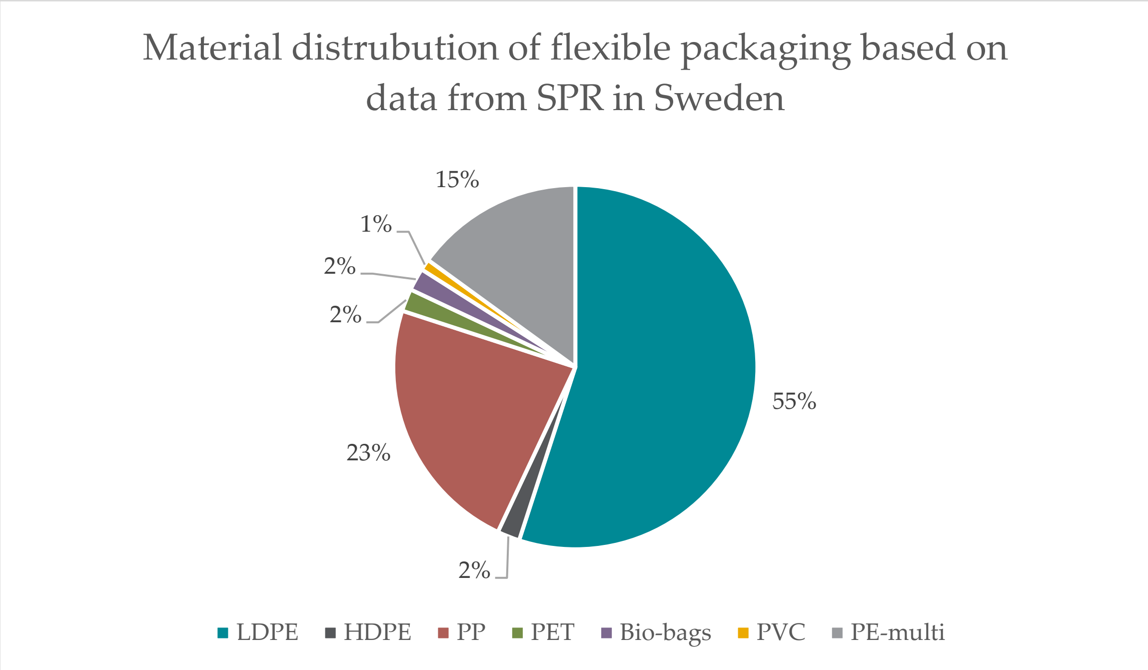

Figure 3: Material distribution by surface of flexible plastic packaging measured by NIR scanners of collected materials. The distribution was measured during two weeks of operation in May 2022 in SPR's sorting plant in Motala.

The sorting efforts carried out by SPR in 2022 mean that the distribution of flexible packaging plastic packaging on the Swedish market could be studied. The NIR-sensors categorized 15% of the collected material as multi-materials flexible films. Meanwhile, the estimation based on data provided by a Swedish food retailer which was used as proxy-data for all grocery goods sold in Sweden. According to this method approximately 24% of the flexible plastic packaging put on the Swedish market is MMLs. There are multiple potential reasons for the discrepancies between these estimations. For example, there could be different collection rated for different types of material put on the market. A possibility is that there is a lower collection rate for multi-material packaging used for fresh products such as meat, fish, or cheese as these may not sorted out by the consumer due to the packaging contain a lot of sticky food residues. In addition, other reasons for the discrepancies could be wrongful categorisation of the NIR-sensors due to thick outer layers or an overestimated share of multi-material put on the Swedish market.

Appendix IV – Summary of different design-for-recycling guidelines criteria

Table 5: A summary of a selection of different design-for-recycling guidelines and their respective criteria connected to flexible packaging. Most guidelines utilise a "traffic light"-system to evaluate the recyclability of packaging where green signalises fully compatibility and yellow limited compatibility with today's recycling technology. This summary includes the criteria for both the compatible and the limited compatibility.

Organisation	Source	Barrier	Adhesives for bonding layers	Colour	Printing and labels	Inks and lacquers	Additives and fillers
FTI	(FTI, n.d.; Swedish Plastic Recycling, 2021)	i. EVOH, max 2% by weight ii. SiOx iii. AlOx iv. Metallisation *If it can be ascertained that the barrier does not impede identification and sorting of the packaging*	Multi-layered materials must not be joined together with glue/adhesives	Unpigmented or pale colours. However, black is not accepted	Printing and labels cover <60% of the outer surface. Includes e.g., PE, PP, PET and PLA labels with water soluble glue	Not determined	All materials must be free of fillers (e.g., chalk, talc, wood fibre)
RecyClass	(RecyClass, n.d., n.d.)	i. <5% EVOH ii. SiOx, AlOx and metallised layers without additional coatings *As well as a couple of specific tested and approved barriers*	Not determined	Unpigmented, light colours or NIR-detectable dark colours	Printing covering <50%. Water soluble or water-releasable at less than 60°C adhesives. PE,PP or paper labels without fibre loss	Non-toxic inks (according to EUPIA guidelines)	Additives that do not increase the density >0,97 g/cm³
Ceflex	(Ceflex, 2020b)	i. Laminated and printed metallised layers	Polyurethane, acrylic, and natural rubber latex	Clear, natural, or pale colours. For darker colours, NIR	Same material of the label as the main material. If other material, a label size of <	Lacquers and inks (without PVC binders)	Additives and fillers are permitted but usage should be

		ii. AlOx, SiOx, EVOH, PVOH, Acrylic <5% (compatible) >5% (limited compatibility)	adhesives as well as non-PE or non-PP based tie-layers <5% by weight (compatible) or >5% (limited compatibility)	detectability is recommended	30% on each side facing NIR-machine and easily removable	<5% (compatible) or >5% (limited compatibility)	minimised. A density < 1 g/cm³ is required
Citeo	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cyclos-HTTP	N/A	N/A	N/A	N/A	N/A	N/A	N/A
COTREP	(COTREP, n.d.)	i. EVOH with tie layer ii. Black carbon in internal layer iii. Coating SiOx, AlOx		Colourless and all colours except from non-detectable black colorants in external layer	Laser marked and direct printing – not washable ink at room temperature Labels utilising water releasable at room temperature and without residue on packaging and made out of: i. PE with a water releasable adhesive (without covering conditions) ii. Paper with a water releasable adhesive iii. PE with a not water releasable adhesive iv. Plastic d>1 with a water releasable adhesive (ex. PET, PETG, PS)	EuPIA Good pratice	Expanded/foamed PE d<1 (gaz, blowing agents)
APR (guidelines specifically for flexible PE)	(APR, n.d., n.d.)	i. SiOx and AlOx barrier coatings ii. Metallisation, EVOH, PVOH, and nylon	Laminating adhesives, cold seal adhesives should be limited	Unpigmented (Natural), white, buff, or lightly coloured film	Polyolefin labels that have been tested and found to be compatible with current recycling systems including PE and PO labels that have	Tested inks, primers, coatings, and laminating adhesives that	Many additives are allowed as long that they do not increase the density >1 g/cm³.

		requires recycling test to determine if the material is compatible or not			been found to be compatible with PE recycling. In addition, inks and adhesives that are tested	disperse in the final polymer without having an impact on quality	
RECOUP	(RECOUP, 2021)	i. <5% EVOH ii. SiOx, AlOx and metallised layers without additional coatings *As well as a couple of specific tested and approved barriers*	Not determined	Unpigmented, light colours or NIR-detectable dark colours	Printing covering <50%. Water soluble or water-releasable at less than 60°C adhesives. PE,PP or paper labels without fibre loss	Non-toxic inks (according to EUPIA guidelines)	Additives that do not increase the density >0,97 g/cm³
Efficient Consumer Response (ECR)	(ECR, 2020)	i. SiOx, AlOx and carbon plasma coating ii. EVOH and metallisation are considered limited compatible with recycling	N/A	Preferably unpigmented or as translucent ass possible	i. If labels are used, they should be made of the same base material as the packaging (e.g., HDPE, LDPE, MDPE, LLDPE). ii. If the decoration is made of a material other than PE, a maximum of 50% of the packaging surface should be covered so as not to hinder the correct sorting of the base material.	Printing inks must at least be EuPIA-compliant and non-bleeding	Additives can be added if the density of the base material remains < 0.97 g/cm3

Der Grüne Punkt (guidelines specifically for flexible PE)	(Der Grüne Punkt, 2019)	EVOH barrier layers, SiOx, AlOx, inside metallisation	N/A	Not printed, clear/colourless, light colours and or printing	Soluble adhesives applications, paper lables, proportion of non-poluolefin polymers	No hazardous ingredients in the ink (in accordance with EuPIA)	N/A
Netherlands Institute for Sustainable Packaging (KIDV) (information from decision tree)	(Netherlands Institute for Sustainable Packaging (KIDV), 2021, 2020)	N/A	N/A	Not coloured black	The label is made from the same material as the main packaging. Water soluble or water-releasable at less than 60°C adhesives	N/A	N/A

IVL Swedish Environmental Research Institute Ltd.
P.O. Box 210 60 // S-100 31 Stockholm // Sweden
Phone +46-(0)10-7886500 // www.ivl.se