The quantity and quality-optimised cycle of Polyolefin films

Findings from the FFG Collective Research project "flex4loop"

March 2025

Findings/results from the "flex4loop" research project (2022 - 2025)

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Motivation and starting position

The motivation behind the project stems from the determination of all stakeholders to establish a recyclable material flow along the value-added cycle of polyolefin packaging films in the food sector. The Flex4loop project researched the potential of closing the loop for small-part films, thus laying an essential foundation for the implementation of relevant development steps in practice. This is because the ambitious European recycling targets of 50% (2025) and 55% (2030) of the European Circular Economy Strategy can only be achieved through a cross-loop development approach and the necessary involvement of stakeholders.

The project developed technically feasible packaging that has been verified on the product and recycling side, which can actually be collected, sorted and recycled in future offering the highest possible quality in recycled products.

Motivation and starting position

The following objectives were defined in the Flex4loop project:

- Cross-industry development and implementation of material solutions based on polypropylene (PP) and polyethylene (PE) monomaterials (recyclability >90%) that guarantee high-quality recyclates from the small-particle food film fraction (≤A4), with consistent product protection and machinability, taking into account disruptive factors relevant for recycling (labelling, printing, etc.).
- Research and development of practical solutions that enable efficient sorting of the PE and PP monofilm fraction from the standardised, volume-increased light packaging (LVP) collection and significantly increase the current sorting depth from 34% to 80%.
- Investigation and generation of sufficiently high recyclate qualities for the production of unmixed PE and PP packaging for high-quality applications (secondary packaging, hollow bodies, multilayer film, technical components) with the highest possible recyclate input quantities. The aim is to increase the current recycling yield from 72% to 80%.

1. Design4recycling

1.1	Valuation methods
1.2	Extract of recyclable packaging examples from the project partners
1.3	Practical assessment of recyclability according to cyclos-HTP standard
1.4	PPWR and its impact

1.1 Valuation methods

In recent years, many assessment methods for measuring the recyclability of packaging have been developed on the European market.

Design for Recycling Guidelines operate on the basis of a checklist of recyclability criteria and the result is the categorisation of recyclability (red, yellow, green) on an ordinal scale. They act as design guidelines for the development of mainly plastic packaging, are published by various institutions and are constantly updated.

The assessment of theoretical recyclability is based on Design for Recycling Guidelines, is limited to existing material types and assesses these on the basis of existing data and limit values. Practical considerations of individual packaging are not included in the theoretical assessment. In addition, the packaging is assessed in its original condition on the basis of the material, which means that the influence of impurities in a sorting plant, for example, is not simulated.

The EU's PPWR (Packaging and Packaging Waste Regulation) was finally adopted in December 2024. This requires **a gradual recyclability assessment**, which quantifies the technically feasible recyclability of each individual packaging in percentage points. The PPWR must be applied to all packaging materials and take into account national collection, sorting and recycling infrastructures from 2035 onwards.

1.2 Extract of recyclable packaging examples from the project partners

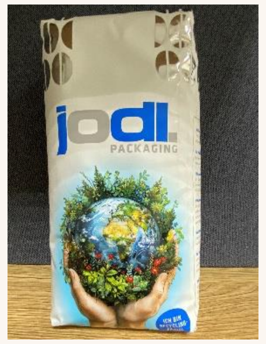
Berger ham packaging 100g
Films consisting of polypropylene (PP)/ethylene-vinyl alcohol copolymer (EVOH)/polypropylene (PP), polypropylene label
Evaluation of the overall packaging 93% (cyclos-HTP, 2024)

Picture: ©Fleischwaren Berger

Instantina dry products flowpacks
Film consisting of polypropylene (PP)/polypropylene (PP)
Evaluation of the overall packaging 93% (cyclos-HTP, 2024)

Picture: ©Instantina

Jodl packaging coffee tubular bag
Film consisting of polypropylene (PP)/polypropylene (PP) metallised/ polypropylene white, polypropylene valve and polypropylene label
Evaluation of total packaging 91% (Circular Analytics, 2024)



Picture: ©Jodl Packaging

1.3 Practical assessment of recyclability using the cyclos-HTP standard as an example

Evaluation of the packaging along 13 material flow paths based on 10 evaluation criteria according to a test scheme:

- Determination of recyclable material content, sorting path allocation (all packaging materials can be measured)
- Identifiability in the NIR (near infrared) and discharge behaviour, electrical conductivity, ferromagnetism
- Material density (float/sink analysis), melting behaviour, Digestion behaviour in water
- non-separable contaminants (roasting tests, label bleeding tests, adhesive/label tests)
- Additional criteria from individual path analysis (e.g. format criteria)

⇒ **Recyclability in %**

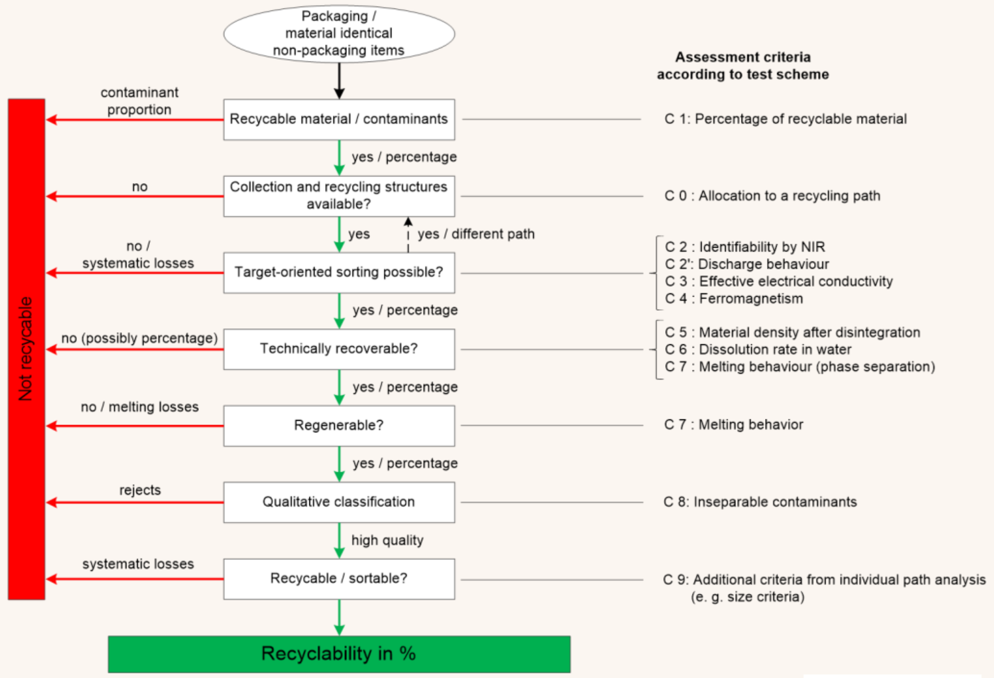


Figure 1: Procedure of the assessment

Compatibility tests can be used to analyse new materials and unknown contaminants for their recycling compatibility in a practical manner and confirm their recyclability by means of individual verification.

1.4 PPWR and its impact

The European Union's Packaging and Packaging Waste Directive (PPWD), which was adopted on 17 December 2024, will have to be implemented in all EU member states within 18 months. The following is an excerpt of packaging-related targets that must therefore be implemented by the countries over the next few years:

- Packaging waste reduction measured against 2018 by 5% from 2030, by 10% from 2035 and 15% from 2040
- Use of recyclable packaging ≥70% recyclability (performance class C) from 2030; packaging with a recyclability rating <70% will be banned from the market from 2030 onwards.
- Fulfilment of Design4Recycling criteria by 2030 (classification according to performance classes A≥95%, B≥80%, C≥70% recyclability) and sufficient quality for the replacement of primary raw materials by 2035.
- From 2030 onwards, plastic packaging must fulfil recyclate quotas of 10-35% depending on the material and application, which will increase further to 50-65% by 2040.

1.4 PPWR and its impact

- From 2035, packaging must fulfil the status of "recycled at scale" and thus undergo industrial collection, sorting and recycling and be used again as a secondary raw material for the high-quality and sustainable substitution of primary raw materials.
- From 2038, the threshold value "technically non-recyclable" will be extended to performance class C, and all packaging <80% recyclability will be banned from the market.

2. Sorting

2.1	Improving the spectral quality of 2D packaging
2.2	Sorting depth of new, recyclable ham packaging
2.3	Sorting depth of new, recyclable flowpacks for dry products
2.4	AI options in sorting of 2D packaging

2.1 Improving the spectral quality of 2D packaging

Conventional near-infrared sorting units work on the basis of diffuse reflection. The low layer thickness of 2D packaging, which is an advantage during use, leads to low quality spectra during sorting as part of the recycling process, as a large proportion of the radiation intensity is lost in transmission due to the low layer thickness. These spectra either contain no information or just enough to allow a rough classification of the material. The measurement in transflection allows several beam passes through the specimen and reduces transmission losses. The spectra obtained in this way contain information about the layer structure of the packaging film and therefore also allow multilayer and singlelayer films to be recognised and sorted.

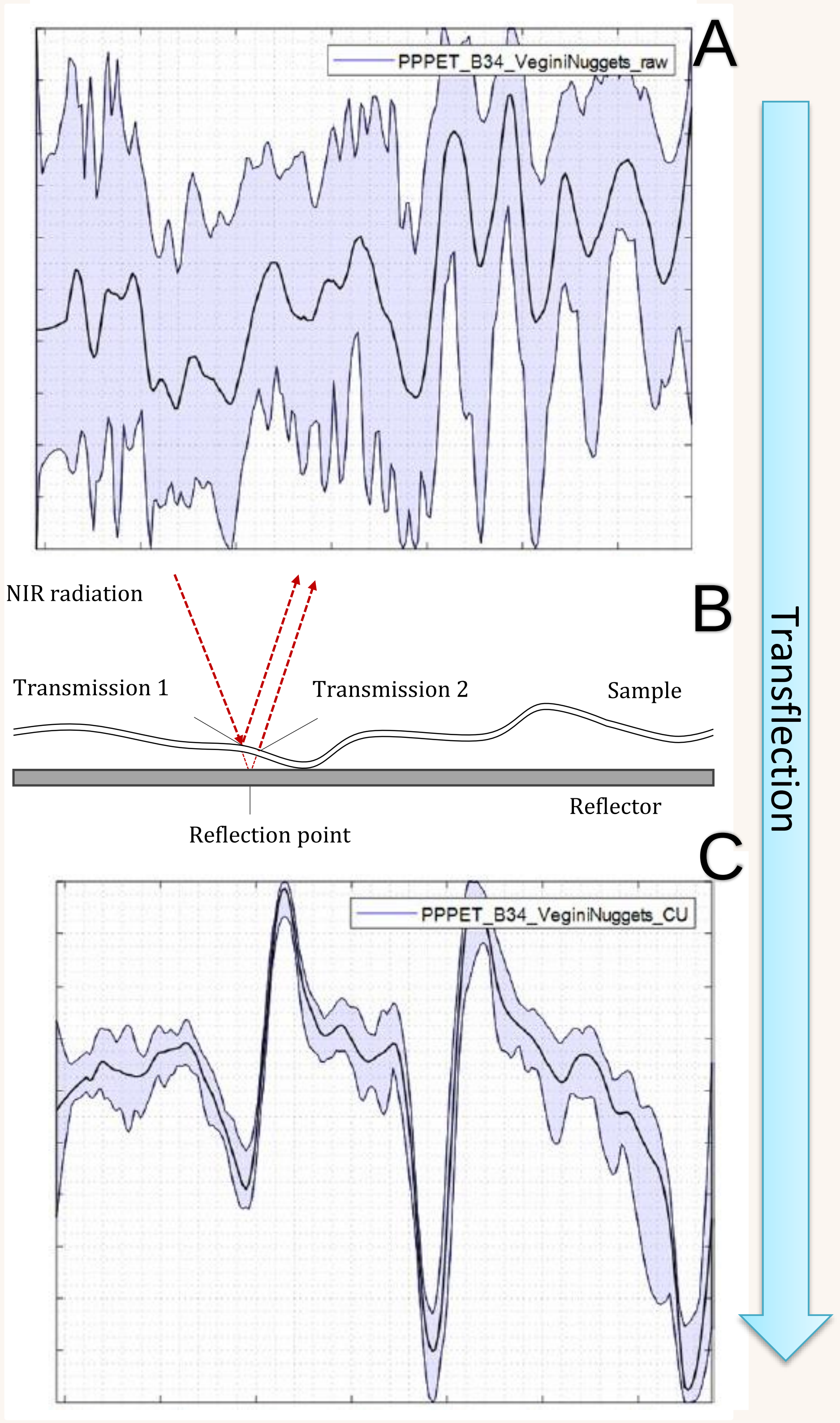
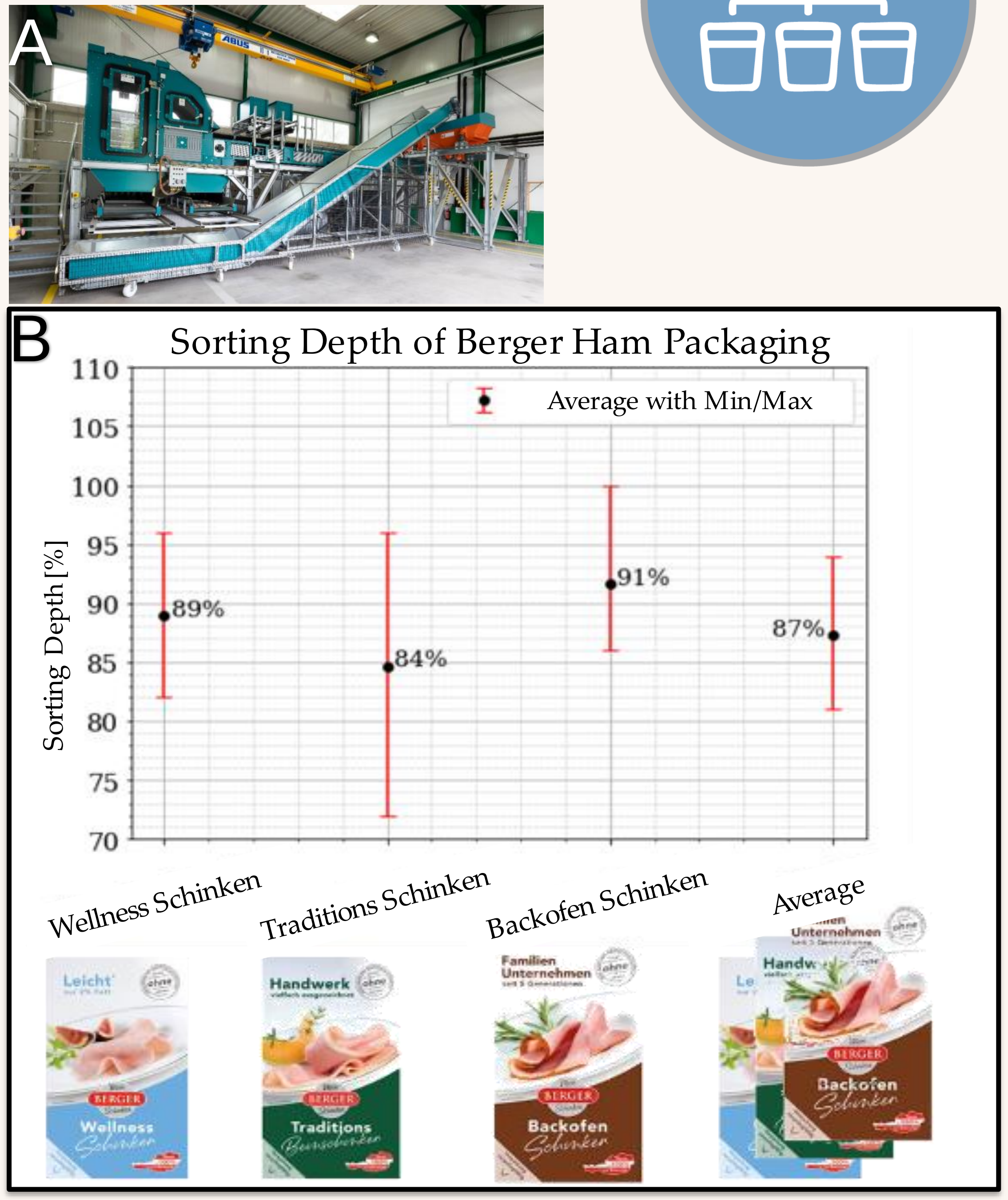


Figure 2:
[A] Representation of the variability of spectra of a thin-layer PPPET packaging film recorded in reflection;
[B] Functional principle of transflectance measurement;
[C] Representation of the variability of spectra of a thin-layer PPPET packaging film recorded in transflection

2.2 Sorting depth of new recyclable ham packaging

As part of the semi-industrial upscaling and verification of the polyolefin film cycle in the lightweight packaging fraction, the improved Berger Schinken packaging, consisting of polypropylene (PP)/ethylene-vinyl alcohol copolymer (EVOH)/polypropylene (PP) with a polypropylene label, was subjected to sorting tests on a sorting plant. The behaviour of the recyclable packaging in the real waste stream was investigated. The tests with a feed quantity of around 10,000 objects showed a sorting depth of around 80%. It was also observed that the sorting depth depends on the type of printing. As already observed in spectral analyses during the course of the project, dark green printing, for example, leads to poorer NIR spectra and therefore to a comparatively lower sorting depth.



Picture: ©Fleischwaren Berger

Figure 3: [A] Illustration of the technical centre infrastructure used; [B] Illustration of the sorting depth achieved per packaging type with mean, minimum and maximum values recorded during the repeated tests.

2.3 Sorting depth of flowpacks for dry products

Furthermore, flowpacks packaging with increased recyclability consisting of polypropylene (PP) was examined in sorting tests for its sortability using NIR and its behaviour in a real waste stream in a sorting facility. The high recyclability of the new packaging itself was also demonstrated in these industry-related conditions. Even when the pilot plant was fed with real lightweight packaging waste, a sorting depth of the new packaging of approximately 80% was achieved. The choice of printing, material and layer thickness resulted in good NIR recognition. The slightly lower sorting depth of this type of packaging is due to the more problematic discharge using compressed air (industry standard).

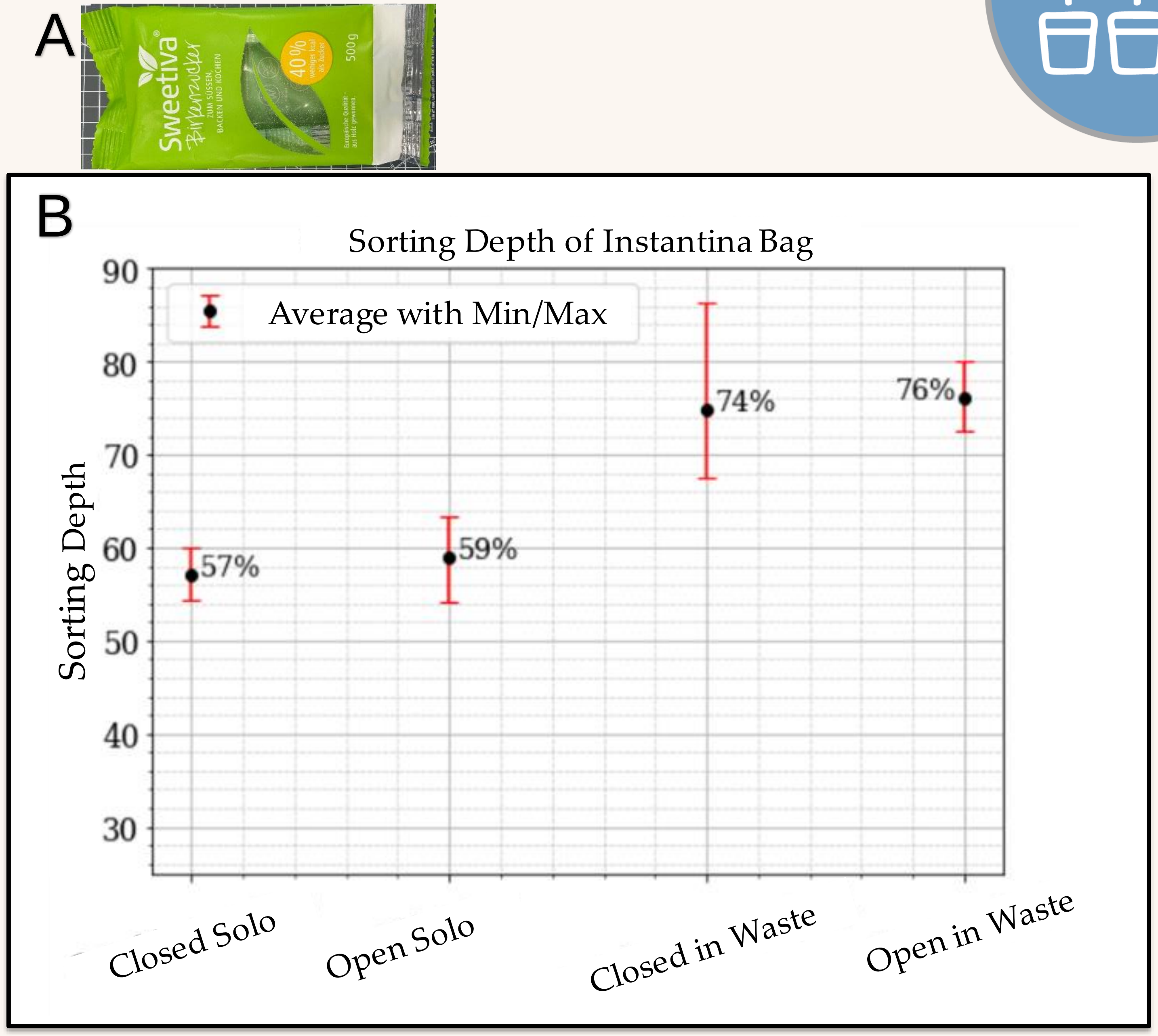


Figure 4: [A] Exemplary illustration of the tested flowpacks before the sorting tests; [B] Illustration of the sorting depth achieved in the multiple sorting tests. Dots represent the mean value achieved in the tests. Red bars represent the range of variation in the sorting depth achieved. closed means that the flowpacks were used unopened. Open means that the packaging was used torn open. Solo means that a pure fraction of the particles was fed in. InWaste means that an LVP fraction was spiked with flowpacks and this was then sorted, with flowpacks representing the target fraction.

2.4 AI options in 2D sorting

The application of machine learning methods to distinguish monolayer from multilayer materials without having to store the NIR fingerprints of each multilayer combination separately in a library requires that there are overarching differences between these two classes. These differences must originate from the layer structure and not depend on individual material types. If these differences exist, the classification between these two material types can take place at a higher level of abstraction and is not dependent on the actual layer structure of the particles. It has been shown that such differences exist. To enable inline classification, it is also necessary to create models that achieve a compromise between accuracy and speed. This can be achieved by applying selection methods that prioritise the input channels according to their relevance. Trained shallow neuronal networks achieved sorting accuracies of approximately 80%.

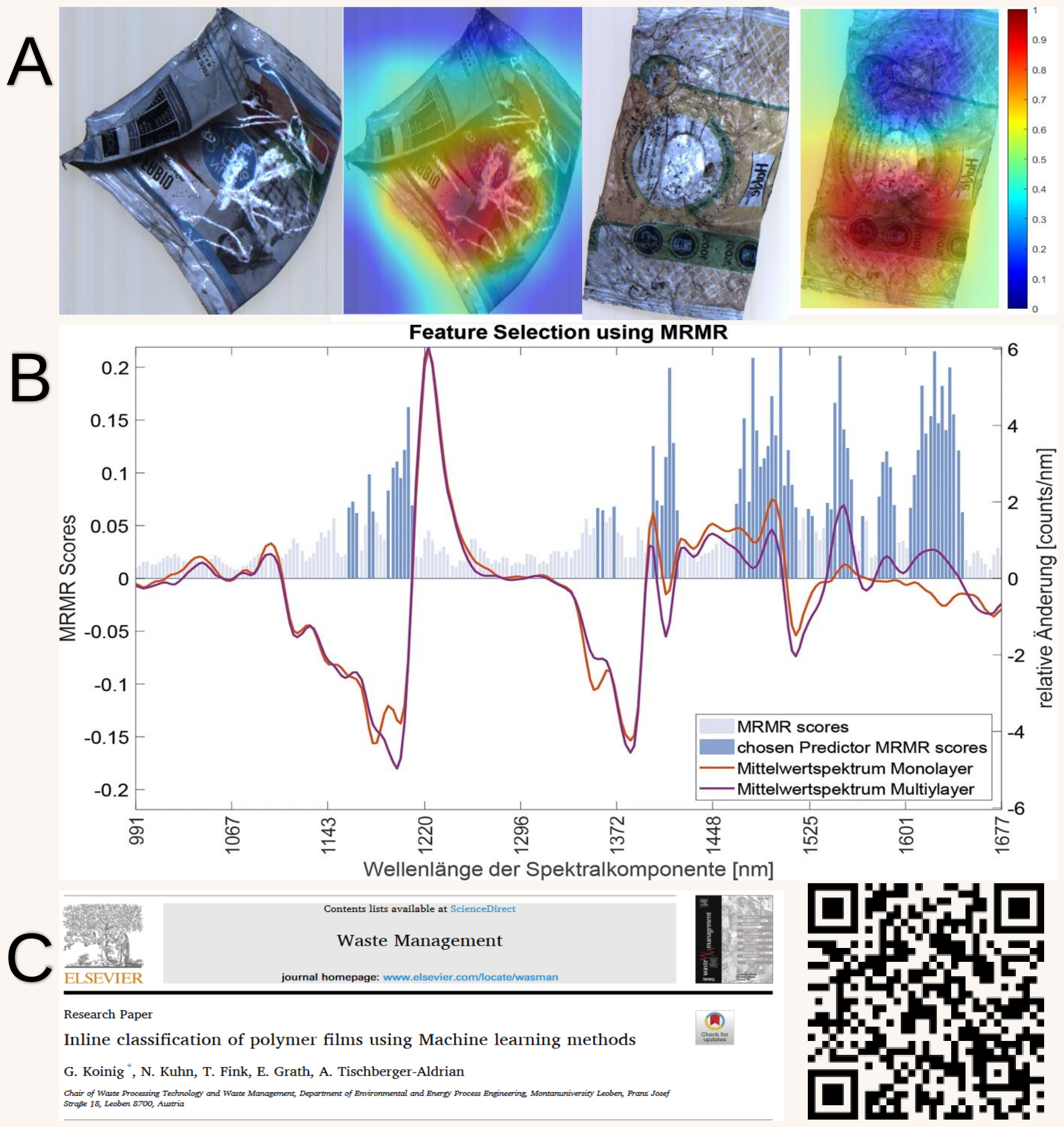


Figure 5: [A] Class Activation Maps of the classification of film packaging using image classification. Red: High information content. Blue: Low information content; [B] Average spectra of monolayer and multilayer packaging. Blue bars represent the information content of the respective wavelength; [C] Publication on the classification of film packaging using AI methods.

3. Recycling optimisation

3.1	Findings after a single recycling cycle in injection moulding
3.2	Films and bottles
3.3	Results of a sample packaging

3.1 Findings after a single recycling cycle in injection moulding

- **Laminating adhesives and colour systems** had shown **little to no influence** on the **mechanical strength or MFR** (melt mass flow rate) of 100% polypropylene (PP) recyclates in injection moulding applications.
- **No significant influence of the EVOH content between 2% and 5%** on PP recyclates in injection moulding applications in the tensile test and in the notched impact strength.
- After Analysis the mix of PP/EVOH/PE with a 2% EVOH content and PE/EVOH/PE with a 10% EVOH content in the packaging system generally exhibited comparable characteristic values at 100% recycled granulate content in the tensile test and with regard to notched impact strength, from which **no significant influence of the EVOH content** can be derived.
- The MFR showed a slight downward trend with increasing EVOH content.
- From the investigations carried out in the project **on 100% recycled** PP and PE-based packaging films with EVOH and polyvinyl alcohol (PVOH) gas barriers, metallisation, laminating adhesives and printing, it can be concluded that **for many PP or PE-based packaging films, no significant impairment of** the material flow can be identified when considering relevant mechanical parameters or the MFR **in injection moulding applications**.

3.1 Findings after a single recycling cycle in injection moulding

- In the lightweight packaging fraction, the packaging mix results in a significant reduction in possible impurities in the material flow under dilution, which significantly reduces mechanical parameter changes in the recyclate.
- From a sensory point of view, there is a clear odour deviation of the 100% regranulate, especially with printed or laminated films. However, these samples were not subjected to odour removal during extrusion, as is quite common today. This results in an even more relevant optimisation potential.
- Possible health-relevant effects of printing inks and adhesives used for recyclates from PP- and PE-based food packaging on humans in case of superficial contact are currently not sufficiently known, which should be taken into consideration when using them.
- Furthermore, the influence of material-identical labels on PP and PE packaging has not yet been sufficiently analysed in the project, which will have to be investigated in future projects.

3.2 Films and bottles

- It was not possible to produce extruded mono-material films of satisfactory quality from the 100% recyclates of the PP and PE packaging analysed for all samples.
- Extrusion blow-moulded bottles could only be produced from 100% recyclate for very few samples.
- Even when using 10-30% recyclate in combination with commercially available post-consumer PP and PE recyclate, only a few packaging recyclates were able to produce satisfactory film and bottle qualities.
- A similar trend was seen in the films and bottles that could be produced from PP packaging as in injection moulding. Printing inks and laminating adhesives had no significant influence on the analysed mechanical properties when 100% recycled material was used.
- As the requirements for the production of films and bottles in the extrusion process are significantly higher than for many injection moulding applications, the quantity and possibility of the recyclate used here is much more dependent on the recyclate quality required for the respective application.

3.3 Results of a sample packaging

The results of the mechanical testing of injection moulding test rods made from 100% recycled material of different packaging material compositions (influence of the printing and the adhesive of the sealing film, different material composition of the sealing film and the thermoformed bottom film) of the recyclable PP/EVOH/PP packaging for Berger ham are listed below. The results show that **no significant differences** were detected **in the presence or absence of the potential contaminants analysed**. In addition, the mechanics are comparable to a commercially available PP copolymer recyclate without impurities.

Figure 6:
Injection moulding test rod

	Commercially available PP copolymer recyclate	20% Berger top film PP/EVOH/PP printed (80µm) with 80% Berger bottom film PP/EVOH/PP transparent (300µm)	100% Berger bottom film PP/EVOH/PP transparent (300µm)	15% Berger top film PP/EVOH/PP unprinted (60µm) with 85% Berger bottom film PP/EVOH/PP transparent (300µm)
E-modulus [MPa]	**648+/-11**	**1094+/-22**	**1153+/-11**	**1032+/-15**
Tensile strength [MPa]	**20,5+/-0,2**	**27+/-0,4**	**28+/-0,2**	**27+/-0,2**
Elongation at break [%]	**592+/-0,5**	**716+/-75**	**770+/-13**	**612+/-147**
Notched impact strength [kJ/m]^2	***6,0+/-0,6***	**5,7+/-0,4**	**5,4+/-0,2**	**4,2+/-0,6**

Table 1: Mechanical characteristics of 100% recyclate of different packaging material compositions of PP/EVOH/PP packaging

Picture: ©Fleischwaren Berger

Summary

- It has been shown that in many cases it is possible to process small PE and PP food packaging films into high-quality recyclates in a one-off recycling cycle, even with supposed impurities (gas barrier, printing, laminating adhesives, etc.). These can then replace up to 100% primary raw material in injection moulding applications, which is the main application from a current sorting perspective, depending on the mechanical component requirements and the area of use.
- The design4recycling of packaging has a significant influence on recyclate quality. The assessment methods for recyclability are currently diverse and range from theoretically based guidelines to technically based methods that already cover parts of industrial practice. In future, the PPWR will require a gradual assessment of recyclability in per cent. This is the only way to make an accurate statement about recyclability, provided that the methodology also covers as many practice-relevant parameters as possible.
- It was also recognised that plastic packaging with high recyclability ratings >90% also leads to good recyclate qualities in a one-off recycling cycle.

Summary

- By using measurements in NIR transflection, the quality of the spectra of ultra-thin 2D packaging films can be improved in such a way that the layer structure and layer thickness become more recognisable.
- The PP-based ham packaging showed good behaviour in a simulated real waste stream. Sorting depths of around 80% were achieved. Furthermore, it became apparent that the type and colour of the printing also has a strong influence on the sortability of the packaging in large-scale tests.
- The dry product flowpack packaging also showed good NIR sortability. Design4Recycling was successfully implemented here.
- In the future, it will be important to allow a deeper sorting decision based on layer composition and polymer type in order to produce high-quality recyclate. Machine learning methods can help here by utilising high-dimensional data, such as NIR data. The project was able to show that these methods are able to distinguish well between mono and multi-material film packaging.

List of sources:

1. G. Koing et al, Inline classification of polymer films using machine learning methods, December 2023
   Source link: https://www.sciencedirect.com/science/article/pii/S0956053X2300716X

Further helpful links:

German minimum standard, Mindeststandard_VerpackG_2024.pdf

Institut cyclos-HTP GmbH, Institute for Recyclability and Product Stewardship, https://www.cyclos-htp.de/

Mag[a] . Anja Fredriksson, MSc; Dr Angelika Derler; Dr Michael Washüttl: Study on the topic "Comparison of the suitability of different evaluation systems for the recyclability of packaging materials in Austria", August 2021, conducted for the Austrian Chemical Industry Association - FCIO, 2021-ofi-studie-wko.pdf

Image sources:

OFI, MUL AVAW, Fleischwaren Berger, Jodl Verpackungen, Instantina GmbH, Institut cyclos-HTP

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