3D View of Sustainability

Why Recycled Films Are Not Necessarily Sustainable

The increasing volume of plastic waste and the growing pollution of the oceans by such waste have brought the sustainable handling of plastic products into the focus of society and politics. Both recycling and bioplastics can be a part of a strategy for greater sustainability, but they are not free of side effects. In order to avoid irrational decisions, it is important to assess their effects comprehensively.

If a film is used in the packaging sector, it should be made of at least a recycled material – leading to the common opinion that assumes that materials in circulation are automatically more sustainable. However, a detailed life cycle analysis, which considers all relevant energy and material flows on the basis of a generally valid calculation method, shows that it is not that simple (© dusk – stock.adobe.com)

Despite all public criticism of plastics (**Fig. 1**), they make an important contribution to sustainability, for example through fuel savings in the transport sector. Fuel savings can be attained through reduced vehicle weight and lighter packaging. The problem, however, is that clear recommendations to increase the sustainability of plastic products do not exist at the moment.

Higher recycling rates do not necessarily mean increased resource efficiency, and bioplastics are criticized for the use of pesticides and high-water consumption as well as poorer working conditions in cultivation [1, 2]. It is thus important to find out which measures make sense in specific applications »

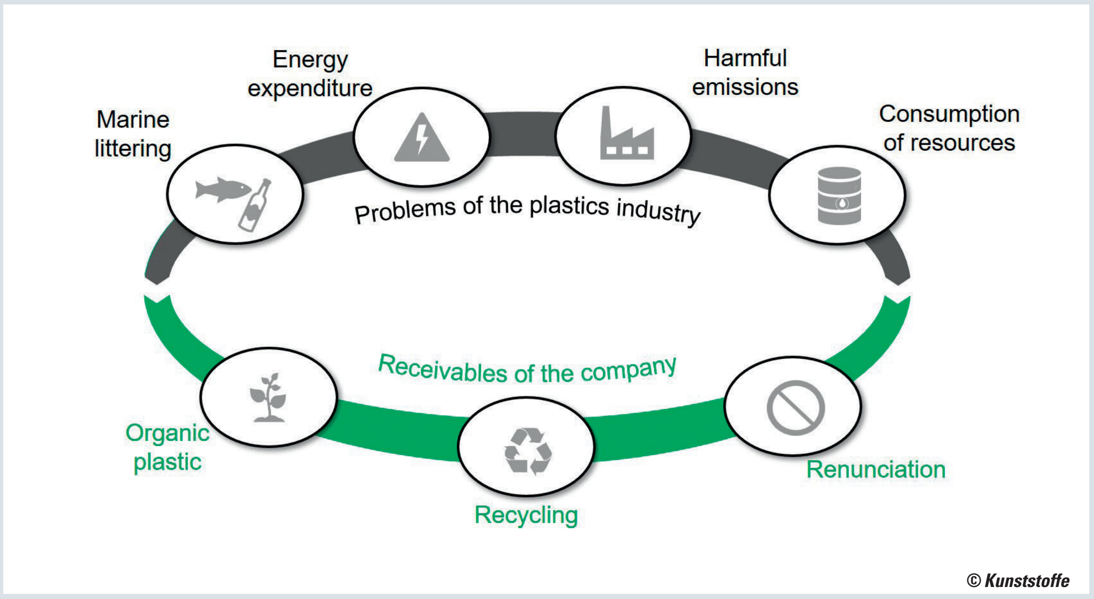

Fig. 1. Challenges in the production and use of plastics and demands of society (source: IKV)

and contribute to a measurable increase in sustainability.

How Can Sustainability Be Comprehensively Assessed?

Sustainability is generally based on three pillars: ecological, economic and social sustainability [3]. The ecological problems of the 21st century include global warming, the use of resources, the destruction of biodiversity and threats to human health. Economic problems include the instability of the financial markets, national debt and negative developments in the labor market. Social problems are poverty, demographic aberrations, violent conflicts and inequality of opportunity [4]. The weighting of the individual fields is controversial, but ecological sustainability is given the highest priority [5].

Life cycle analysis (LCA) can be used to assess the ecological sustainability of a product, for example, over its entire life cycle [6]. With the introduction of DIN EN ISO 14040 on 19 June 2006, the European Committee for Standardization (CEN) laid down principles and framework conditions for LCA preparation, the phases and interactions of which are described in more detail in DIN EN ISO 14044 (**Fig. 2**) [7, 8].

A lot of LCA studies for plastic products have already been published [9–11]. Although the results of the studies can provide recommendations for greater sustainability, the statements must always be viewed in their respective contexts.

Furthermore, the statements are not generally valid. This is due to a lack of standards, so that the respective choice of

- the functional unit,
- the allocation method,
- the life cycle inventory,
- and the method of impact assessment

strongly influence the result of an LCA.

Against this background, the Reifenhäuser Group of Troisdorf, Germany, developed, in cooperation with the Institute for Plastics Processing (IKV), Aachen, Germany, a generally applicable calculation method for an LCA that includes all relevant energy and material flows along the life cycle of plastic films and nonwovens.

The calculation concept should support product designers in the development of sustainable plastic products. The analysis covers the entire life cycle of these products: the scope of the study therefore includes the production of raw material, the processing into plastic granulate, further processing in extrusion, and thermal recovery or mechanical recycling, considering all necessary transport routes.

Structure of a General Calculation Method

In the following, the framework conditions of the developed calculation method for the preparation of an LCA are presented:

As the **functional unit** for the film or nonwoven, 1m^2 of the product is used in the calculation concept, which is also common in previous studies [9 to 11]. For a comparison of two products, attention must be paid in each case to the functional fulfilment. Two films or nonwovens can only be compared if both have the required properties to fulfil the function. This means that the comparable products must have e.g. the same barrier or mechanical properties.

If the use of recyclate is also accounted for in an LCA, responsibility for the environmental impact of the recycling process must be apportioned. The question is whether the distributor of the recyclable product or the user of the recyclate has to pay for the environmental impact of the recycling process, and how a credit for recycling-friendly design can be issued. There are different methods for allocating environmental impacts over the life cycle.

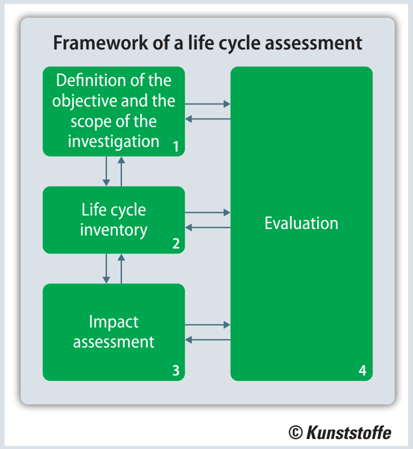

Fig. 2. Phases in the preparation of a life cycle assessment according to DIN EN ISO 14040/14044 [7] (source: IKV)

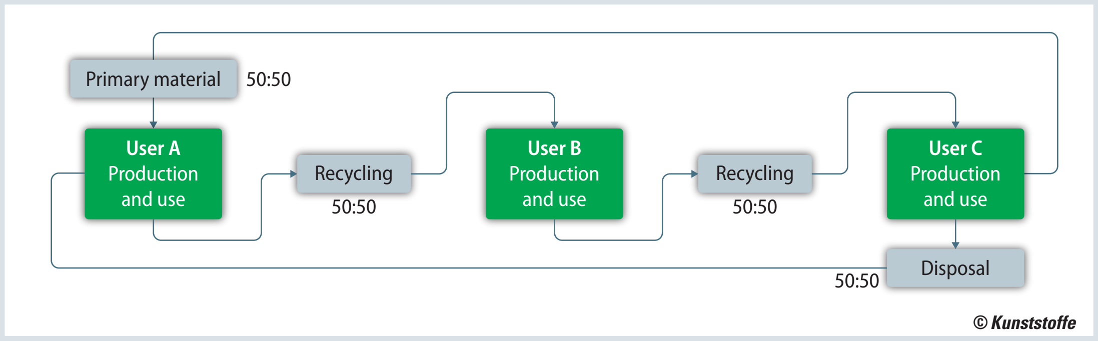

Fig. 3. Allocation of responsibilities for the use of recyclate and the manufacture of recyclable products with a 50:50 allocation (source: IKV according to [12])

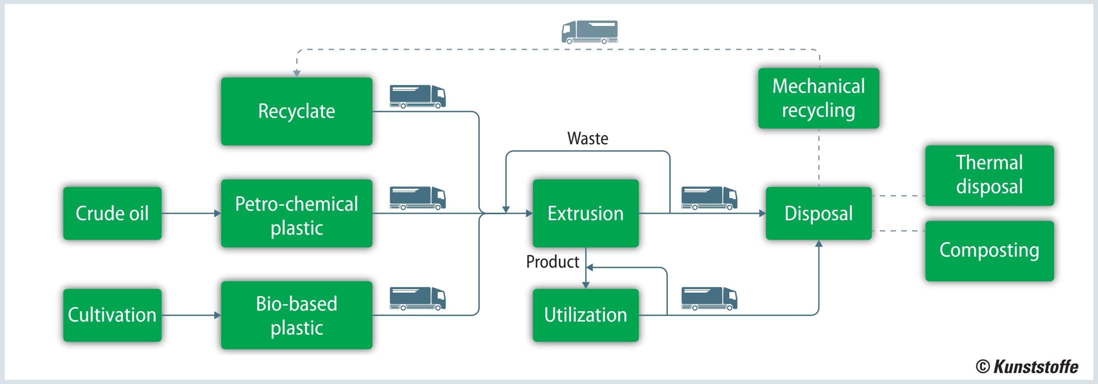

Fig. 4. Life cycle and considered process and transport steps for creating an LCA with SimaPro based on Reifenhäuser data sources (source: IKV)

Assuming that both the placing on the market and the acceptance of recycled material need to be encouraged in the current market, the present study assumes a **50:50 allocation** [12], which encourages both the use of recycled material and the production of recyclable products. **Figure 3** schematically shows the allocation of responsibilities. Users A and C pay the costs for the production of the virgin material and for the disposal of the product in equal proportions, and also 50% of the recycling costs. User B only has to pay 50% of the costs of the upstream or downstream recycling process, because he puts recycled material back into circulation. As long as the recycling process has advantages compared to the production and the use of virgin material, User B therefore has the lowest value in the LCA.

After the functional unit and the allocation method have been determined, an LCA is created in a next step. For the data collection in the life cycle **inventory analysis**, all relevant energy and material flows along the entire life cycle of the extrusion products film and nonwoven must be considered. **Figure 4** shows a schematic representation of the life cycle and the process steps. The process steps include the use of recyclate, the production of petrochemical and bio-based plastics, extrusion, disposal and transportation.

The data used to create the LCA are taken from Reifenhäuser, raw material suppliers and the software tool SimaPro (manufacturer: Pré Consultants BV, Amersfoort, Netherlands) for LCA creation that contains numerous databases. The balance sheets of the individual process steps (explained in detail in [13]) are combined into an overall balance sheet, which has to be evaluated with regard to its sustainability in a final step. The CO_2 footprint (carbon footprint) is not sufficient here, because it falsifies the result, especially when bio-based plastics are used. For example, acidification (acid rain), eutrophication or water and land requirements in agriculture are not considered [10, 14]. Eutrophication refers to the input of nutrients containing phosphorus or nitrogen into ecosystems through agricultural fertilization, wastewater and combustion processes. Effects of acidification include fish mortality, forest damage, vegetation damage due to nutrient leaching and groundwater contamination by remobilized heavy metals [3, 10, 14].

For a better **impact assessment**, the ReCiPe method (**Fig. 5**) is suitable, in which 18 results categories are identified from the results of the LCA and grouped into three categories "human toxicity, ecotoxicity and resources" [15]. The carbon footprint is hidden behind the impact category "global warming".

"Human toxicity" describes the effects of the release of chemicals into the environment and the associated damage to human health [17]. The used scale is the reduced life expectancy due to diseases such as cancer and the lost life years as a result, expressed by the DALY index (Disability Adjusted Lost Life Years) [18].

"Ecotoxicity" means the effects of harmful substances on terrestrial and aquatic organisms [3, 19]. The uptake of pollutants or changes in living conditions can lead to changes in individual organisms, an entire population or the ecosystem. The indicator "species/FU" refers to the local loss of a species in an ecosystem and the associated consequences [3, 18].

The assessment of economic viability is based on "resource consumption", which describes the cost of the product in US dollars (USD) per functional unit.

Evaluation Based on Various Case Studies

With the developed calculation concept, different application examples can subsequently be evaluated. Different films »

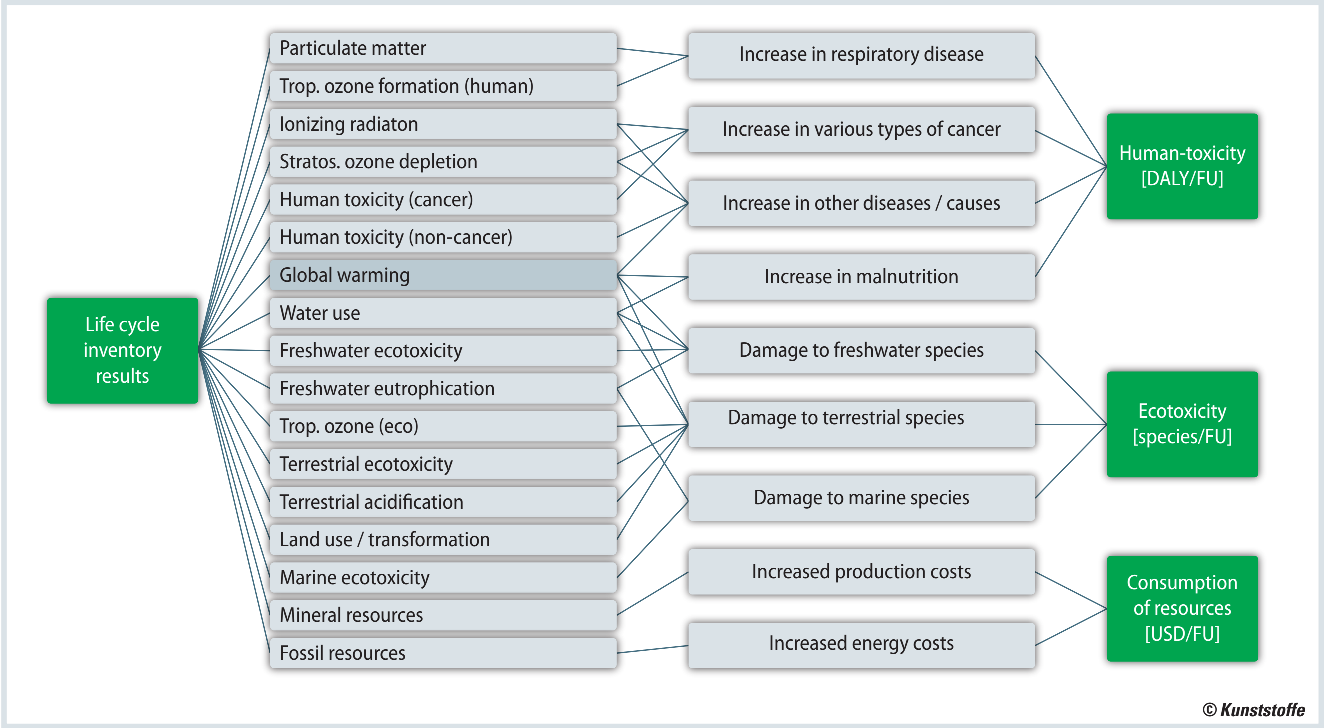

Fig. 5. Impact assessment method according to ReCiPe 2016 [16] (source: IKV)

with similar properties that are suitable for the same applications are compared. The data are based on real production parameters. For a better assessment of the results, the diagrams also show the values for human toxicity, ecotoxicity and resources for a 1 km car journey with a "Euro 5 diesel engine".

Example: Fruit and Vegetable Bag

In a first example, the environmental impacts of fruit and vegetable bags made of petrochemical and bio-based plastics in supermarkets are assessed, and the disposal scenarios for the bags are compared (**Fig. 6**). Thermal recycling (scenarios S1, S3, S5) and mechanical recycling of post-consumer recyclate (S2) can be used for this purpose. Post-industrial recycling is not considered here, since the fruit and vegetable packaging is disposed of only in private households. The hypothetical scenario of home composting (S4) for the bioplastic PLA is also considered.

The lowest human toxicity values are achieved by HDPE fruit bags (scenarios S1 and S2), with mechanical recycling (S2) performing slightly better than thermal recovery (S1). In terms of ecotoxicity, S1 even achieves a negative value because thermal recovery leads to energy substitution. Since the calorific value of polyolefins (up to 44 MJ/kg) is even higher than the calorific value of fuel oil (42 MJ/kg), so much energy can be substituted that the ecotoxicity of production is overcompensated [20]. The resource consumption in scenario S2 is lower than in S1 because mechanical recycling conserves resources.

Scenarios S3 to S5 deal with bio-based plastics (PLA), which are more resource-efficient than petrochemical plastics, but have higher human and ecotoxicity values. This increase is due to eutrophication as well as the water and land requirements in agriculture required for the cultivation of maize. S3 and S4 compare the disposal by thermal recovery and composting from PLA.

It can be shown that composting has advantages in terms of resource consumption. But the thermal recovery performs better in terms of human toxicity and ecotoxicity, which is also a consequence of energy substitution in thermal recovery. Scenario S5 considers PLA production from Brazilian sugar cane instead of German sugar beet. The additional 10,000 km of shipping increases human- and ecotoxicity, but saves resources compared to petrochemical plastics.

The Authors

Lars Kraus, M.Sc., is Team Leader "Process Engineering Extrusion" at the Institute for Plastics Processing (IKV) at RWTH Aachen University; lars.kraus@ikv.rwth-aachen.de
Dr.-Ing. Tim Pohl is Director Business Development & Sustainability at Reifenhäuser GmbH & Co. KG Maschinenfabrik, Troisdorf, Germany
Ilka Pfisterer, M.Sc., wrote her thesis [13] at Reifenhäuser and IKV.
Prof. Dr.-Ing. Christian Hopmann holds the Chair for Plastics Processing and is Head of IKV.
Martin Facklam, M.Sc., is Head of Extrusion and Rubber Technology at IKV.

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Example: Packaging Film

Another example compares "packaging film made of virgin material (vPE) with packaging film made of recycled material (rPE)". The film is intended for industrial applications such as mattress packaging. The respective scenarios are shown in **Figure 7**.

The reference film (S1) has a thickness of 100 µm. Since the mechanical properties usually decrease when recycled material is used, the thickness of the rPE film is increased to 150 µm (S3), but an rPE film with a thickness of 100 µm (S2) is also considered for better comparability. Since the PE film only consists of one monolayer, it is recyclable.

Figure 7 shows that the use of recyclate (S2) has a positive effect on the conservation of resources and human toxicity, although it has a higher ecotoxicity than S1. On the one hand, the higher ecotoxicity can be explained by water and energy consumption during the recycling step (S2). On the other hand, thermal recovery (S1) leads to a higher energy credit, which reduces the ecotoxicity in S1.

Scenario S3 shows that the advantage of using recycled material in the human toxicity category is quickly exhausted with increasing film thickness. Scenario S4 also looks at mechanical recycling of virgin material in China, in which transport of the material by ship over a distance of 12,000 km is included in the calculation. This leads to significantly worse results than with mechanical recycling in Germany (S1).

The comparison with paper is also interesting. Compared to the use of plastic in the form of virgin material, the use of paper can conserve fossil resources, but significantly increases human toxicity and ecotoxicity on the basis of the SimaPro database.

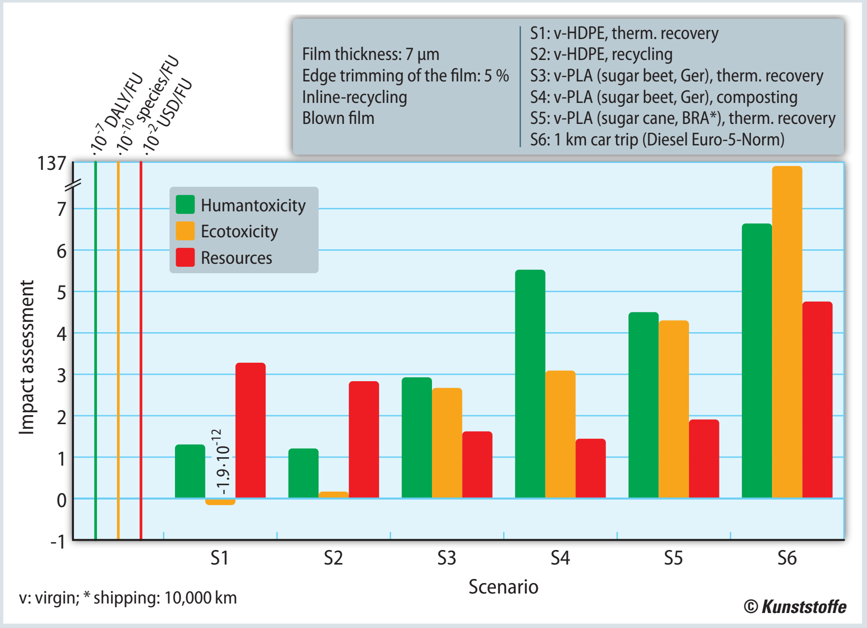

Fig. 6. Balance sheet for fruit and vegetable bags for use in the supermarket from fossil and bio-based plastic (source: IKV)

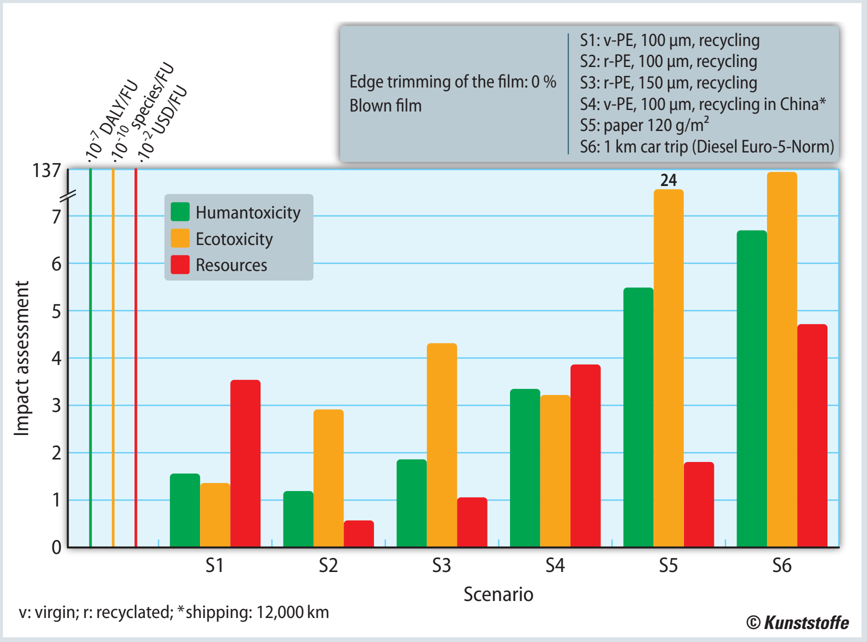

Fig. 7. Balance sheet for a packaging film for inferior applications from virgin material and recyclate (source: IKV)

Conclusion

The sustainability of a product is generally assessed by LCA based on the CO_2 footprint. However, this is not sufficient for a complete ecological assessment, so that a calculation concept with three-dimensional impact assessment was created and used. The developed calculation concept showed that the use of recycled materials is a good approach to increase the sustainability of the product, but only if the material use is the same.

In contrast to petrochemical plastics, bio-based plastics contribute to the conservation of resources even considering long transport routes, but they increase human and ecotoxicity.

Composting of PLA does not make much sense because the energy contained in the plastic is not recovered. In addition, it can be shown that a substitution of plastic by paper is not a good alternative with regard to lower values in human and ecotoxicity.

The balance sheets drawn up for three categories create a basis for comprehensive analysis, but do not allow a direct recommendation for action, because guidelines for prioritizing the categories would be necessary. Furthermore, the database must be improved, e.g. in order to take more detailed account of the work involved in the mechanical recycling process. ■