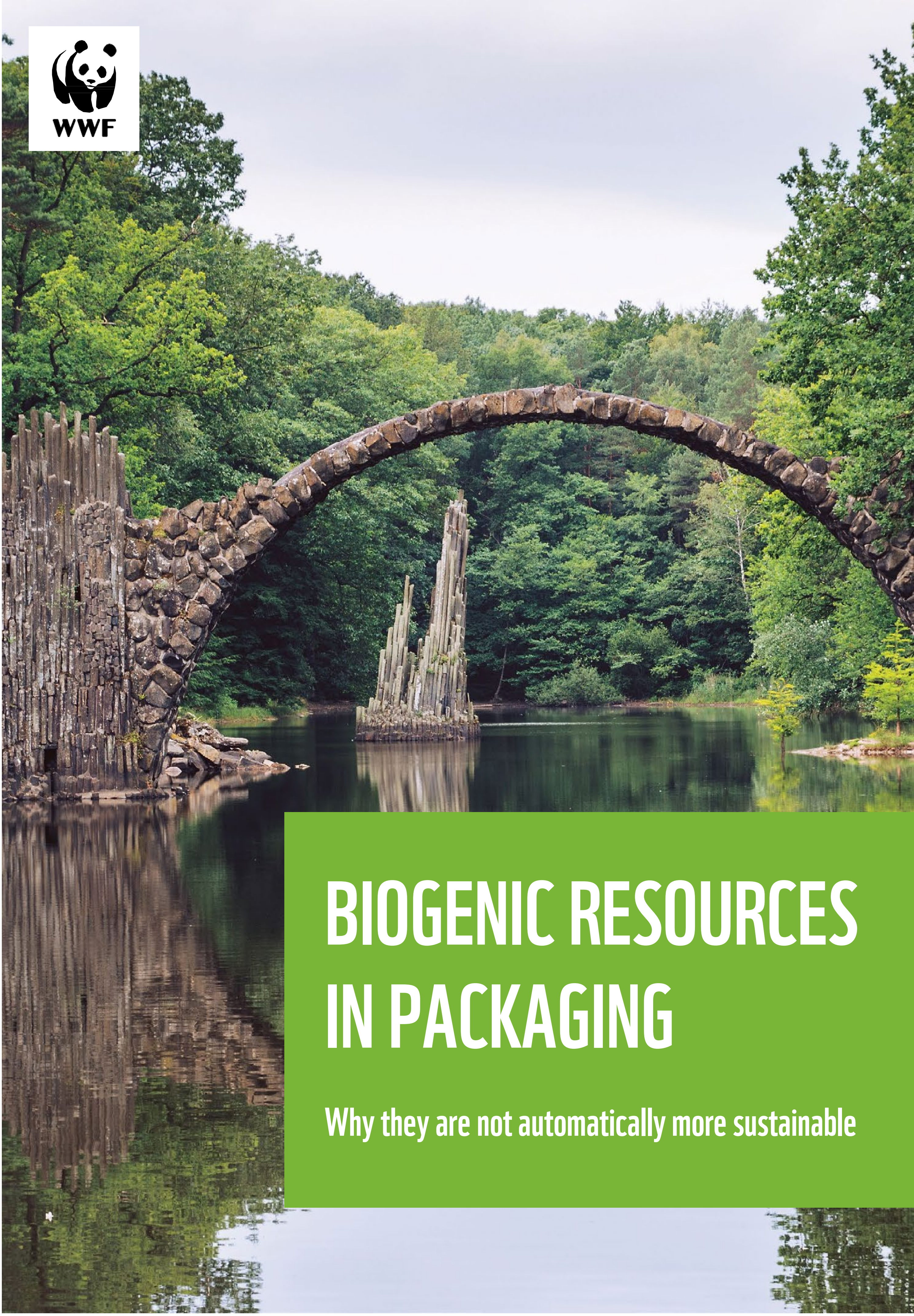

BIOGENIC RESOURCES IN PACKAGING

Why they are not automatically more sustainable

IMPRINT

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Abstract

German

Die ifeu/GVM-Studie „Einsatz biobasierter Rohstoffe in Verpackungen im Sinn der Kreislaufwirtschaft sowie des Natur- und Klimaschutzes“ untersucht, inwieweit der künftige Bedarf an Verpackungen in Deutschland aus biobasierten Rohstoffen mit möglichst geringem und ökologisch verträglichem Biomasseeinsatz gedeckt werden kann. Die Studie zeigt, dass trotz eines rückläufigen Verpackungsaufkommens und eines steigenden Anteils an Recyclingmaterialien der Flächen- und Wasserbedarf durch den wachsenden Einsatz biobasierter Kunststoffe zunimmt. Zudem verursacht die Nutzung von Biomasse in Kunststoffen im Vergleich zu Papier höhere Umweltbelastungen. Daraus leitet die Studie drei zentrale Handlungsempfehlungen ab: (1) Vorrang für Vermeidung, Wiederverwendung und Recycling vor einer großflächigen Verwendung biobasierter Kunststoffe, (2) deutliche Reduktion des Primärholzeinsatzes zugunsten von Altholz und Reststoffen sowie (3) ein gezielter, aber verantwortlicher Einsatz von Power-to-X-Kunststoffen als Ergänzung, um ökologische Zielkonflikte zu verringern und die Nachhaltigkeit im Verpackungssektor zu stärken.

English

The ifeu/GVM study "Use of Bio-Based Resources in Packaging in the Context of Circular Economy, Nature and Climate Protection" examines the extent to which Germany’s future demand for packaging can be met using bio-based resources while keeping biomass use as low and environmentally compatible as possible. The study shows that, despite declining packaging volumes and an increasing share of recycled materials, the need for land and water rises through the use of bio-based plastics. Furthermore, the use of biomass in plastics causes higher environmental pollution compared to paper. From this, the study derives three key recommendations: (1) giving priority to prevention, reuse, and recycling over the wide-spread use of bio-based plastics, (2) substantially reducing the use of primary wood in favour of waste wood and recycled materials, and (3) employing Power-to-X plastics in a targeted yet responsible manner as a complementary option to reduce conflicts of ecological objectives and fortify sustainability in the packaging sector.

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aF-eq	artificial area equivalents
BAU scenario	Business-as-usual scenario
BLE	Federal Office for Agriculture and Food
BMEL	Federal Ministry of Food and Agriculture (now: BMLEH)
CED	Cumulative energy demand
DNP	Distance-to-nature potential
EUDR	European Union Deforestation Regulation
FAO	Food and Agriculture Organisation of the United Nations
FEFCO	Fédération Européenne des Fabricantes de Papiers pour Ondulé
FKN	Beverage carton (also commonly used as the name for the waste category)
LDPE	Low-density polyethylene
LPB	Liquid Packaging Board - raw material for composite beverage cartons made from 100% primary fibre
LWP	Lightweight packaging
PA	Polyamide
PE	Polyethylene
PFC	Private final consumption
PLA	Polylactide
P-Mat	Primary material
PPC	Paper, paperboard, cardboard
PPWR	Packaging & Packaging Waste Regulation
PTT	Polytrimethylene terephthalate
PtX	Power-to-X
REC	Recycled content
S-Mat	Secondary material
WIP	Waste incineration plant

Executive summary

Starting point and objectives

Germany aims to be greenhouse gas neutral by 2045. The use of biomass is a central component of the defossilisation strategy necessary to do so. This study examines which bio-based resources will be available in the future to cover the projected demand for packaging, which ecological challenges are associated with their use and which alternatives and optimisation potential can be derived from this.

Bio-based resources and their evaluation

A total of 13 bio-based resources were analysed in depth. The evaluation focuses on three key indicators: *land consumption*, measured via distance-to-nature potential (DNP), *cumulative energy consumption* (CED) and *water consumption*. A distinction is made as to whether the respective raw material is use to produce paper-based packaging (PCC packaging) or plastic packaging. The evaluation showed the following key findings:

- Bio-based plastics are more energy-intensive to produce than paper-based packaging with identical raw materials.
- Alternative pulp sources such as leaves, grass, cup plant, and crop residues can significantly reduce the land footprint without significantly increasing energy or water consumption.
- The use of waste and by-products such as tall oil, waste wood and waste paper has the lowest environmental impact in terms of land and energy needs; however, water consumption in the production of plastics using waste wood and waste paper is higher.
- There is a conflict of objectives between land and energy needs: Improvements in one area are often at the expense of the other.

Projected packaging consumption up until 2045 and derivation of the demand for bio-based resources up until 2045

The environmental effects are not evaluated exclusively at the level of the individual packaging materials but are interpreted in the context of current and expected future packaging consumption in Germany. A material flow model for packaging in Germany for 2023, 2030 and 2045 was developed in combination with data and estimates on packaging volumes, the recycling situation and the status of recyclate use. The model shows that the use of primary materials will fall by 37% compared to 2023 by 2045 and the proportion of materials returned to the packaging material flow will increase from 52% to 64%. Despite the decline in packaging consumption in Germany and the significant expansion of the circular economy, the proportion of bio-based materials in the primary material input within the packaging material flow increases significantly – particularly as a result of the increasing use of bio-based plastics by 2045. The share of bio-based primary plastics in all plastic packaging will increase from currently 3% (68 kt) to 43% (363 kt) in 2045. At the same time, it is clear that even in 2045, a significant proportion of packaging will still be disposed of by means of thermal utilisation at the end of its life due to a lack of recyclability or will leave the material flow for other, non-packaging-related applications.

Summary of environmental evaluation and raw material needs

To analyse the question of the extent to which changes in packaging consumption in Germany – in particular due to a long-term reduction in overall consumption – and the shifts in the use of the biomass of bio-based resources – less PCC, more bio-based plastics – have an impact on the contributions to the analysed parameters of land needs, energy consumption, and water needs, the study compares the developed evaluation developed and demand for bio-based resources. The results show that avoiding packaging, expanding working reuse solutions and increasing both recycling quotas and the use of recyclates are key levers for reducing the demand for raw materials and the associated environmental impact. As a result, all assessed contributions to the three parameters analysed will initially decrease up until 2030. Contributions do not show a significant rise and exceed the initial levels in 2023 until the point of time at which bio-based resources increasingly enter the system as raw materials for bio-based plastics.

As part of a scenario analysis, the study therefore examines various optimisation approaches: the use of agricultural biomass; the increased use of waste and by-products; the use of packaging waste that currently flows into other applications – such as thermal recycling – and the use of PtX plastics as synthetic alternatives. The results of the optimisation scenarios show:

- The greatest potential lies in waste and by-products as well as in packaging waste – currently utilised outside of the packaging material flow – as they allow significant reductions in land, energy, and water consumption.
- Due to its large mass flow, waste wood offers great potential as a substitute for primary wood.

Conclusion

In order to effectively limit the environmental impact of the future packaging volume, a consistent reduction in packaging consumption, the expansion of functional reuse systems, a focus on a high degree of recycling and the increased use of recycled materials are absolutely essential. Although bio-based plastics can substitute fossil raw materials, they should primarily be used where circular solutions are not technically or economically feasible – and should not be seen as a blanket alternative solution for a circular economy. Waste wood and other secondary raw materials also have high potential as substitutes for primary wood. Overall, a systemic transformation of the packaging industry is necessary in order to minimise its environmental impact sustainably and in the long term.

Based on the analysis, it is clear that the use of bio-based resources for the production of plastic packaging is neither a priority course of action nor an equivalent substitute.

1 Background and objectives of the study

This report was produced on behalf of WWF Germany by ifeu – Institut für Energie- und Umweltforschung Heidelberg) ("ifeu – Institute for Energy and Environmental Research Heidelberg") and GVM Gesellschaft für Verpackungsmarktforschung ("GVM Association for Packaging Market Research") from October 2024 to October 2025; the report documents the results of the project.

Starting point

Germany has set itself the target of becoming greenhouse gas neutral by 2045. This requires the far-reaching decarbonisation of all economic sectors – including value chains in the packaging sector. The use of biomass is one way of significantly reducing greenhouse gas emissions. At the same time, agricultural and forestry cultivation that can be utilised provide only limited biomass potential that can be utilised sustainably. The efficient and targeted use of biogenic resources is therefore essential in order to harmonise ecological and economic objectives.

More than 60% of all packaging in Germany is already bio-based: wood, liquid packaging board (LPB), paper/paperboard/cardboard (PPC) and, to a lesser extent, plastics in the shape of bio-based plastics. It is safe to assume that the trend towards substituting biogenic resources for fossil-based plastic packaging will continue in the coming years. The main drivers of this development are, in particular, the regulatory requirements of the European Union, such as mandatory quotas for the use of plastic-specific recyclates as well as corporate strategies to reduce fossil packaging materials.

Research questions

Against this background, this report addresses the following key issues:

- What ecologically meaningful role can bio-based resources play in the packaging sector in the future?
- To what extent are sufficient (sustainable) bio-based resources available to cover the projected demand for bio-based packaging in Germany?
- How are the environmental challenges of the various bio-based resources to be evaluated?
- What alternative carbon sources are available today and will be available in the future and how do they compare to bio-based resources?

Objectives

The study aims is to identify specific options for using biogenic resources in packaging in a way that is ecologically meaningful and conserves resources – at all times in harmony with the overarching goals of greenhouse gas neutrality, resource efficiency and the conservation of biodiversity. Based on the analyses carried out in the report, the study draws fact-based conclusions that enable a proper assessment of the options examined. These are supplemented by recommendations for action that address both decision-makers in politics and actors along the packaging value chain.

2 Approach and methodology

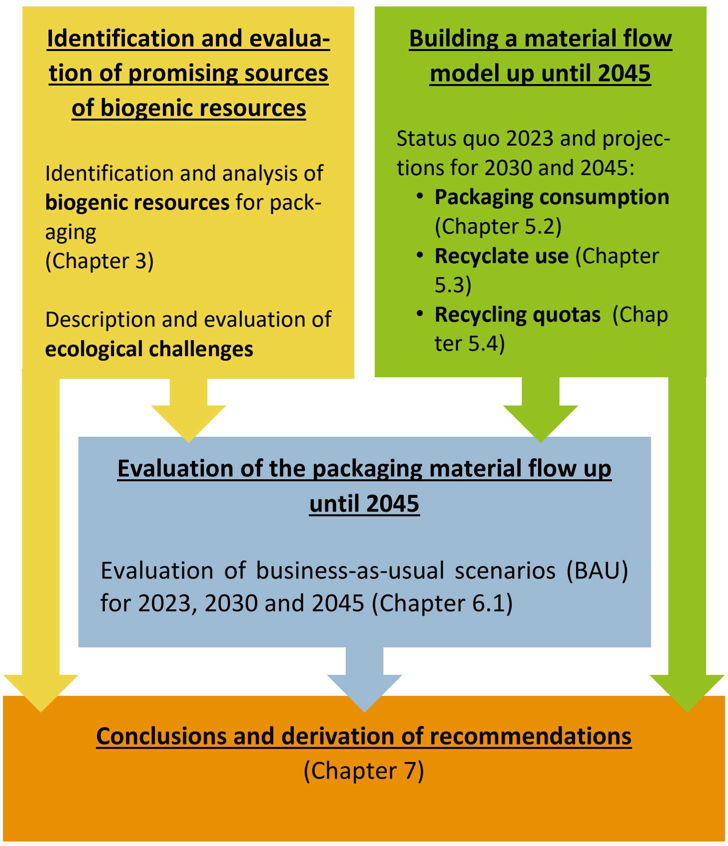
A systematic approach that combines both qualitative and quantitative methods was chosen to realise the project. This chapter introduces the execution concept, explains key terms in the context of biogenic resources for packaging and describes the methodological basis of the ecological assessment conducted. It also describes how each step is structured and which criteria were used to analyse and contextualise them.

2.1 Concept

The content-related analysis of the research questions defined in Chapter 1 followed a multi-stage logic that was divided into several work packages and steps, each with a different focus. The results of each step were finally summarised in an overall evaluation.

Figure 1 illustrates the structure and process of the project. It shows the sequence of the work packages as relates to content and their logical connection within the overall project.

Figure 1: Structure of the project



Each step is briefly described below:

- **Identification and evaluation of promising sources of biogenic resources:** In the first step of the study, the biogenic resources relevant for further analysis are selected and described. These resources are then analysed with regard to their environmental impact. Where available, life cycle assessment parameters are used to evaluate key environmental aspects such as land, energy, and water consumption. The aim of this step is to identify those biogenic resources whose utilisation is associated with the lowest possible environmental impact and which are therefore particularly suitable for use in packaging from an ecological point of view.

Content of Chapters 3 and 4

- **Building a material flow model for packaging up until 2045:** Parallel to the identification and ecological assessment of suitable biogenic resources, packaging consumption in Germany up until 2045 is projected, with 2030 serving as the base year. This step aims to derive future demands for bio-based packaging and the associated raw material requirements. The projection of future packaging consumption is supplemented by an estimate of the development of recycling quotas and utilisation rates of secondary materials up until 2045. A material flow model for packaging in Germany is built on this basis with the aim of quantifying the demand for primary biogenic packaging materials.

Content of Chapter 5

- **Evaluation of the packaging material flow:** Chapter 6 evaluates the demand for primary biogenic packaging materials developed in Chapter 5 while considering the specific environmental values and other qualitative environmental aspects developed in Chapter 4. The evaluation is carried out both in the context of a business-as-usual scenario (BAU), in which it is anticipated that the same raw materials used to meet the demand for bio-based packaging today will still be employed until 2045, and in the context of various optimisation scenarios. The aim is to show how the environmental impact of the demand for primary materials within the packaging material flow is likely to develop, what potential there is for optimisation, and to what extent these measures complement or, if applicable, contradict each other.

Content of Chapter 6

- Based on the scientific findings obtained in the work packages, well-founded **conclusions** are derived in the final chapter of the report; these serve to answer the research questions in an appropriate and fact-based manner. In addition to directly answering these questions, further recommendations are derived based on the knowledge gained.

Content of Chapter 7

2.2 Definitions and contextualisation

A clear definition of key terms is necessary to understand the report. This chapter defines the most important terms in the context of packaging, organic raw materials and packaging materials.

Packaging

Packaging fulfils key functions along the product value chain. It is used to protect, store, transport and promote goods, in the course of which various materials such as plastic, paper, metal or glass are used. Functionally, packaging can be divided into three categories: direct primary packaging, middle secondary packaging and outer tertiary packaging. In addition to its basic protective functions, packaging contributes significantly to hygiene, shelf life, consumer information, and marketing. It also provides considerable product safety, help to reduce food waste, and unfolds a strong communication effect at the point of sale.

Bio-based resources

Bio-based (or biogenic) resources are renewable alternatives to fossil raw materials. In addition to plant-based materials, this may also include animal-based raw materials. These may be both specifically cultivated renewable raw materials from agriculture and forestry as well as other forms of biomass, such as by-products, residual and waste materials from agriculture, animal husbandry, and forestry.

Bio-based plastics

Bio-based plastics are plastics that are made exclusively or partially from renewable raw materials (The German Environment Agency ("Umweltbundesamt", UBA) 2023). In 2022, 4.5 million tonnes of bio-based plastics were produced worldwide (Nova Institute 2024), which corresponds to 1% of the total production volume of fossil-based plastics. Among the bio-based plastics, polylactides (PLA) are dominant, with a share of 22%, followed by bio-based polyamide (PA) with a share of 20%, polytrimethylene terephthalate (PTT, 17%) and polyethylene (PE, 5%) (EUWID Packaging 2024).

Wood and PPC packaging as bio-based packaging

Bio-based packaging made from wood and wood-based materials such as **paper, paperboard and cardboard**are among the oldest forms of bio-based packaging. They are made from lignocellulosic biomass and are thus renewable, easily recyclable, and often biodegradable. Areas of application range from transport packaging made of solid wood and plywood to corrugated cardboard packaging to folding boxes and paper bags in the retail sector. Its market share is particularly high in the food, shipping, and consumer goods packaging sectors.

2.3 Methodological specifications

Framework of the study

The scope of this study concentrates exclusively on the packaging sector in Germany. Its focus is on the following types of bio-based material:

- packaging made of wood;
- packaging made of paper, paperboard and cardboard (PPC);
- packaging made of bio-based plastics.

Quantitative environmental evaluation based on life cycle assessment parameters

The ecological challenges are evaluated on the basis of a combination of qualitative and quantitative methods. The quantitative environmental evaluation focuses on three key environmental indicators:

- land utilisation,
- energy expenditure,
- water consumption.

The data required for this evaluation are taken from relevant references, existing studies, and publicly accessible databases and compared to one another.

Qualitative descriptive environmental evaluation based on expert knowledge

In addition to the quantitative ecological evaluation, a **qualitative environmental evaluation** of the data is conducted in the context of existing competing uses and ecological impact limits. In the course, quantitative environmental evaluations in particular are taken into account, based on measurable parameters:

- current availability,
- land use efficiency,
- competing uses.

Delimitation and restrictions

This study does **not** claim to provide comprehensive life cycle assessments for the biogenic resources assessed. Instead, an indicative, comparative environmental evaluation is carried out on the basis of selected parameters. This deliberate restriction is the result of existing methodological and data-based limitations. The comprehensive integration of all environmental, economic, and social requirements as well as of competing uses of biogenic materials is currently not feasible. Similarly, it is not possible to take a holistic view along the entire value chain – including upstream and downstream processes. Interactions with other industrial sectors are included qualitatively and in relation to potential competing uses.

Interpretation and contextualisation

The environmental evaluation is not to be seen as a static ranking of analysed materials, but as a critical contextualisation of the respective environmental impacts. The report expressly does not aim to criticise bio-based plastics or the material use of biomass in principle. The results should be seen as a guide and aim to enable a differentiated discussion around sustainable packaging solutions. They are intended to support decision-makers in recognising ecological potential and conflicting goals more easily and, on this basis, to develop functional strategies for the use of biogenic packaging materials, and thus conserve resources.

3 Biogenic resources for packaging: Selection, availability and application potential

For the in-depth analysis within the framework of the project, the project team selected 13 biogenic resources that are of particular relevance for bio-based value chains due to their current utilisation and development potential.

3.1 Selection and categorisation of potential biogenic resources

Selection criteria

The selection criteria were based on a combination of market relevance, innovation potential, and ecological evaluation. In addition to bio-based materials already in use today, such as wood, pulp, and selected cultivated biomasses such as maize and sugar beet/cane, promising raw materials in early stages of development, such as leaves or grasses, were also taken into consideration. By-products and waste products with potential for use as materials were also considered in the selection, including bagasse from sugar cane processing, tall oil and lignin from paper production, and packaging waste such as waste paper and waste wood.

Less established materials such as cup plant (also known as Silphium perfoliatum), bamboo and paludiculture crops were also included in order to open up new avenues for packaging applications. In the course, particular focus was placed on raw materials that are suitable for the production of fibre-based packaging, as the demand for paper packaging is currently much higher than that for bio-based plastics.

Tabelle 1 provides an overview of the 13 biogenic resources that were selected.

Table 1: Biogenic resources: Explanations

Resource	Examples of materials/sources	Brief description	Application considered in the context of the study
Primary wood	Frequent: spruce, pine; rare: beech, oak, eucalyptus	Directly from freshly felled trees, untreated	Wooden packaging (pallets, fruit crates) & primary fibres in PPC packaging
Leaves	Leaves collected by municipalities	Collection of seasonal biomass waste – mostly from forestry and urban greenery	substitute for primary fibres in PPC packaging

Resource	Examples of materials/sources	Brief description	Application considered in the context of the study
Waste wood	Residual industrial wood, used wood	Wood waste products from processing or utilisation	Substitute for primary wood in cellulose & raw material for bioplastics
Waste paper	Paper, paperboard, cardboard from recycling	Secondary raw material with cellulose, filling materials, etc.	(Established) substitute in pulp production, raw material for bioplastics
Grasses	Grass from permanent pastures	Mown grass from unfertilised pastures or surplus areas	substitute for primary fibres in PPC packaging
Cup plant	Entire plant	Mowings of the perennial plant of the aster family with a high yield	Substitute for primary fibres in PPC packaging
Paludiculture	Reeds, bulrushes, peat moss etc.	Mowed reeds from wet peatland cultivation	Substitute for primary fibres in PPC packaging
Bamboo	Giant bamboo, umbrella bamboo, *Phyllostachys*	Mowed fast-growing giant grass, stable and light	Substitute for primary fibres in PPC packaging
Maize	Maize silage, grain maize, maize leaves	Harvested crop with fruit, leaves, and straw	Leaves/straw: Substitute for primary fibres in PPC packaging Fruit: Raw material for bioplastics
Sugar beets	Shreds, molasses, residues	Sugar-rich plant, by-products can be used industrially	Leaves/straw: Substitute for primary fibres in PPC packaging Fruit: Raw material for bioplastics
Sugar cane/ bagasse	Sugar cane juice, press residue	Juice for ethanol, bagasse as a fibre	Bagasse: substitute for primary fibres in PPC packaging Juice (ethanol): Raw material for bioplastics
Tall oil	By-product of pulp production	Mixture of resin acids, fatty acids, alcohols	Raw material for bioplastics
Lignin	By-product of the paper industry	Biopolymer, lignifies plant cell walls	Raw material for bioplastics

3.2 Global availability and development potential of biogenic Resource

The global availability of biogenic raw materials varies greatly depending on climate-related, geographical, and agricultural factors as well as existing competing uses in other economic sectors – such as the production of food and animal feed or the generation of bioenergy. These factors have a significant influence on both the current and the potential use of biogenic materials for packaging applications.

The following section describes the global availability and development potential of each of the 13 resources analysed. Each resource has been appraised as to its regional spread, current use, and possible competing uses in order to create a sound basis for evaluating its potential in the packaging sector.

- **Primary wood** In 2020, global wood consumption totalled around 4.3-5 billion m³ (roundwood incl. bark; WWF Germany 2022). Around 31% of global land mass is forested (FAO 2020a), with the largest share in Russia (20%) (Suhr 2020). Long-term utilisation is to be ensured through sustainable forestry and biodiversity criteria. Certification systems such as PEFC and FSC aim to guarantee that wood comes from responsible forestry. However, only around 8.5% of the world's forested area is currently managed in accordance with PEFC guidelines (PEFC n.d.) and around 4% in accordance with the stricter FSC criteria (FSC Connect n.d.).
- **Leaves** Large quantities of leaves accumulate seasonally, especially in the deciduous and mixed forests of temperate zones. There is a lack in quantitative global information; availability is heavily dependent on the geographical region and season. While there is potential for use, this is currently barely being exploited systematically.
- **Waste wood** Worldwide, waste wood is predominantly produced from construction and demolition timber, furniture and packaging. In Germany, around 70% is used for energy and 30 % for materials (BAV e. V. 2018). At present, packaging wood is primarily recycled in the timber industry, as it is generally apparent that it is untreated.
- **PPC (paper, paperboard, cardboard)** Around 252 million tonnes of paper are recycled globally every year (Die Papierindustrie ("The German Association for the Paper Industry") 2020; European Paper Recycling Council 2023). This resource is created in especially large quantities in industrialised countries and is easily accessible through established collection systems. Competing uses primarily exist in the paper industry itself.
- **Grasses** Grasses are found on all continents (except Antarctica) and are potentially available in large quantities; for the most part, these are wild stands or stands that are less cultivated. To date, there is no comprehensive survey of usable biomass quantities.
- **Cup plant** Cup plant is a perennial plant with dry mass yields of 16-36.6 tonnes/ha per year (Daniel & Rompf 1994). Cultivation is currently limited to specific regions, especially in Germany, but can be expanded. There is a lack of data on global availability, but there is potential for developing larger areas in Europe and beyond.

- **Paludiculture** Paludiculture on rewetted peatlands is still at an early stage of development and its large-scale utilisation has not yet been established. Global availability is therefore low, with potential for the future.
- **Bamboo** Bamboo is mainly found in the tropics, subtropics and in some temperate zones. The plant is extremely fast-growing, but has not been developed comprehensively; China is one of the main producers. Bamboo is not native to Germany, but has the potential to be utilised economically – even if the plant has so far been used more in horticulture and landscaping.
- **Maize** With a global harvest of approx. 1,158 million tonnes per year, maize is one of the most frequently cultivated crops (1,157.88 million tonnes; Deutsches Maiskommitee ("German Maize Committee") n.d.). The USA alone produces 32.6% of the global volume (US Department of Agriculture 2024). Competing uses are found primarily in food, animal feed, and energy applications.
- **Sugar beets** With a global yield of around 260 million tonnes per year, sugar beet is readily available, especially in Europe (FAO 2023b). The yield is approx. 76 tonnes/ha per year (Wirtschaftsvereinigung Zucker ("The Sugar Trade Association") 2024). Sugar beet cultivation requires crop rotation, which restricts the continuous regional availabilities.
- **Sugar cane and bagasse** According to the FAO (Food and Agriculture Organization of the United Nations), around 1.92 billion tonnes of sugar cane were produced worldwide in 2022. As a by-product of sugar cane processing, large quantities of bagasse are also produced worldwide (approx. 570 million tonnes per year; own calculation in accordance with FAO 2023a). Bagasse is especially common in tropical countries such as Brazil and India. While no bagasse is produced in Germany, it can be imported.
- **Tall oil (from forestry)** Tall oil is a by-product of pulp production from softwood. Its availability is bound to the wood and pulp industry, however, it is relevant across the globe.
- **Lignin** As a component of wood, large quantities of lignin are created during pulp production. So far, it has mostly been used for energy. There is a lack in actual global production figures, however, the potential for its use as a material is increasing with as technology progresses.

Conclusion The data on availability, regional spread, and competing uses of the biogenic resources examined in the study and gathered in this chapter are the contextual foundation for the qualitative evaluation in Chapter 4.2. Here, the information is systematically categorised in order to integrate non-standardisable factors such as land use efficiency, availability, and conflicting uses into the overall evaluation, besides the quantitative analysis.

3.3 Excursus on the dilemma of using primary woods: The impact on carbon storage and biodiversity

Forests – especially primary forests – are key carbon sinks and habitats for the majority of terrestrial biodiversity (FAO & UNEP 2020). Despite a declining net loss of forest areas, deforestation, especially for agricultural and grazing purposes, remains a global problem. In 2022 global wood extraction reached a record level of 4 billion m³, around 50% of which was industrial wood, of which in turn around a third was used to produce pulp (FAO 2024, 2025). Europe accounts for around 20% of global production, with pulp accounting for around 25%.

In Europe, the area of canopy loss is growing – especially in the Baltic states – due to an increase in timber harvesting and climate-related disturbances such as storms, insect infestations, and fires (Turubanova et al. 2023). This development reduces the carbon sequestration effect: according to the National Forest Inventory, German forests have not been net carbon sinks since 2017, and instead were a source of emissions in 2022 (BMEL[1] 2024). Models predict a further decline in the sequestration effect; under severe climate change (RCP8.5), the release of additional CO_2 can be expected even in the event of moderate disturbances (Albrich et al. 2023; Korosuo et al. 2023).

Conversion risk in accordance with EUDR

As of the end of 2025, Regulation (EU) 2023/1115 (EUDR) on deforestation-free products bans timber imports and exports from areas that were deforested or structurally degraded after 31 December 2020. This also includes the conversion of primary or natural forests into timber plantations. The risk of such conversions varies depending on the region of origin:

- low in Central, Western, and Southern Europe;
- high in Northern and Eastern Europe (e.g. Baltic states, Scandinavia, Ukraine);
- high in Southeast Europe;
- high in North America (with a decline in intact forests despite expanding forest areas);
- high in Russia (expansive primary forest areas, pressure to employ forestry).

Conclusion

The origin of the wood is thus a decisive factor in evaluating its impact on the climate and biodiversity. Against the background of limited resources and ecological risks, the use of primary wood as a material – especially in short-lived products such as paper – increases competing uses in climate protection, the conservation of biodiversity, and industrial utilisation.

[1] From spring 2025 on BMLEH (Federal Ministry of Agriculture, Food and Regional Identity).

4 Description and evaluation of ecological challenges

This chapter evaluates the environmental challenges of the 13 selected biogenic resources for packaging both quantitatively and qualitatively. In addition, this chapter examines power-to-X plastics and their potential environmental impact compared to biogenic alternatives with regard to research question 4 *("What alternative carbon sources are available today and in the future and how should they be evaluated in comparison to bio-based resources?"*).

PtX plastics as an alternative source of carbon

Power-to-X (PtX) refers to technologies that convert electrical energy into other energy sources or basic chemicals. This includes plastics: PtX-based plastics do not differ from conventional plastics in terms of their chemical composition, making them suitable for the same applications, such as packaging (PE), textile fibres (PET) or technical components (PP). The most common process for converting electrical energy into plastics is synthesis: catalytic processes (e.g. Fischer-Tropsch synthesis) produce hydrocarbons as the basic elements for plastics such as polyethylene (PE) or polypropylene (PP). PtX plastics offer fossil-free alternatives if the electricity comes from renewable sources. However, it should be noted that the conversion chain (electricity → hydrogen (H_2) → hydrocarbons) is associated with high energy losses.

4.1 Quantitative evaluation – calculating specific environmental values

The quantitative environmental evaluation focuses on three key environmental indicators:

- **Land use:** The area required to provide the examined biogenic resources serves as a key parameter for assessing potential competition for land.
- **Energy consumption:** Energy consumption is recorded along the value chain of biogenic resources and waste materials to packaging materials – e.g. in the production of paper, cardboard, or bio-based plastics. Processes with high energy consumption, such as drying or chemical processing, are particularly taken into account, as their energy consumption can have a considerable ecological impact.
- **Water consumption:** The water needs in the examined systems are also included in the assessment. However, due to insufficient available data, it is not possible to analyse water availabilities on a region-specific basis. It should be noted that the ecological relevance of water consumption depends heavily on the regional water situation.

When developing the emission factors, a distinction was made between the target products wood, plastic, and paper, as their treatment processes differ considerably. However, since not all resources identified in Chapter 3 are equally suitable for the production of packaging papers or plastics, each resource has been specifically allocated to the corresponding target products.

The methodological procedure for calculating specific environmental values and data sources used for modelling are documented in Tabelle 2.

Table 2: Procedure for calculating specific environmental values, including main sources used

Target product and raw material	Assessed product	Modelling procedure/sources used
Packaging wood from forestry	Wooden pallet without steel	Ecoinvent 3.10 (2023) – dataset for Euro pallets, minus steel content
Packaging paper made from primary wood	Paper made of 100% pulp from primary wood	Primary paper (LPB), based on ACE & ifeu (2020)
Packaging paper made from cup plant	Packaging paper/cardboard made of 50% cup plant fibres and 50% pulp from primary wood	Authors' calculations based on Maga et al. (2021) and Out- Nature (n. d.), cup plant fibres pass through the production process along with pulp from wood fibres, are therefore blended with primary paper process, energy value of cup plant based on straw
Packaging paper made from leaves	Packaging paper/cardboard made of 40% leaf fibre and 60% pulp from primary wood	Authors' calculations based on cup-plant paper, as (Releaf n. d.) leaves converted to fibre using advanced technology without sulphates, sulphites and chlorine. Author's assumptions on gathering, harvesting and drying, pulp yield (Releaf Paper (n. D.) and sustainable paper (Herbstlaub 2024), energy value of straw and primary paper production
Packaging paper made from grass	Packaging paper/cardboard made of 50% grass fibre and 50% pulp from primary wood	Authors' calculations based on Terlau et al. (2017) and internal ifeu data
Packaging paper made from paludiculture	Packaging paper/cardboard made of 50% straw fibre from paludiculture and 50% pulp from primary wood	Authors' calculations based on cup-plant paper, assumption: 50% reed, harvest based on grass harvest – extensive use, yield/moisture content/energy value and pulp content based on Greifswald Moor Centrum (2016), Fiedler et al. (2023), and VIP (n. d.) and primary paper production
Packaging paper made from bamboo	Packaging paper/cardboard made of 100% bamboo fibre	Authors' calculations, paper production based on Ecoinvent 3.10 (2023), FEFCO-Kraftliner dataset, bamboo input based on Braskem (2018)
Packaging paper made from bagasse	Packaging paper/cardboard made of 100% bagasse fibre	Authors' calculations based on FEFCO & Cepi Container Board (2022) and Poopak & Roodan (2012): 100% bagasse paper, FEFCO as base, 100% bagasse use and changes in chemicals (no bleaching agents), bagasse dataset from Econinvent 3.10 (2023)
Packaging paper made from sugar beets	Packaging paper/cardboard made of 35% sugar-beet shreds	Author's calculations, paper production based on FEFCO & Cepi Container Board (2022), pulp and waste paper substituted with dry pulp based on quantity from Vaccari et al. (1995)

Target product and raw material	Assessed product	Modelling procedure/sources used
	and 65% pulp from primary wood	
Packaging paper made from waste wood	Packaging paper/cardboard from waste wood	Literature analysis from M'hamdi et al. (2017), energy value calculated using formula from Orbit-Online (n. d.)
Packaging paper made from crop residues	Food trays made from 75% crop residues, remaining fibres from primary wood	Calculation based on internal ifeu data
Sugar-cane-based plastics	Bio-PE from sugar cane	Calculation based on Braskem (2018) and internal ifeu data
Plastics made from primary wood	Cellophane made from primary wood	Authors' calculations, based on Ecoinvent 3.10 (2023) – dataset on viscose fibres and internal ifeu data for processing into cellophane
Maize-based plastics (PLA)	PLA from maize	Literature analysis from Vink & Davies (2015)
Plastics made from sugar beets	Bio-PE made from sugar beets	Authors' calculation, based on Ecoinvent 3.10 (2023) – dataset for ethanol from sugar beets, polymerisation from tall oil and ethylene modelled based on Braskem (2018)
Plastics made from tall oil	HDPE based on tall oil	internal ifeu data
Plastics made from lignin	Carbon fibre-reinforced plastic made from 100% lignin fibres	Authors' calculation, based on Ecoinvent 3.10 (2023) – dataset for carbon fibre-reinforced plastic Dataset adjustments: - Substitution of fossil input with lignin fibres - Energy input adjusted based on Hermansson et al. (2020) and Obasa (2022) - Spinning of lignin fibres based on Hermansson et al. (2020) - Lignin extraction based on LCA Commons (2018), dataset on kraft lignin extraction and Culbertson et al. (2016), adjustment of allocation to 5% (economic) based on Hermansson et al. (2019), energy value based on dry fibre from Stockschläder et al. (2022)
Plastics made from waste wood	Cellophane made from waste wood	Authors' calculations, based on Ecoinvent 3.10 (2023) – dataset on viscose fibres, substitution of primary wood in the pulp that goes into viscose production, use of internal ifeu data for processing into cellophane

Target product and raw material	Assessed product	Modelling procedure/sources used
Plastics made from waste paper	Cellophane made from waste paper	Authors' calculations, based on Ecoinvent 3.10 (2023) – dataset on viscose fibres, use of internal ifeu datasets for waste paper pulp that goes into viscose production and for processing into cellophane
PtX plastics	HDPE PtX-based.	Use of data from Dittrich et al. (2020)

Assessment of land consumption

When assessing the land needs of the examined biogenic resources, a distinction is made between the following types of land use: *Forest, timber plantations, grassland, arable land* and *settlement areas*. The land use of these categories is aggregated to form the DNP indicator value using the hemeroby concept. The hemeroby concept describes the degree of human influence on ecosystems by categorising areas into seven hemeroby classes ranging from *natural* to *artificial.* This makes it possible to combine different forms of land use in a standardised indicator value that is used for ecological assessments. The methodological basis includes the work of Schmitz & Paulini (1999) and further developments by Fehrenbach et al. (2015, 2021) and Lindner et al. (2020).

It should be noted that the analysis only takes into account those areas that are directly used for the extraction of the main resource. Other areas, for example for starch production in paper production, transport infrastructures or for processing steps, have not been taken into account.

Assessment of energy consumption as CED_{Total}

The study does not just focus on land needs, but on the energy consumption of the examined systems as well. In order to capture this consumption comprehensively, the study uses the cumulative energy demand (CED_{total}) as a benchmark.

Assessment of water consumption

To complete the quantitative ecological evaluation, the study analyses the scarce resource *water* alongside the limited resources *land* and *energy.* The water values shown here are to be interpreted with caution due to the uncertainties described in Chapter 2. Nevertheless, they allow general statements to be made about the intensity of water consumption in the examined systems.

Summary of emission factors for the quantitative environmental evaluation

Tabelle 3 presents the results of the calculation of the specific environmental values for the parameters *land needs*, *energy,* and *water.* To ensure a clear and transparent presentation, the results have been documented in the form of value tables. The values have been divided into six to eight classes for each parameter, with each class representing the bandwidth between the respective minimum and maximum values. For more clarity, a colour coding system has been used in which *bright* colours indicate low environmental impact and *dark* colours indicate high environmental impact.

For clearer differentiation, the three emission factors are shown in different colours: land needs in *green*, energy needs in *orange,* and water consumption in *blue*.

Table 3: Emission factors for identified biomass potential

Target product	Resource	Land needs		Energy as total CED	Water consumption
		in ha/t	ha aF-eq. *a /t[2]	in MJ/t	in m^3/t
Packaging wood	Wood	< 0.35	< 0.045	≤ = 30,000	≤ = 20
PPC packaging	Primary wood	< 0.5	< 0.075	≤ = 45,000	≤ = 100
PPC packaging	Leaves	< 0.25	< 0.035	≤ = 45,000	≤ = 80
PPC packaging	Grass	< 0.3	< 0.045	≤ = 45,000	≤ = 80
PPC packaging	Cup plant	< 0.25	< 0.035	≤ = 45,000	≤ = 80
PPC packaging	Paludiculture	< 0.5	< 0.017	≤ = 45,000	≤ = 80
PPC packaging	Bamboo	< 0.25	< 0.085	≤ = 55,000	≤ = 50
PPC packaging	Bagasse	< 0.01	< 0.001	≤ = 30,000	≤ = 50
PPC packaging	Sugar beets	< 0.35	< 0.045	≤ = 45,000	≤ = 50
PPC packaging	Waste wood	0	0	≤ = 30,000	≤ = 100
PPC packaging	Crop residues	< 0.05	< 0.017	≤ = 45,000	≤ = 20
Plastics	Sugar cane	< 0.5	< 0.25	≤ = 75,000	≤ = 50
Plastics	Primary wood	< 0.3	< 0.045	≤ = 85,000	≤ = 200
Plastics	Maize	< 0.2	< 0.085	≤ = 65,000	≤ = 100
Plastics	Sugar beets	< 0.2	< 0.085	≤ = 75,000	≤ = 50
Plastics	Tall oil	< 0.01	< 0.001	≤ = 45,000	≤ = 20
Plastics	Lignin	< 0.6	< 0.085	> 500,000	≥ = 300
Plastics	Waste wood	0	0	≤ = 65,000	≤ = 200
Plastics	Waste paper	0	0	≤ = 65,000	≤ = 200
Plastics	PtX (energy)	< 0.05	< 0.035	> 100,000	≤ = 20

The following exemplary findings can be derived from the comparative values shown in Tabelle 3 to evaluate the environmental impacts of the examined biogenic resources analysed:

Conclusions drawn from the quantitative evaluation

- The production of plastics generally requires more energy than the production of paper-based packaging materials, even if identical resources (e.g. primary wood, waste wood) are used.
- In relation to an identical mass of output (kg or tonnes), packaging plastics made from agricultural biomass have overall higher land and energy needs compared to paper-based packaging (PPC).
- The use of alternative pulp sources (e.g. leaves, grass, cup plant, biomass from paludiculture, crop residues) can considerably reduce the land footprint without significantly increasing energy or water consumption.
- Waste and by-products such as tall oil, waste wood, and waste paper have the lowest environmental impact in terms of land and energy consumption. However, a comparatively high water consumption in the production of plastics must be taken into account for waste paper and waste wood.

[2] Indicator of hemeroby unit.

These exemplary results illustrate the wide range of potential environmental impacts associated with the choice of resource. They emphasise the need for a differentiated ecological evaluation when developing and selecting bio-based packaging solutions.

4.2 Qualitative evaluation of availabilities and identification of potential competition

In the qualitative evaluation, the 13 biogenic resources examined are systematically and comparatively categorised according to the criteria *current availability, land use efficiency,* and *competing uses*. The aim is to present existing risks, conflicts of use, and possible synergies in a transparent manner and to expand the results of the quantitative analysis to include a context-related perspective.

Methodological definition of the selected criteria

The following explains the methodological definitions of the three parameters and on what basis the evaluation documented in Table 4 has been carried out.

- **Current availability:** The evaluation of current availability is generally based on the global yields of the various biomasses. The analysis recontextualises the figures compiled in Chapter 3.2 and translates them to the specific requirements of the use of raw materials for bio-based packaging. In the course, a direct comparison with the availability of alternative agricultural biomass or types of residual and waste materials that can be primarily used for packaging purposes is only possible to a limited extent.
  - - Resources with high global availability are categorised as *high* in the evaluation. This categorisation has a positive connotation in the context of this study and are accordingly highlighted in *green*; this does not, however, imply an ecological benefit.[3]
  - - Resources with generally high potential whose availability is limited to certain regions – such as sugar beets or bamboo – are evaluated as medium.
  - - Resources that have not yet been developed commercially are categorised as *neutral,* as it is unclear whether and to what extent their potential can be developed until 2045.

  It should be noted that in this case, this categorisation does not constitute an environmental evaluation.
- **Land use efficiency:** The assessment of land use efficiency is primarily based on information on yields per hectare – i.e. the amount of usable biomass that can be produced per unit area under the given conditions. This indicator allows the direct categorisation of land use efficiency of specifically cultivated primary raw materials in particular.

  Such an evaluation is not possible in the case of residual materials, waste or by-products, as there land cannot be directly allocated to these types of resource. They are generated as part of other production processes – for example in agriculture, wood processing or the food industry – and are therefore not land-based in the conventional sense. In these cases, no evaluation is made in the context of land use efficiency.

[3] In the sense of: in general, there is a lot of this resource available. However, the environmental impact resulting from the cultivation and use of this resource supply is not evaluated here! In the course, it is emphasised that the current availability of a resource does not automatically indicate that it is ecologically harmless. The evaluation must also take into account the long-term sustainability of the affected ecosystems. If a resource such as wood is already heavily utilised in several sectors, its continued use as a packaging material may be ecologically critical despite its formal availability.

- **Competing uses:** The evaluation of potential competing uses is indicative. For example, when utilising primary wood, the origin of the wood is a decisive factor in evaluating its impact on the climate and biodiversity. Against the backdrop of limited resources and ecological risks, the use of primary wood as a material – especially in short-lived products such as packaging – increases competing uses with regard to climate protection, the conservation of biodiversity, and industrial utilisation.

  For other biomasses, the following applies: if there is a competitive situation concerning high-value uses of global relevance – such as food production or the provision of essential ecosystem services – this is categorised as critical and rated *high* in the table below. This evaluation has a **negative connotation** and indicates a potentially problematic competition for resources.

  If, on the other hand, there exist competing uses as materials that are industrially relevant but have not been given existential or ecological priority (e.g. as a raw material for non-packaging products), these are rated *medium.*

  If the competing uses of the examined biomass are primarily low-value – such as composting or energy utilisation (co-incineration) – or if the examined biomass is not currently being used for any commercial purpose at all, competing uses are rated *low.*

The following Table 4 summarises the central framework conditions of the examined biogenic resources, in particular with regard to their current availability, their land use efficiency, and potential competing uses with other fields of application (e.g. food production, energetic use or ecosystem services).

Table 4: Qualitative evaluation of the bio-based resources examined in the study

Resource	Current availability	Land use efficiency (yield per hectare)	Competing uses
Primary wood	High	Low	High Ecosystem services, construction timber, wood
Leaves	Not specified, as currently only limited commercial use	Medium	Low Leaves as a material in composting
Waste wood	High	Not specified	Medium Waste wood as an energy source
Waste paper	High	Not specified	Medium Waste paper as a raw material for magazine and sanitary paper and as an energy source
Grasses	Not specified, as currently only limited commercial use	Medium	Low Grasses as a material in composting
Cup plant	Not specified, as currently only limited commercial use	Medium	Low Currently hardly any commercial use
Paludiculture .	Not specified, as currently only limited commercial use	Medium	Low Currently hardly any commercial use
Bamboo	Medium	Low	High Ecosystem services
Maize	High	Low	High Food
Sugar beets	Medium	High	High Food
Sugar cane	High	Low	High Food
Bagasse and crop residues	High	Not specified	Medium Bagasse as an energy source Crop residues as bedding
Tall oil	Not specified, as currently only limited commercial use	Not specified	Low Currently hardly any commercial use – max. as an energy source in primary paper production
Lignin	Not specified, as currently only limited commercial use	Not specified	Medium Currently hardly any commercial use as a material – however, as an energy source in primary paper production

Conclusion

The key findings from the previous analyses are summarised below.

- Forests fulfil key ecosystem services and, with the resource of primary wood, provide a raw material for packaging that is currently used on a large scale. However, primary wood used for packaging competes with numerous other uses, which results in a conflict of objectives between the forests' ecological limits and the current and projected demand for wood. Increased use of wood as a resource for bio-based plastic packaging would further intensify this conflict of objectives.
- Resources such as maize, sugar beets, and bamboo have considerable competing uses in food production or the provision of ecosystem services; their suitability for material applications is therefore limited.
- Secondary raw materials such as waste wood, waste paper, bagasse, and crop residues are currently readily available. There is minor competition around their use as a source of energy or in established forms of recycling.
- To date, resource options such as grasses, cup plant, paludiculture, tall oil, and lignin are not yet of significant commercial importance. In the long term, however, they could develop relevant potential – provided that availability, development and material flows continue to develop and competing uses remain low.

This evaluation illustrates that when selecting suitable biogenic resources for packaging solutions, ecological values must be taken into account just as much as the accessibility of the resources and existing competing uses.

5 Building a material flow model for packaging up until 2045

Key facts:

Determining the demand for primary material by building a packaging material flow on the basis of the data and projections on

- Packaging consumption 2023/2030/2045 → **decrease up until 2045**
- Recyclate use quotas 2023/2030/2045 → **increase up until 2045**
- Recyclate use quotas 2023/2030/2045 → **increase up until 2045**

Comparative evaluation of the material flows for 2023 and 2045:

- Primary material input falls by 37% from 8.5 million tonnes to 5.4 million tonnes
- Share of recycling within the packaging material flow increases from 52% (9.3 million tonnes) to 64% in 2045 (9.7 million tonnes)
- Share of paper in primary material input increases from 19% (1.6 million tonnes) to 42% (1.6 million tonnes)
- Share of bioplastics in primary material input increases from 3% (0.07 million tonnes) to 43% (0.36 million tonnes)

Objective

This chapter aims to determine the future demand for biogenic resources. This demand is first calculated for base year 2023 and then projected for 2030 and 2045. For the ecological evaluation of bio-based packaging materials, it is not the total packaging volume that is decisive, but the **use of primary materials** – i.e. materials that are newly introduced into the packaging system and do not come from recycling processes.

5.1 Procedure for deriving packaging material flows

To determine the demand for biogenic primary materials, the study developed a material flow model that maps the inflow and outflow of materials in the packaging cycle. It shows which quantities of material enter the cycle and which leave it permanently. For each material group, the following three parameters are taken into account and are included in the calculation of the material flows:

- total packaging consumption;
- the actual use of recyclates in the packaging system;
- the output-orientated recycling quota (proportion of waste that is recycled).

Figures for the three parameters are available for the base year 2023; the figures for 2030 and 2045 are projections.

Definition of material flows

The model assumes that recyclates are prioritised for reuse in the packaging sector – but only if the recycling feed-in rate is higher than the use of recyclates. Otherwise, not enough secondary material will be available to meet the demand in the packaging sector. In the course, material flows that remain within the packaging system are taken into account. External material outflows, such as

- material utilisation in other areas (e.g. construction);
- energy utilisation; or
- losses in the recycling process

are not considered as contributions to covering packaging material demands.

Examples of material flows

The packaging material flows include both existing and projected material flows, differentiated by material group:

- Waste paper → corrugated cardboard and paper-based packaging;
- Plastics → secondary plastics for packaging applications;
- Metals and glass → equivalent material reuse.

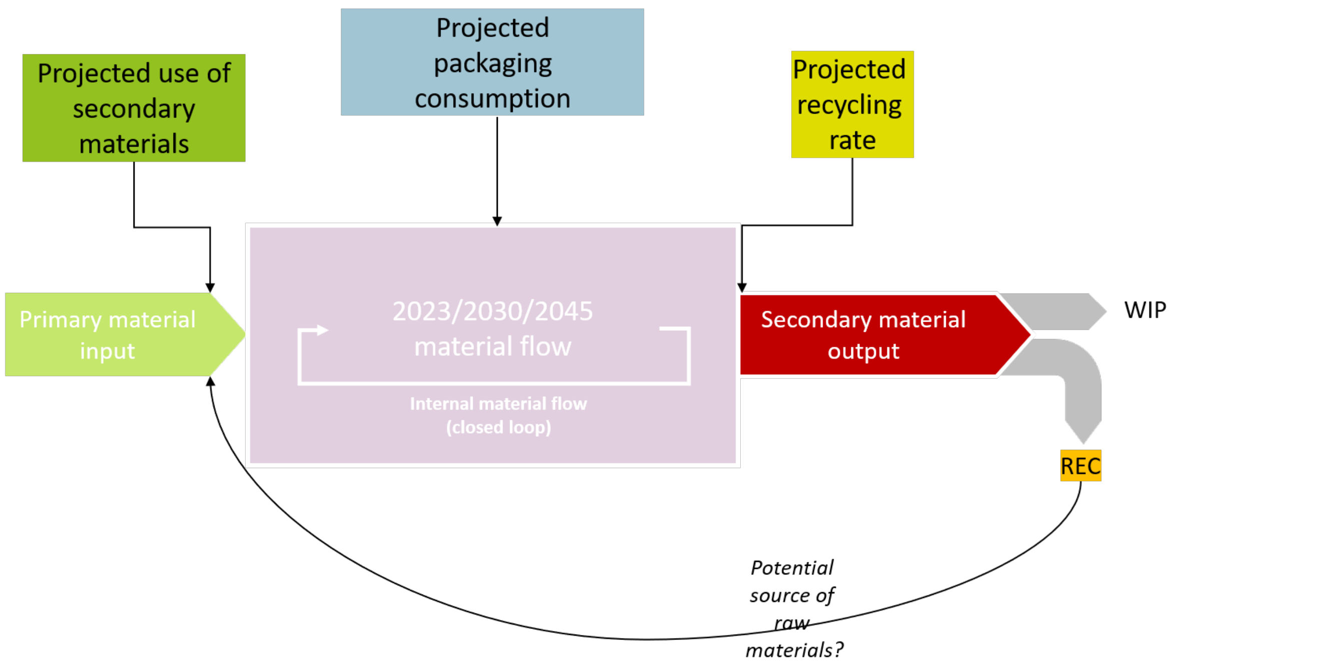
In order to ensure a consistent and system-inherent evaluation, the study expressly does not provide for the replacement of primary materials with materials recycled externally outside of these packaging material flows.

Relevance for environmental evaluation

The chosen methodology allows a clear distinction to be made between internally closed cycles and external material flows. This is particularly relevant for the environmental evaluation of bio-based packaging solutions, as only the materials actually used in the packaging system are included in the life cycle assessment.

The following diagram in Figure 2 shows the steps taken to build the material flows:

Figure 2: Procedure for deriving material flows for 2023/2030/2045



5.2 Projected packaging consumption up until 2045

Basis for projections

The portrayal of packaging consumption in 2023 and the projection of future developments based on that consumption was compiled by GVM. The data basis for packaging consumption in 2023 is essentially based on the results of the GVM study *Recycling Assessment for Packaging* (*Recycling-Bilanz für Verpackungen*, GVM 2024). These values form the basis for the extrapolation of packaging consumption in Germany up until 2045. 2030 serves as a supporting year for the calibration and interim evaluation of the projection. Current developments and trends as well as political and regulatory framework conditions in the packaging sector are taken into account.

The five main packaging material groups were included in the study: *wood; paper/paperboard/cardboard (PPC); plastics; glass;* and *metals*, including the respective *composite types*. Packaging waste was subdivided according to its source of generation, so that the projection model is based on five sub-parts: *households; comparable sources of waste generation; single-use beverage packaging with deposits; transport packaging;* and *sales packaging* for the industry and trade.

The projection model employed has been extrapolated by GVM for several years and forms the basis of various publications (including DVI 2023). This study took into account the latest findings on the relevant influencing parameters and integrated specific forecasts for the bio-based plastics sector.

Central factors influencing the projection

The projected development of packaging consumption is influenced by a number of structural, technological, legislative, and social trends. The most important influencing factors include:

Demographic developments

- According to a population scenario run by the Federal Statistical Office of Germany, the German population will increase by around 2% by 2030, under assumptions that are considered likely (high net migration, moderate decline in the birth rate). By 2045, it is assumed that the population will fall back roughly to the 2022 level.
- This development has a direct impact on consumption and therefore also on the volume of packaging.

Economic framework conditions

- Persisting economic uncertainties, such as inflation and deindustrialisation, are slowing down demands for packaging in the industrial sector in particular.
- Investments are increasingly shifting to climate-relevant infrastructures, making certain types of packaging less important.

Technical innovation and digitalisation

- Advances in material technology enable lighter packaging and a lower use of resources.
- Progressing digitalisation means a significant reduction in paper consumption in the office and service sector in particular.
- The use of artificial intelligence and automation leads to efficient logistics systems with reduced packaging needs.

Legal and social framework conditions

- Regulations such as the EU Packaging and Packaging Waste Regulation (PPWR) or the ban on individual single-use plastic products (SUPD) lower the use of plastic packaging.
- At the same time, it is assumed that the importance of reusable packaging and bio-based materials will increase.

The projection shows the following core results:

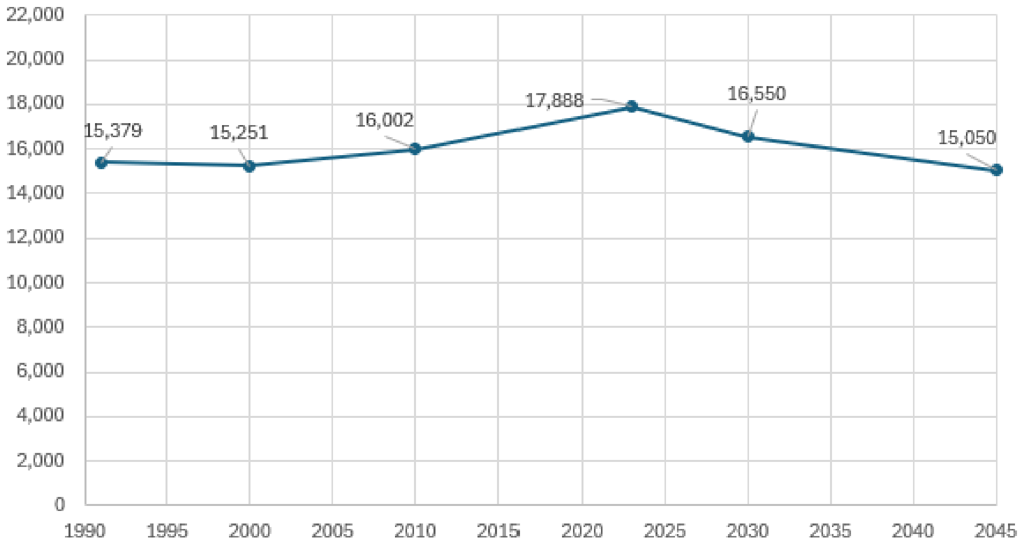
Results for 2023

- Packaging consumption of all relevant materials reached an all-time high in 2023 with 17,888 kt. Paper, paperboard, and cardboard packaging (PPC) accounted for the largest share with 44% of the total tonnage. Wood and plastic packaging each contributed 17%, while glass packaging achieved a share of 16%. Together, ferrous metal and aluminium together accounted for around 5% of total packaging consumption. Bio-based plastics in packaging in Germany made up a share of 2%.

Long-term decline in packaging consumption predicted after peak in 2023

- For the following years, the study projects a significant decline in packaging consumption from 17,888 kt in 2023 to 15,050 kt in 2045, which corresponds to a decrease of around 15.8 %. Figure 3 shows the chronological development of packaging consumption over the examined period and portrays both the initial level and the expected decrease up until 2045.

Figure 3: Projected packaging consumption in kilotons (kt)



At 48%, PPC packaging accounts for the largest share in 2045. Glass packaging accounts for 18% of the total, while wood accounts for 15% and plastic for 13%. Together, ferrous metal and aluminium account for 5% of total consumption. The share of bio-based plastics in packaging will increase to 9% until 2030 and to 43% until 2045.

The largest reductions in packaging volumes are seen in non-private end use and are therefore not directly perceptible to end consumers. At 9.5 million tonnes, non-private end use accounted for 53.2% of the total packaging volume in 2023 and will decrease by 17.2% to 7.9 million tonnes up until 2045 as a result of deindustrialisation, digitalisation, and the expansion of reusable systems. Packaging consumption in the private sector, on the other hand, declines more moderately by 14.3%, from 8.4 million tonnes to 7.2 million tonnes.

Main factors influencing packaging consumption in 2045

Table 5 shows the packaging consumption in 2023 and the projected packaging consumption in 2045 for each packaging material group under consideration, as well as the changes in per cent. The share of bio-based materials within the packaging material groups is also shown. In order to interpret the values, the main factors influencing the changes in the packaging material groups relevant to this study have also been documented.

Table 5: Comparison of packaging consumption in 2023 and 2045

	Consumption 2023		*Projection 2045*			
Material (total quantity primary and secondary materials)	*Total*	*of which are bio-based*	*Total*	*of which are bio-based*	*Prior year total in %*	*Main influencing factors*
Glass	2,911 kt	0 kt	2,708 kt	0 kt	-7.0%	Substitution of disposable glass with reusable packaging and alternative disposable materials due to high energy consumption in glass production.
Aluminium	156 kt	0 kt	127 kt	0 kt	-18.6%	Projected decline due to relocation of energy-intensive steel and aluminium production abroad.
Ferrous metal	779 kt	0 kt	660 kt	0 kt	-15.3%	
***PPC** (paper, paperboard, cardboard)*	7,346 kt	7,346 kt	6,218 kt	6,218 kt	-15.4%	Increase in mail order business with simultaneous reduction in the use of materials due to lightweight construction leads to an overall moderate decline.
Composites, paper-based	353 kt	319 kt	917 kt	830 kt	+159.8%	Strong increase expected as paper composites are increasingly replacing single-use packaging made of plastic, glass, and aluminium. Exception: LPB
Liquid packaging board	167 kt	123 kt	109 kt	80 kt	-34.7%	
Fossil plastics	2,898 kt	0 kt	1,053 kt	0 kt	-63.7%	Declining consumption due to stricter regulatory requirements, image problems, and substitution with paper-based composite materials.
Bio-based plastics	80 kt	80 kt	806 kt	806 kt	+907.5%	Expected increase due to increasing social acceptance ("perceived sustainability"), government support measures and technological progress.
Composites, plastic-based	52 kt	0 kt	34 kt	0 kt	-34.6%	Declining consumption due to stricter regulatory requirements, image problems, and substitution with paper-based composite materials.
Wood	3,109 kt	3,109 kt	2,326 kt	2,326 kt	-25.2%	Substitution of disposable pallets with reusable pallets and the substitution of wooden packaging with plastic.
Textiles	27 kt	27 kt	81 kt	81 kt	+200.0%	
Other	10 kt	2 kt	11 kt	2 kt	+10.0%	
Total	17,888 kt	11,006 kt	15,050 kt	10,343 kt	–15.9 %	

The projection of packaging consumption up until 2045 shows a far-reaching structural change in the packaging market. While consumption reached an all-time high in 2023, a significant decline is expected for Germany in the coming decades – due to a complex interplay of technological innovations, regulatory measures, economic developments, and social change processes. Technological advances in material development, digitalisation along the value chain, and the expansion of cycle-oriented systems such as logistics for reusable and unpackaged items are particularly influential, as is the ongoing deindustrialisation of Germany as a business location. Added to this are adjustments to the legal framework at European and national level as well as increasing social awareness around environmental and climate protection.

The decline affects almost all material groups, in particular plastic, PPC, glass, wood, and metals. What is striking, however, is the structural shift towards paper composites and bio-based plastics, some of which are being positioned as substitutes for fossil raw materials and are becoming increasingly important, both politically and socially.

Influencing factors for the growth of bio-based plastics up until 2045

Table 5 shows that the demand for bio-based packaging materials in all relevant categories amounted to 11.0 million tonnes in 2023; a decline to 10.3 million tonnes is projected for 2045. The decline in bio-based packaging consumption is largely due to a decline in packaging consumption of PPC (paper, paperboard, cardboard), and wood. Consumption of bio-based plastics, on the other hand, shows a significant increase, from 80 kt in 2023 to 806 kt in 2045. This development is driven by the growing interest in alternatives to fossil fuels and the associated reduction in CO_2 emissions. Geopolitical uncertainties and the desire for less dependence on fossil fuel imports also play a role. In addition, sustainability is gaining strategic importance for the industry: many international companies have publicly committed to reducing fossil-based plastics and are increasingly investing in bio-based packaging solutions.

This trend is supported politically by EU programmes and national funding initiatives – for example by the Federal Ministry of Agriculture, Food and Regional Identity (BMLEH). Research and development in the field of bioplastics specifically are being advanced. Technological innovations are also improving the material properties of bio-based polymers and reducing production costs, meaning these polymers can increasingly compete with conventional plastics. In connection with the EU Packaging and Packaging Waste Regulation, various actors have brought counting the use of sustainable biomass in packaging towards the fulfilment of quotas for the use of recyclates into the discussion; a legislative proposal to this effect could be presented as early as 2028. The increase in the demand for bio-based plastics that this could trigger has not yet been taken fully into account in current market projections.

In parallel with market growth, the production of bio-based plastics is increasingly shifting to countries with low production costs and strong economic growth – particularly to Asia and South America. Countries such as China, Thailand, and Indonesia are investing heavily in the chemical and bioplastics industry, which is also likely to influence the European market in the long term (Nova Institute, 2024).

Conclusion

The analysis of the current and projected packaging consumption up until 2045 shows a differentiated picture: by 2045, the total volume of packaging shows a reduction of 15.8%. At the same time, the use of bio-based packaging also shows an overall decline. The main reason for this development is the decrease in packaging made from paper, paperboard, and cardboard (PPC), while paper composites and bio-based plastics exhibit considerable growth (the latter by a factor of nine).

However, the decline in the consumption of bio-based packaging does not directly reflect the demand for biomass. For the final evaluation, it is necessary to link consumption data with life cycle assessment parameters (Chapter 4).

5.3 Recyclate use quotas

The recyclate use quotas for 2023 are mainly based on information from associations, market-leading companies, and relevant expert studies. Binding regulatory recyclate use quotas and voluntary manufacturer-related commitments contribute to an increased use of recyclates. The potential for optimisation is particularly limited for materials with an already high recyclate use quota. Due to legal framework conditions and an improvement in the general collection, sorting, and recycling infrastructure, the availability of high-quality recyclate is expected to increase.

Table 6 below shows the use of recyclates in packaging – including secondary and transport packaging.

Table 6: Recyclate use in packaging (incl. Secondary and transport packaging) in per cent

Material	2023	2030	2045
Glass	70.0%	74.0%	80.7%
Aluminium	61.0%	71.8%	79.4%
Ferrous metal	58.0%	65.5%	71.5%
PPC (paper, paper-board, cardboard)	85.2%	87.7%	87.9%
Composite packag-ing, paper-based	0.0%	5.0%	20.0%
Liquid packaging board	0.0%	5.0%	35.0%
Plastic	15.1%	40.0%	55.0%
Wood	1.5%	3.5%	7.5%

Paper, paperboard, and cardboard (PPC) have the highest share of recyclate use across all periods examined in the projection, with 85.2% in 2023, 87.7% in 2030, and 87.9% in 2045. In contrast, the most significant growth is in the area of plastic packaging, for which the study projects an increase in the share of recyclates of 40 percentage points between 2023 and 2045.

Fundamental assumptions made to project recyclate use

The projection assumes that extensive structural and regulatory measures will be implemented in the coming years which will fundamentally change the packaging sector. In the course, the central focus lies on packaging that is designed for recycling. Simplifying and harmonising material compositions and eliminating impurities such as PVC, pigments or complex multi-layer systems aims to significantly improve the recyclability of packaging.

Preserving recyclates in the packaging cycle is just as important. The aim is to prioritise the use of recyclates in closed material cycles and thus avoid downcycling. To supplement this, collection and sorting are to be optimised – for example through targeted collection systems for certain types of packaging or the extension of the deposit obligation to additional product groups.

In addition, it is expected that cross-material use quotas will be introduced in order to prevent shifting between different packaging materials and ensure balanced use. Financial incentives in accordance with Section 21 VerpackG are intended to specifically promote recycling-friendly packaging solutions and the use of recyclates.

Overall, these measures are crucial to achieving the projected use of recyclate – especially for plastic packaging. At the same time, they make it clear that a comprehensive transformation along the entire value chain is necessary in order to sustainably strengthen the circularity of packaging materials and utilise resources more efficiently.

5.4 Recycling quotas

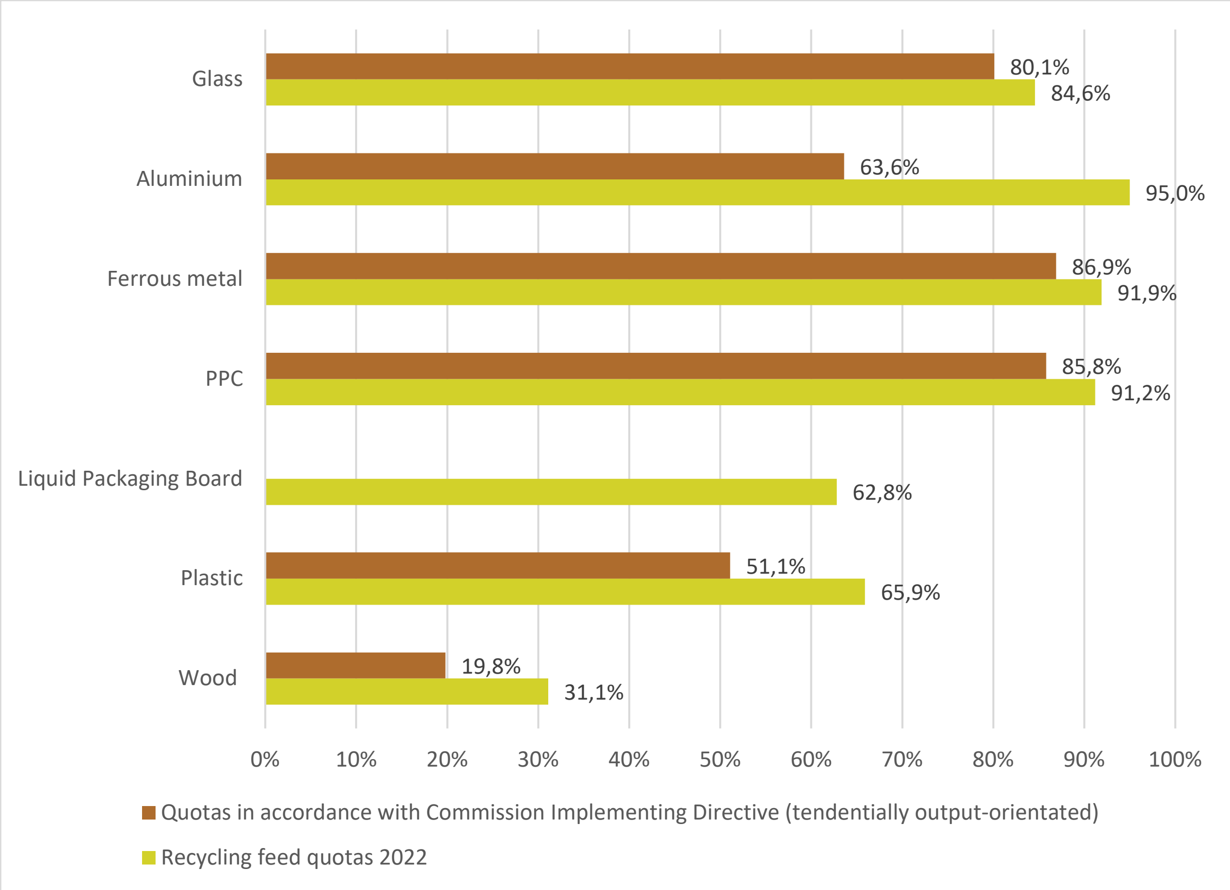
The recycling quotas in the status quo are based on the results of the GVM recycling assessment for reference year 2023 and the results from the German Environment Agency, which will be published in the coming months. The quotas documented there are recycling feed-in rates. The recycling feed-in rate refers to the share of a specific material flow that is actually fed into material recycling – i.e. is transferred to the recycling process, e.g. through sorting facilities or waste processing plants. It does not refer to the share that is actually recycled in the end, but only what is fed into the recycling process from the waste stream.

Recycling feed-in rates are therefore only able to reflect the actual quantities of material realistically available for reuse to a limited extent. It therefore makes sense to include recycling quotas in accordance with the EU Commission Implementing Decision[4] in the examination. The name of these quotas, which are often referred to as "output quotas", suggest a direct statement on the reusability of the recycled materials. However, this interpretation is misleading, as even the recycling quotas according to the Commission Implementing Decision do not allow any direct statement to be made on the quantities of material that are actually available as secondary raw materials on the market. Nevertheless, the quotas calculated in accordance with the EU Commission Implementing Decision tend to provide a more realistic assessment of the potential for material reuse compared to recycling feed-in rates. Another characteristic of this methodology is that the quotas are determined consistently on the basis of materials and not types, which increases comparability and the informative value with regard to individual material flows.

For Germany, recycling quotas in accordance with the Commission Implementing Decision are currently only available for 2022 and are lower across all materials than the recycling feed-in rates communicated to date. Figure 4 shows a comparison of the quotas for. 4 The difference between recycling feed-in rates is particularly high for the materials aluminium (31%) and plastic (15%).

[4] Commission Implementing Decision (EU) 2019/665 of 17 April 2019 amending Decision 2005/270/EC establishing the formats relating to the database system pursuant to European Parliament and Council Directive 94/62/EC on packaging and packaging waste.

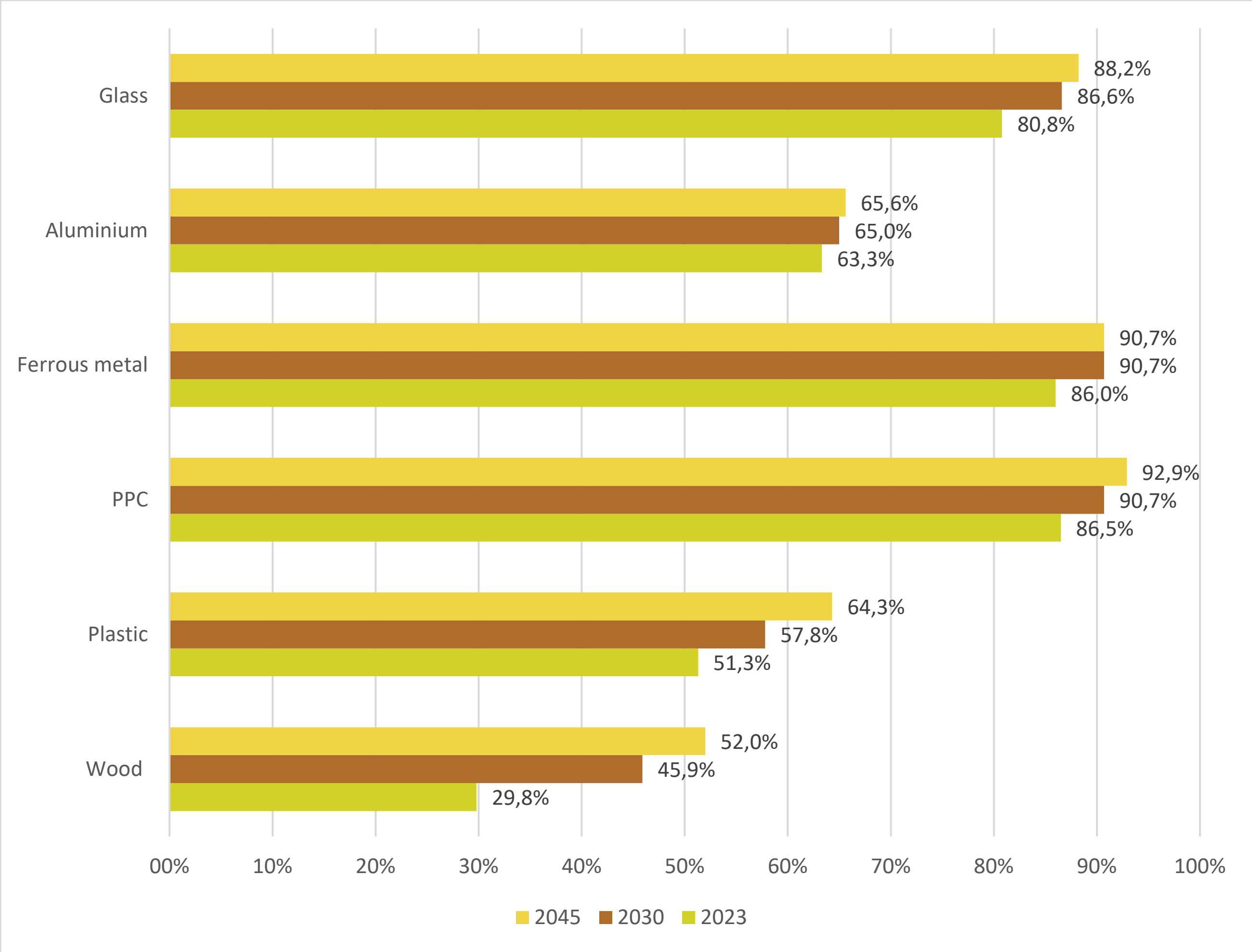
Figure 4: Comparison of the recycling quota for 2022



In its further work, the study uses output-orientated recycling quotas[5]. Figure 5 shows the output-oriented recycling quotas for base year 2023 as well as for projection years 2030 and 2045.

[5] In recycling quotas in accordance with the Commission Implementing Decision, there is only a tendency towards output orientation. This is due to the fact that the Commission Implementing Decision defines the calculation point for each material differently. As a result, the calculation point for aluminium, for example, represents the recycling output quite well (as the calculation point is located after the losses in pyrolysis), whereas the calculation point for paper is far removed from the recycling output (because the calculation point is located before the losses in the drum pulper).

Figure 5: Projected recycling quota (output-orientated)



** Glass, ferrous metal, and wood in general according to feed-in rate; aluminium, PPC, plastic with technological efficiency gains*

In the final analysis, the figure shows that, according to this projection, only PPC (93%) and ferrous metal (91%) will exceed the 90% mark in 2045. Plastics are projected to reach a quota of 64.3% is projected by 2045.

5.5 Building the material flow

The data on current and future packaging volumes derived in this chapter (Chapter 5.2) are linked to the information on the use of secondary materials (Chapter 5.3) and the respective recycling quotas (Chapter 5.4) to build packaging material flows for the years 2023, 2030, and 2045. The aim of the following analysis is to calculate the quantities of primary material required to cover the packaging demand and the quantity of material for secondary applications available outside the packaging material flows. In the course, it is assumed that no additional measures beyond the current ones will be taken to control and close material flows.

Depiction of material flow diagrams

The material flow diagrams for the years 2023, 2030, and 2045 are shown below (Figure 6 to Figure 8).

Figure 6: Result of the calculation of the packaging material flow for 2023

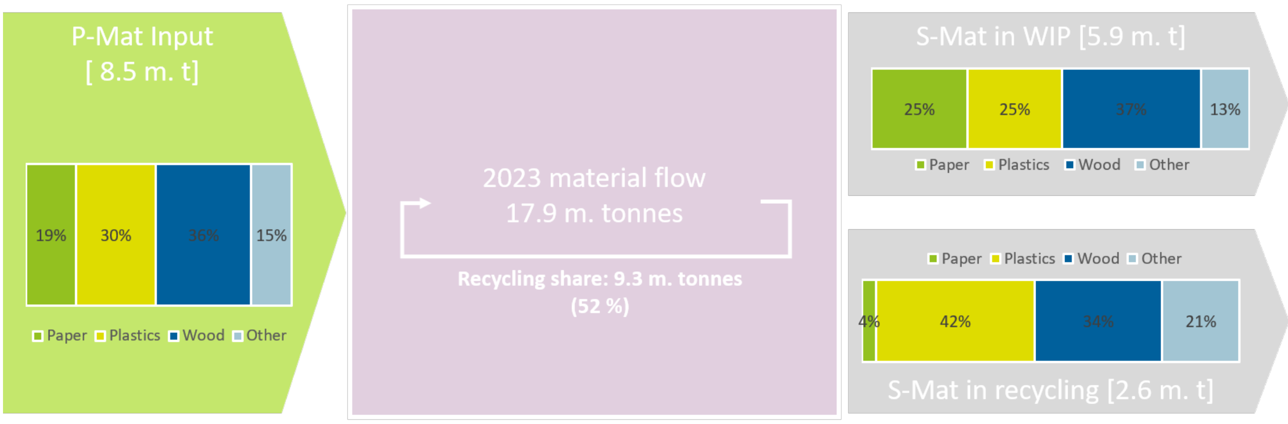


Figure 7: Result of the calculation of the packaging material flow for 2030

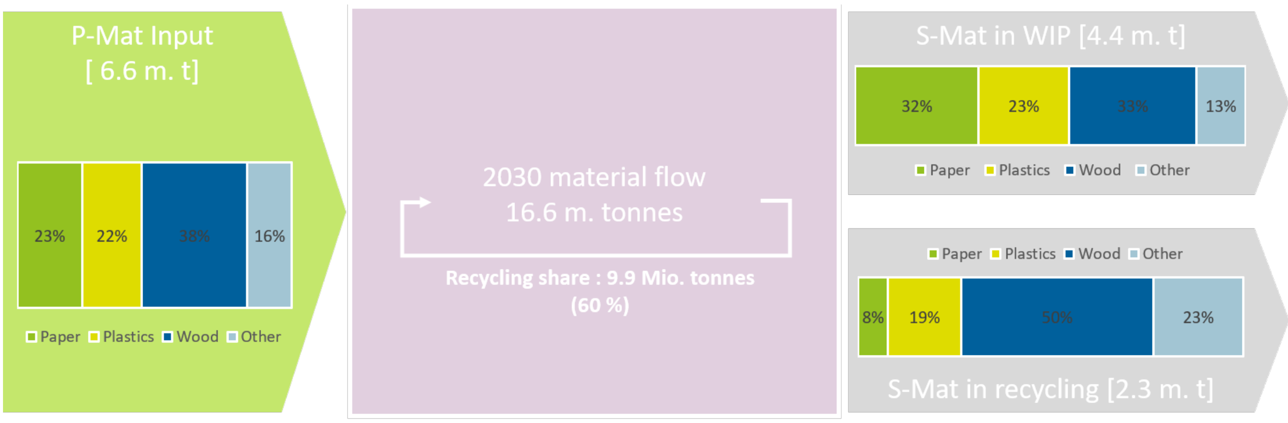
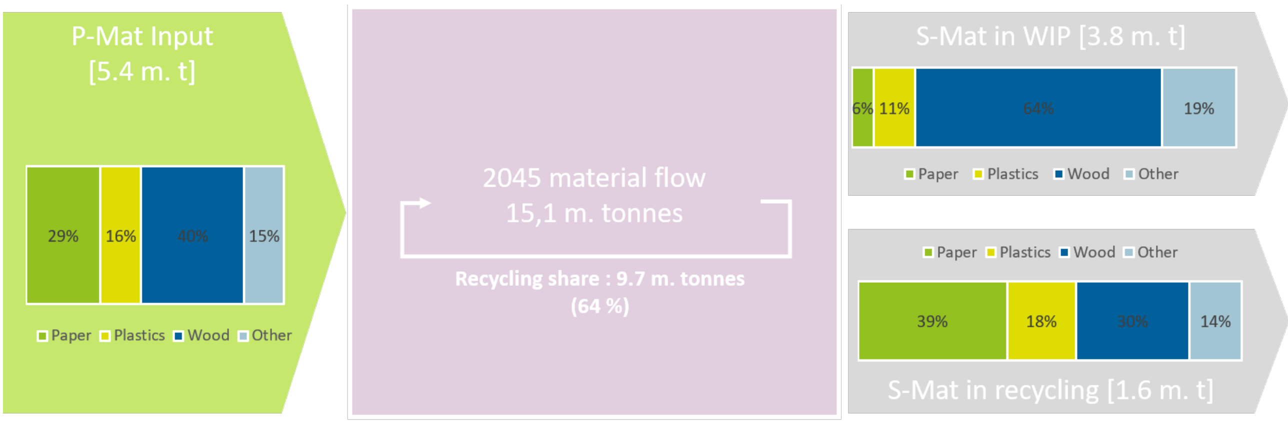


Figure 8: Result of the calculation of the packaging material flow for 2045



Note on Figures 6- 8: The numbers for plastics include fossil-based and bio-based plastics as well as, from 2045 on, PtX plastics.

Explanation of material flow diagrams

The central packaging cycle within the examined material flow system is depicted in the *purple* box in the centre of the graphic. It shows how much packaging material is used in total and how much is returned directly to the packaging cycle. In 2023, 17.9 million tonnes of packaging material were used, of which 9.3 million tonnes were recycled into new packaging (recycling share) – primarily glass, metal, and corrugated cardboard. The block arrow on the left-hand side of the figure shows the necessary amount of primary material (P Mat) that is fed into the packaging material streams: in 2023, this share amounted to 8.5 million tonnes. The band diagram within the arrow illustrates the distribution by material group: 19% packaging paper, 30% plastics, 34% wood, and 15% other materials.

On the right-hand side of the figure, the two grey block arrows show how much material leaves the packaging material stream and the recycling routes to which it is transferred. Here, "S Mat" stands for secondary material produced within the system. The upper arrow indicates thermal utilisation in waste incineration plants (WIP). In 2023, secondary materials in waste incineration plants amounted to a total of 5.9 million tonnes. The bottom arrow represents the recycling of materials outside the packaging cycle, in which processed secondary raw materials are used in other areas of application. In 2023, 2.6 million tonnes of secondary materials were fed into secondary material use outside of the packaging material stream in this way.

The band diagrams in the arrows illustrate the material-group-specific composition of the respective material flows; in the course, it becomes apparent that wooden packaging in particular accounts for a high share of the total volume. It is worth noting that a significant share of this material is predominantly utilised thermally. The potential for the use of this material therefore remains largely untapped – both for cascading use within the packaging sector and for secondary applications in other material cycles. Current practice means that valuable biogenic resources are utilised energetically and thus permanently removed from the material cycle. An increase in the recycling of wood packaging could therefore contribute significantly to conserving resources and reducing the need for primary materials.

Determination of primary material input to packaging material flows

Thus, Figures 6 to 8 thus result in the primary material input to the packaging material flows for 2023, 2030, and 2045 (Table 7). These quantities form the basis for the environmental impact assessment in Chapters 6.1 and 6.2.

Table 7: Calculated primary material input to packaging material flows

Material	2023 in kt	2030 in kt	2045 in kt
Wood	3062	2554	2152
PPC (incl. LPB and composites)	1607	1559	1557
Bioplastics	68	133	363
PtX plastics	–	–	489
Fossil plastics	2505	1315	–
Other materials	*1298*	*1081*	*829*
Total	**8540**	**6643**	**5389**
	Change compared to 2023	*-22%*	*-37%*

Comparative evaluation of the material flows for 2023 and 2045

A comparison of the packaging material flows in 2023 and 2045 shows clear structural changes:

- up until 2045, the input of primary materials to the packaging material flow will fall by 37% compared to 2023.
- The share of packaging that is recycled directly within the packaging material flow will increase from 52% in 2023 (9.3 million tonnes) to 64% in 2045 (9.7 million tonnes).
- The relative share of paper in the input of primary materials increases significantly – from 19% in 2023 to 42% in 2045. In absolute terms, however, the mass of primary paper used as packaging paper remains almost the same.
- The share of bio-based resources in the total input of primary materials will increase from 55% in 2023 to 76% in 2045, which corresponds to an increase of 21 percentage points. Despite this relative increase, the absolute quantity of bio-based primary materials falls by 666 kt in the same period.
- The share of primary material in bioplastics in all plastic packaging increases significantly in both relative and absolute terms, the relative share rising from 3% in 2023 to 43% in 2045. In absolute figures, the demand for primary bioplastics grows from 68 kt to 363 kt – an increase by a factor of 5.3.
- The amount of secondary materials that leave the packaging material stream for other applications falls from 2.6 million tonnes to 1.6 million tonnes in the projection period – a decrease of 38%. This development is largely due to declining packaging volumes and an increase in recycling within the packaging material flow.
- Despite all efforts to reduce the volume of packaging and close loops – including at regulatory level (PPWR) – 3.8 million tonnes of packaging waste are still expected to be sent for thermal utilisation in 2045. This includes 1.5 million tonnes of packaging paper alone and 1.1 million tonnes of waste wood from packaging.

To summarise, the projected reduction in packaging volumes up until 2045 means that both input and output flows within the material flow will decrease overall. At the same time, a relative increase in the share of recycled materials is to be expected, which indicates improved circularity within the system.

A reduction in packaging; in return, an increase in circular economy as well as in bio-based packaging

It should also be noted that the share of bio-based materials increases over the same period. As a result, environmental impacts that are primarily associated with the use of renewable raw materials, such as land use, biodiversity impacts or emissions from agricultural production, will become increasingly relevant.

A comprehensive evaluation must therefore clarify the extent to which the effects of an overall decline in the use of materials and the increasing use of bio-based resources reinforce, weaken, or compensate for, one another.

6 Evaluation of the material flow model for packaging up until 2045

Key facts:

Environmental evaluation of future scenarios:

- Decrease in the assessed (environmental) parameters of land, energy, and water by 2030
- Increase in land and water needs from 2030 to 2045 exceeding 2023 levels due to the large-scale use of bio-based plastics
- Energy significantly influenced by the phasing out of fossil-based plastics
- Optimisation possible if crop residues, waste wood, and waste paper are used consistently

This chapter brings together the contents of Chapters 4 and 5. This overall evaluation aims to analyse the extent to which the overall decline in the use of materials and the increasing employment of bio-based resources influence each other and what effects this will have on the future shape of the packaging system. The evaluation is based on a business-as-usual scenario (BAU), which anticipates that the same raw materials will continue to be used to meet the demand for bio-based packaging up until 2045. In addition, various optimisation scenarios are developed and analysed which take alternative paths of development and control into account.

6.1 Evaluation of BAU scenarios

As part of the evaluation of the BAU scenarios, the results of which are presented in the following three sections, this chapter determines the contribution to the three parameters *area*, *energy,* and *water* resulting from the employment of bio-based resources using life cycle assessment calculations.

Definition of the BAU scenario

The following assumptions are made in assessing the BAU scenarios:

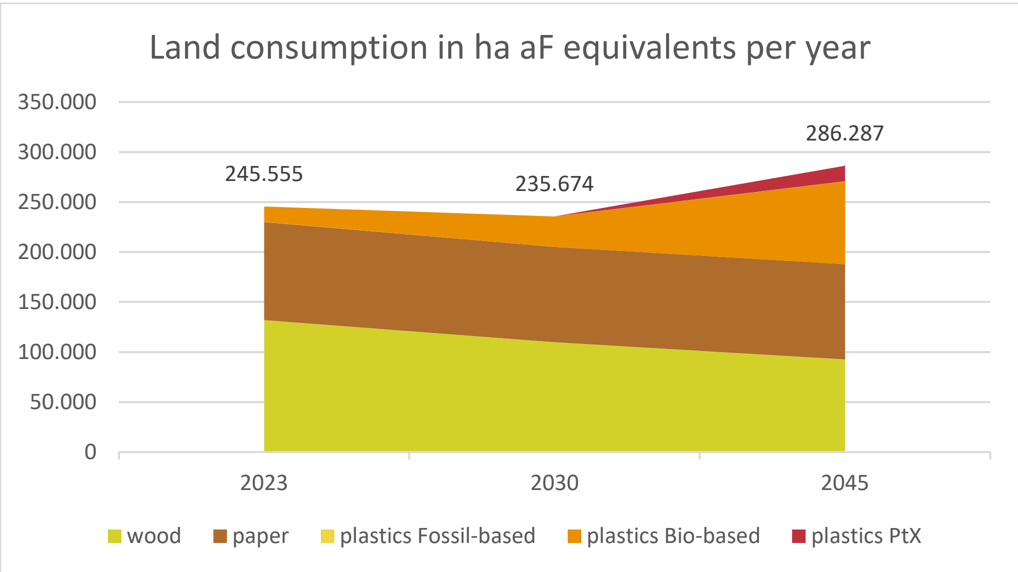
- Wood packaging is consistently assessed as packaging made from primary wood in each year (2023, 2030 and 2045).
- Paper packaging consistently uses pulp from forestry (i.e. primary wood) in each year (2023, 2030 and 2045).
- Bio-based plastics are consistently assessed as sugar cane-based plastics in each year (2023, 2030 and 2045).
- Non-bio-based plastics are assessed as fossil-based plastics in 2023 and 2030. In 2045, non-bio-based plastics are assessed as PtX plastics in order to account for endeavours to

achieve full defossilisation; the energy needs of these PtX plastics lie within the boundaries of the assessment.

- The additional material groups in the projection (glass, metals, other) are not included in the assessment as no bio-based alternatives are available and they thus lie beyond the scope of this study.

As part of the evaluation at hand, the primary material requirements determined in the material flow models (Chapter 5.5) are compared to the specific environmental values from Chapter 4.1. Each of the parameters of *area*, *energy,* and *water*is presented separately in the form of area diagrams, which show developments for the years 2023, 2030, and 2045 (Figure 9 to Figure 11). The segments of each of the bar charts show the calculated results for wood (*green*), paper (*brown*), fossil-based plastics (*yellow*), bio-based plastics (*orange*), and PtX plastics (*red*).

Figure 9: Evaluation of BAU scenario for the area parameter

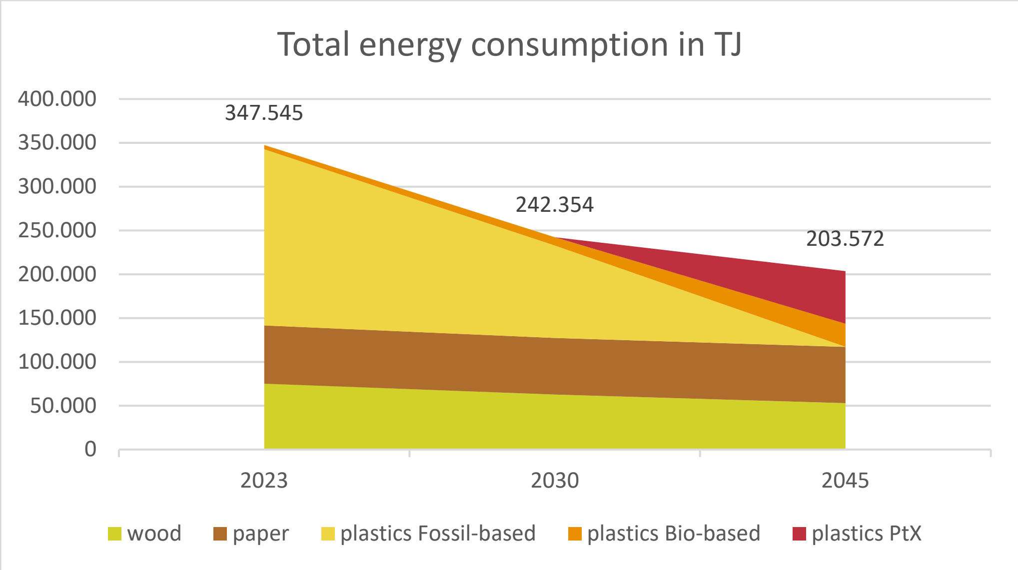


Description of the results for the area parameter

The development of land requirements in the BAU scenario shows that by 2030, the evaluated land needs will fall by around 4%. The reason for this is a decline in packaging consumption, in particular a reduction in wood packaging, the production of which is associated with a comparatively high need for land for cultivating renewable raw materials.

From 2030 onwards, on the other hand, there is a significant increase in the assessed land requirements that exceeds the initial 2023 level by 16.6% by 2045. The main driver of this increase is the large-scale use of bio-based plastics. At the same time, the share of PtX plastics also increases up until 2045; however, it remains lower than that of bio-based plastics. Despite their higher mass flow in 2045, PtX plastics require less land, as they are grounded on power-based synthetic pathways and thus have a lower need for land (immediate location of energy generation only and possible use restrictions in separating areas). Fossil-based plastics still make no significant contribution to land consumption due to their very small land footprint. Overall, developments show that, while the transition to bio-based resources contributes to the substitution of fossil resources; it is accompanied by an increased demand for land and may thus intensify competition for resources in the land use sector.

Figure 10: Evaluation of the BAU scenario for the energy parameter

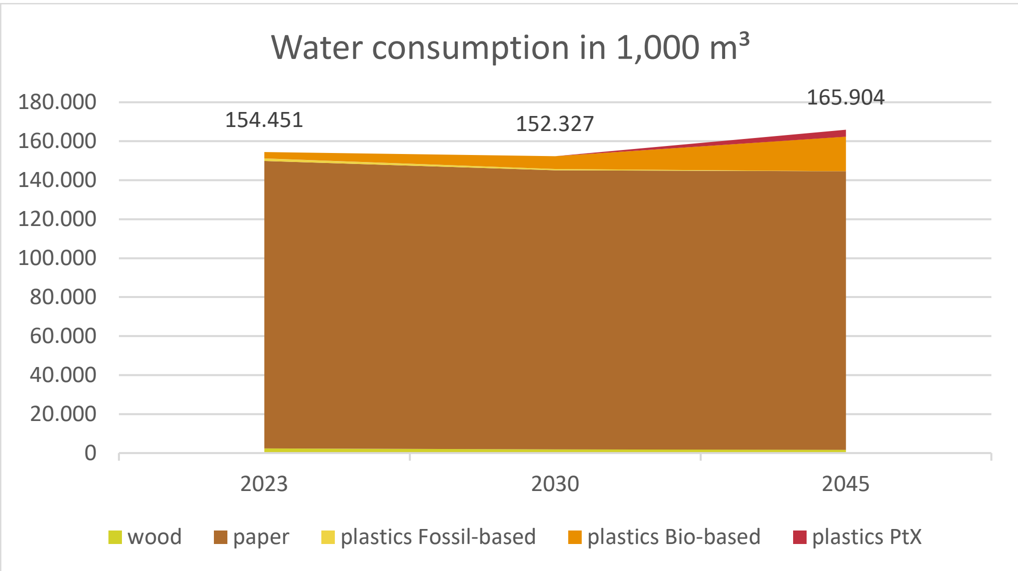


Description of the results of the energy parameter

The development of energy consumption in the BAU scenario is characterised by the steady and complete phasing out of fossil-based plastics by 2045. By 2030, the assessed energy contributions decline significantly by around 30%. From 2030 onwards, however, the pace of reduction slows, which is mainly due to the large-scale use of bio-based plastics, and PtX plastics in particular.

Overall, this development leads to an assessed reduction of 41% in total energy consumption by 2045 compared to 2023. The largest energy consumers within the packaging material flow in 2045 – in descending order – are PtX plastics, packaging paper, wood packaging, and, with the lowest share, bio-based plastics.

Figure 11: Evaluation of the BAU scenario for the parameter water



Description of the results parameter water

The development of water consumption in the BAU scenario is largely determined by the contributions of primary paper production. As the primary material input of fresh paper fibres decreases only marginally over the examined years, the results of the water assessment remain largely stable overall. By 2030, there is merely a slight decrease of around 1% in assessed water consumption. With the onset of the large-scale use of bio-based plastics, the assessed water consumption increases by around 7% by 2045. This development illustrates that use of the resource water in the packaging sector is mainly dominated by paper production, while the substitution of fossil-based plastics with bio-based plastics induces a moderate additional water demand.

Summary of the results

The documented results use the emission factors for the parameters *land*, *energy,* and *water* that were calculated within the framework of the quantitative evaluation. In summary:

- **By 2030** there is a *decrease* in all three parameters (*land*, *energy,* and *water*), which can be understood as a reduction of the environmental impact. This positive development is due in particular to the decline in packaging volumes. In particular, the low share of bioplastics and the switch from plastic to PPC packaging, projected to only a limited extent up until 2030, contribute to this result. With regard to the *energy* parameter, up until 2030 the decline is considerably influenced by the predicted phasing out of fossil-based plastics.
- **From 2030 on, the contributions to the assessed parameters of *land* and**

  ***water* increase until 2045** and even exceed 2023 levels.

  - – This development is due in particular to the **increasing share of bio-based plastics made from sugar cane**.
  - – While the share of bio-based plastics is at 3% in 2023 and increases to 9% by 2030, a share of 43% is projected for 2045. If this demand continues to be met on the basis of the same raw materials as in 2023 (i.e. bio-based plastics made from sugar cane), it would result in a **five-fold increase in land and energy needs** – compared to 2023.
  - – When it comes to the distribution of environmental impacts between bio-based and PtX plastics in 2045, a differentiated picture emerges: only 5% of contributions to the *land* parameter and 2% of contributions to the *water* parameter are attributable to PtX plastics, while their share of the *energy* parameter is significantly higher at 29%. This distribution illustrates that while the use of PtX plastics can reduce the pressure in the land debate, it shifts the problem to the issue of energy availability.

Need for optimisation

In fact, the effects on the parameters of *land* and *energy* largely cancel each other out: an increase in the use of bio-based resources either cancels out, or at least significantly weakens, the potential positive environmental effects resulting from a decline in packaging volumes and the phasing out of fossil-based plastics. A comprehensive analysis of the results at hand illustrates the need for a targeted **optimisation** of the use of biogenic resources, both in the area of plastics and packaging paper. The expected optimisation potential in the area of plastics is unlikely to be sufficient to keep pollution levels in the assessed parameters *land* and *water* below the levels calculated for 2023.

6.2 Analysis and evaluation of possible optimisations

To determine possible optimisation potential, this section supplements the results of the BAU scenarios developed in Chapter 6.1 above by scenarios around possible optimisations, in the course drawing on the qualitative and quantitative evaluations developed in Chapter 4.

Procedure for the selection of optimisation potential

In order to filter out those of the 13 resources analysed that exhibit potential for optimisation in both the qualitative and the quantitative evaluation, the latter are combined in Tables 8 and 9.

For the quantitative evaluation, the results of each resource documented in Chapter 4.1 (Table 3) have been prepared so as to present the values for packaging paper in relation to reference resource primary wood and the values for packaging plastics in relation to reference resource *sugar cane* . This approach enables a clear depiction of the expected environmental impact and reductions thereof compared to the BAU scenarios – i.e. compared to current utilisation patterns.

The following applies to the depiction of this quantitative evaluation:

- Values greater than +25% are classified as a significant impact and shown in *red* .
- Values between +25% and -25% show no significant difference and are shown in *grey*.
- Values under −25% are considered a significant reduction in impact and shown in *green*.
- Values under -50% are classified as an extremely significant reduction in impact and are shown in *green* and in bold.

The qualitative evaluation does not require any such categorisation. In order to obtain a comparable colour pattern for the qualitative evaluation, the categorisations from Chapter 4.2, Table 4 are used and condensed.

Table 8: Summary evaluation to identify optimisation potential for packaging papers

	Quantitative evaluation			Qualitative evaluation		
Packaging papers made from:	**Land**	**Energy**	**Water**	**Availability**	**Land use efficiency:**	**Competing uses**
Primary wood	o	o	o	A	C	C
Leaves	**-50%**	-15%	-17%	o	B	A
Grass	-43%	-18%	-19%	o	B	A
Cup plant	**-51%**	1%	-15%	o	B	A
Paludiculture	**-80%**	-2%	-17%	o	B	A
Bamboo	31%	27%	**-58%**	B	C	C
Bagasse	**-100%**	-35%	**-60%**	A	o	B
Sugar beets	-34%	-14%	**-61%**	B	A	C
Waste wood	**-100%**	-36%	9%	A	o	B
Crop residue	**-73%**	-12%	**-91%**	A	A	B

Table 8 shows the evaluation of packaging paper made from various sources of biogenic resources. Biogenic resources that exhibit as few limitations as possible in their qualitative and quantitative evaluations are suitable for optimisation. For packaging paper, these are

- Cup plant, paludiculture, and sugar beets as agricultural biomass;
- crop residues and bagasse as residue materials and by-products;
- waste wood as waste from the packaging material flow.

Note: Waste paper does not play a role as a resource in this analysis, as the study is only looking at substitute materials for the production of virgin fibres made from primary wood.

Table 9: Summary evaluation to identify optimisation potential for packaging plastics

	Quantitative evaluation			Qualitative evaluation		
Plastics made from:	Land	Energy	Water	Availability	Land use efficiency:	Competing uses
Sugar cane	o	o	o	A	C	C
Primary wood	-83%	12%	289%	A	C	C
Maize	-67%	-11%	76%	A	C	C
Sugar beets	-65%	-1%	-1%	B	A	C
Tall oil	-100%	-52%	-78%	o	o	A
Lignin	-66%	597%	524%	o	o	A
Waste wood	-100%	-17%	301%	A	o	B
Waste paper	-100%	-15%	244%	A	o	B
PtX	-86%	68%	-85%	o	o	o

Table 9 shows the evaluation of packaging paper made from various sources of biogenic resources. The following resources show optimisation potential for plastics compared to the BAU scenario:

- Maize and sugar beet as agricultural biomass
- Tall oil as a by-product
- Waste paper as waste from the packaging material flow
- PtX as a synthetic plastic

Four scenarios for evaluating possible optimisations

For a clearer overview, the scenarios are divided into four categories:

- **Agricultural Biomass** scenario: Cup plant and paludiculture are examined as resources for paper production; maize is examined as a resource for plastics production. In addition, a scenario has been calculated in which sugar beets are used exclusively in both product groups.
- **Waste and By-Products** scenario: This includes crop residues and bagasse for paper production as well as tall oil for plastics production.
- **Packaging Waste** scenario: This scenario takes waste wood for the production of packaging paper and PPC waste for the production of packaging plastics into account.
- **Synthetic Plastics** scenario: This scenario is in line with the BAU path 2045: packaging paper continues to be based on primary wood, while bio-based plastics are replaced by PtX-based plastics.

In addition to the BAU scenario for 2023 and 2045 and the four scenarios described above, a total of seven optimisation options are assessed. Table 10 summarises the basic assumptions made when modelling the optimisation scenarios.

Table 10: Overview of scenarios

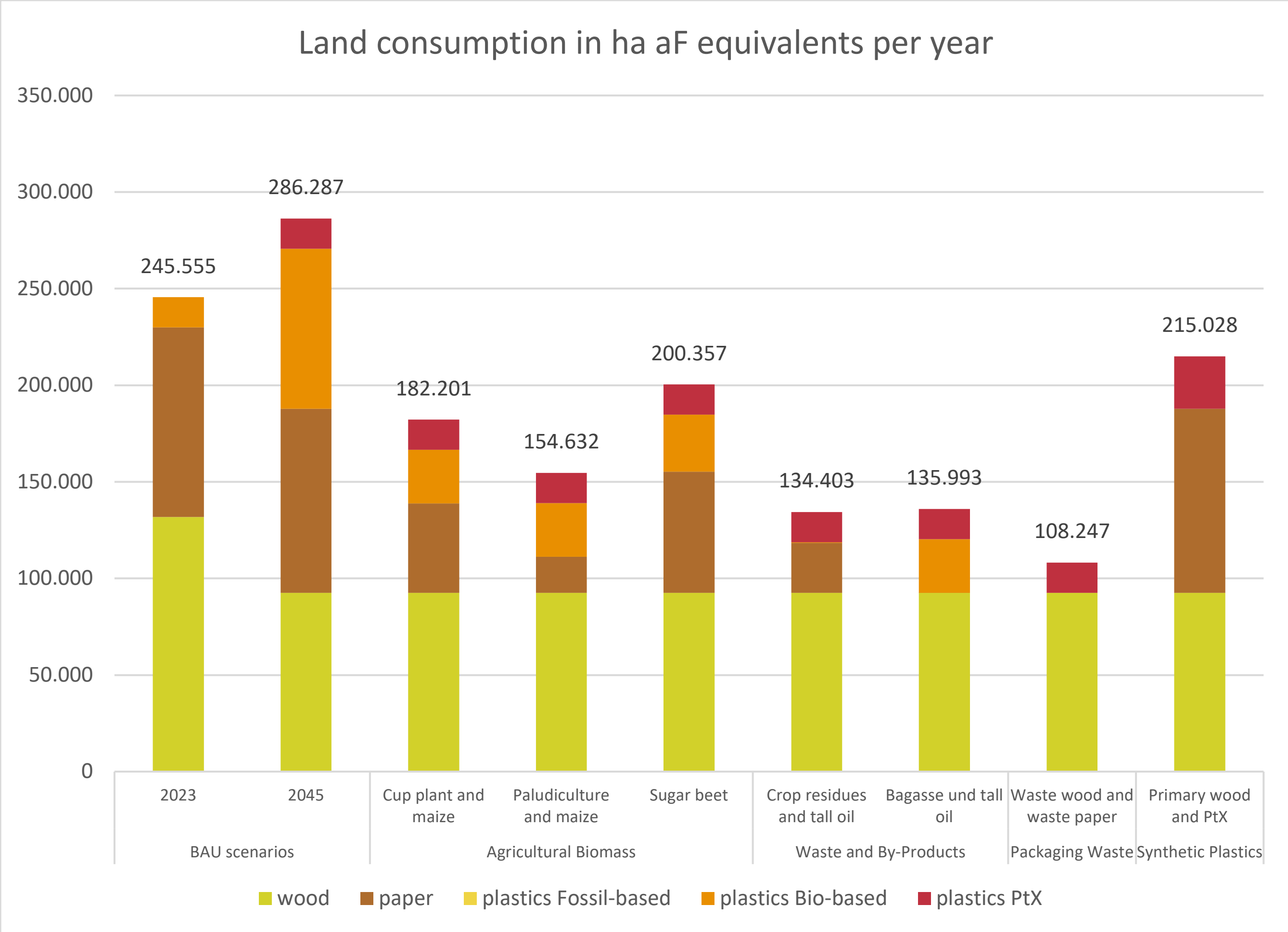
Scenario		Wood packaging	Paper packaging	Packaging made from bio-based plastics
BAU scenario	BAU 2023	made from wood	made from virgin fibres from forestry	based on sugar cane
	BAU 2045	made from wood	made from virgin fibres from forestry	based on sugar cane
Agricultural Biomass	Cup plant and maize	made from wood	made from virgin fibres from cup plant cultivation	based on maize
	Paludiculture and maize	made from wood	made from virgin fibres from paludiculture	based on maize
	Sugar beets	made from wood	made from virgin fibres from pressed beet shreds and beet leaves	based on sugar beet
Waste and By-Products	Crop residues and tall oil	made from wood	made from fibres from crop residues	based on tall oil
	Bagasse and tall oil	made from wood	made from fibres from bagasse	based on tall oil
Packaging Waste	Waste wood and waste paper	made from wood	made from fibres from waste wood	based on waste paper
Synthetic Plastics	Primary wood and PtX	made from wood	made from virgin fibres from forestry	bio-based plastics replaced by PtX plastics

The assessment is performed in accordance with the methodology described in Chapter 6.1: As part of the evaluation at hand, the primary material requirements determined in the material flow models (Chapter 5.5) are compared to the specific environmental values from Chapter 4.1. The results of these calculations are shown in Figures 12 to 14 below.

Firstly, the results of the BAU scenarios for the years 2023 and 2045 are presented. The optimisation scenarios then follow in the sequence shown in Table 10. The environmental parameters of land, energy, and water are shown separately in the form of stacked bar charts for the years 2023, 2030 and 2045. The segments of the bar charts show the contributions of the following materials: wood (green), paper (brown), fossil-based plastics (yellow), bio-based plastics (orange), and PtX plastics (red)[6].

[6] No contributions means that no impact was recognised (e.g. no contributions to the area parameter for paper packaging made from bagasse or waste wood, as no agricultural biomass is used – not even in parts).

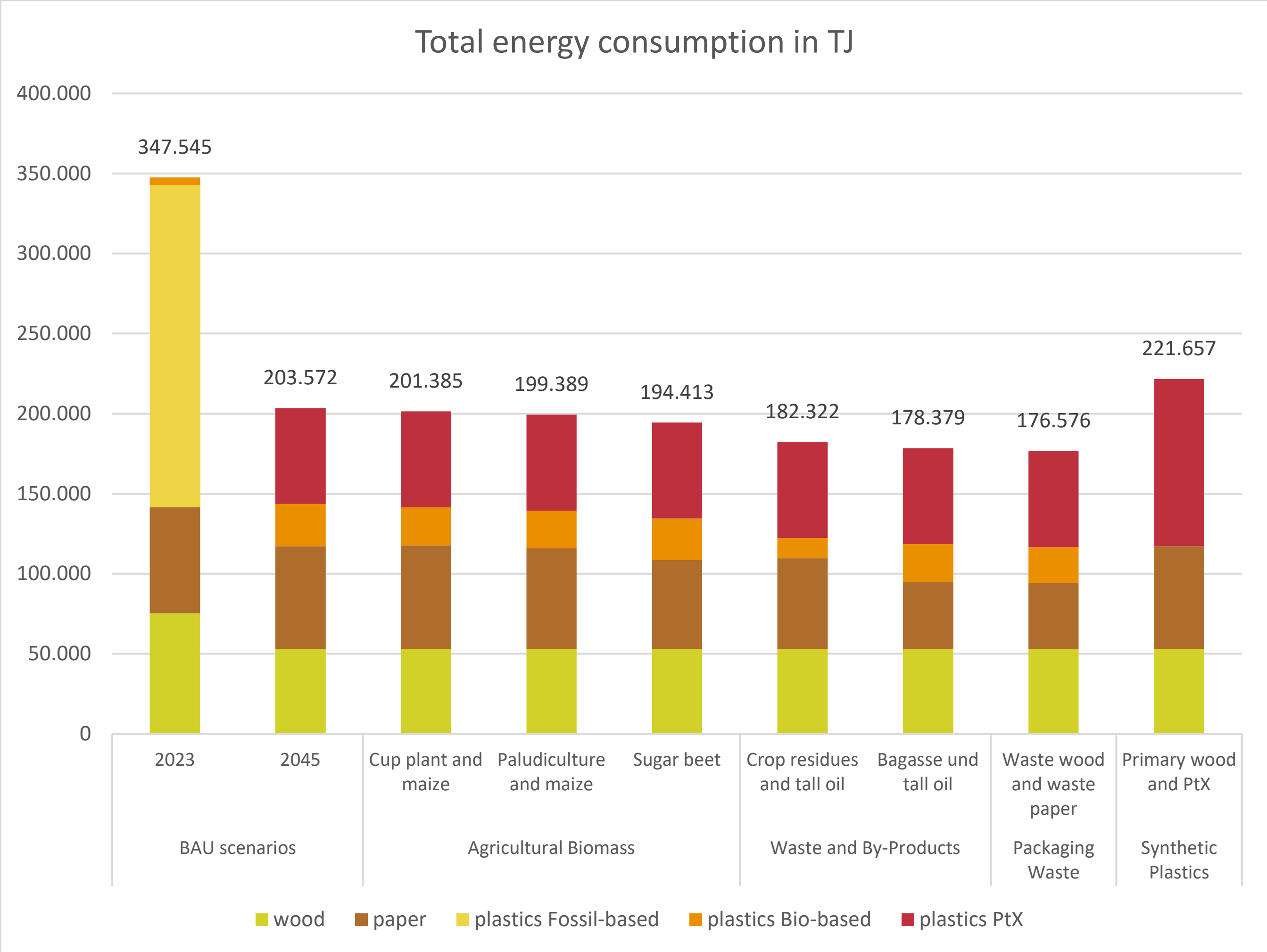
Figure 12: Evaluation of optimisation scenarios for the area parameter



The results of the evaluation of the optimisation scenarios for the area parameter show that

- All optimisation potentials show lower overall contributions than the BAU scenario for 2045 and are also suitable for bringing total land needs below the 2023 level.
- The scenarios in the focus groups *Waste and By-Products* and *Agricultural Biomass*s how the greatest savings.
  - - The scenario *Paper from waste wood and bio-based plastics from waste paper* shows the lowest contributions. The *Bagasse and tall oil* scenario achieves similarly large savings.
  - - The scenarios in the *Agricultural Biomass* focus group show significant improvements overall; however, these are primarily due to the lower contributions in paper packaging. The contributions of bio-based plastics, on the other hand, are higher than those of the plastics sector in the BAU scenario for 2023. This means that the use of bioplastics from agricultural biomass is related to higher land needs in 2045 than in 2023.
- The *Primary wood and PtX* scenario shows but minor improvements. However, PtX plastics have a better impact on land than agricultural biomass.

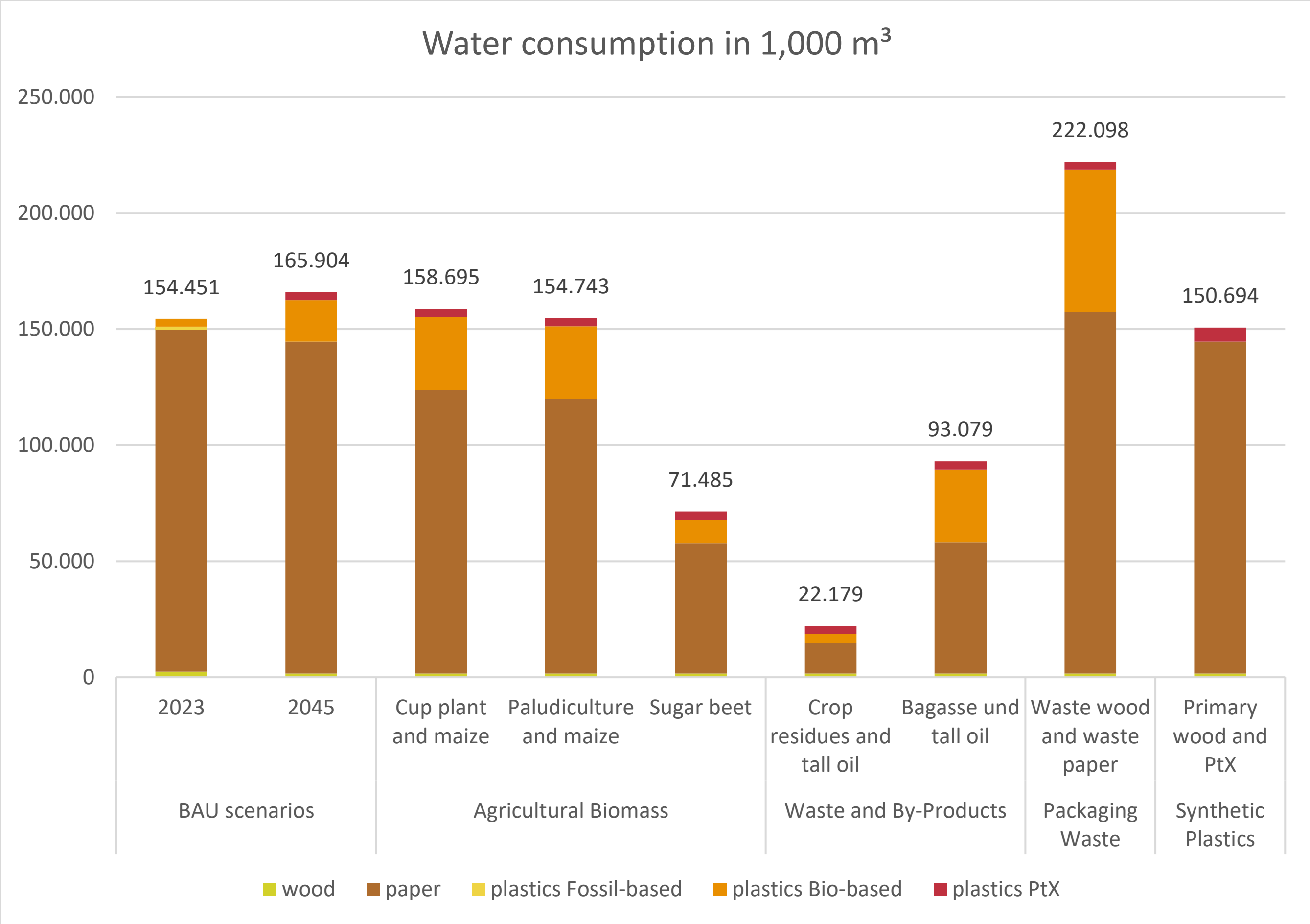
Figure 13: Evaluation of optimisation scenarios for the energy parameter



The results of the evaluation of the optimisation scenarios for the energy parameter show:

- compared to the BAU scenario for 2045, only the scenarios of the focus groups *Agricultural Biomass* and *Waste and By-Products* show a significant reduction in energy consumption, whereby the savings from *Agricultural Biomass* are only minor.
- The *Bagasse and tall oil* scenario exhibits the lowest energy consumption; this is due to the fact that bio-based plastics made from tall oil require less energy than the energy-intensive processing of waste paper into bio-based plastics.
- PtX plastics, on the other hand, cause the highest overall contributions compared to the examined scenarios for 2045 due to their extremely high energy needs during production.

Figure 14: Evaluation of optimisation scenarios for the water parameter



The results of the evaluation of the optimisation scenarios for the water parameter show the following:

- Within the *Agricultural Biomass* focus group, the scenarios with cup plant and paludiculture for paper production show only low reduction potential. The use of maize for the production of bio-based plastics leads to higher water consumption than in the BAU scenario with sugar cane. Sugar beets as a resource for paper and plastic packaging contributes the least to water consumption compared to other agricultural biomasses.
- The *Crop residues* and *Tall oil* scenarios exhibit the lowest water needs in the overall comparison. The *Bagasse* scenario is comparable to the *Sugar beets* scenario.
- By contrast, the scenarios in which *Waste wood* and *Waste paper* are used show significantly higher water consumption, which even exceeds the contributions in the BAU scenario, as the processing of these materials is associated with particularly water-intensive processes.
- *PtX* plastics exhibit the lowest water consumption of all the options examined.

Conclusions

In general, the results show high potential for savings in land for the selected optimisation options compared to the BAU scenarios for 2023 and 2045. However, many of the scenarios examined involve only minor improvements, and even a worsening, in the *energy* and/or *water* parameters (comparison of BAU 2045 with Optimisation 2045). A comparative overview of the results illustrates these conflicting objectives (Table 11)[7].

Table 11: Summary evaluation to identify optimisation potential for packaging plastics

	Focus group:	Agricultural Biomass			Waste and By-Products		Packaging Waste	Synthetic Plastics
	Scenario:	2045 Cup plant + maize	2045 Paludiculture + maize	2045 Sugar beets	2045 Crop residues + tall oil	2045 Bagasse + tall oil	2045 Waste wood + waste paper	2045 Primary wood + PtX
Comparison with BAU 2045	Land	-36%	-46%	-30%	-53%	-52%	-62%	-25%
	Energy	-1%	-2%	-4%	-10%	-12%	-13%	9%
	Water	-4%	-7%	-57%	-87%	-44%	34%	-9%
Comparison with BAU 2023	Land	-26%	-37%	-18%	-45%	-45%	-56%	-12%
	Energy	-42%	-43%	-44%	-48%	-49%	-49%	-36%
	Water	3%	0%	-54%	-86%	-40%	44%	-2%

The visible effects in the *energy* and *water* parameters primarily result from the use of the examined resources in the production of bio-based plastics (Figure 12 to Figure 14). In the production of the latter in particular, a reduction in land needs often goes hand in hand with an increase in energy needs.

Even though almost all of the biogenic resources analysed tend to have a positive effect on the environment compared to sugar cane-based plastics, the large-scale use of bio-based plastics in packaging cannot be recommended. The reason for this is the interplay between land and energy needs: the reduction of one environmental parameter is usually at the expense of another.

Analysis of focus groups *Waste and By-Products* and *Packaging Waste*

The analysis of the *Waste and By-Products* and *Packaging Waste* focus group scenarios shows that both groups exhibit the greatest optimisation potential across all parameters examined.

For the *water* parameter, it should be noted that the results are subject to uncertainties due to the underlying life cycle assessment datasets; these need to be taken into account in the interpretation. The water values, some of which were assessed as negative, represent neither an exclusion criterion for the *Packaging Waste* focus group nor a devaluation when compared to the Waste *and By-Products* focus group.

Availability of biogenic resources

Taking qualitative evaluation criteria into account, it becomes apparent that waste wood and waste paper as waste from packaging material flows perform better in terms of their availability than the scenarios with tall oil. This must be viewed critically, as tall oil is produced exclusively in primary paper production from forestry biomass. The availability of tall oil as a resource for packaging and other utilisation is therefore directly linked to paper production and its base of forestry raw materials. A well-founded assessment of the availability of tall oil is therefore not possible without taking into account the conflict of objectives be-

[7] The scale follows the system used in Table 8.

tween the ecological limits of forests and the existing and projected (high) demand for wood.

Comparison of bagasse and other crop residues

A comparison between bagasse and other crop residues such as wheat or maize straw does not provide a clear result. However, it should be noted that bagasse a resource that is traded globally, while wheat and maize straw are mostly produced and traded regionally. However, an in-depth assessment of these regional aspects is not part of this study.

Functional properties of alternative biogenic products

In conclusion, it is emphasised that the assessment of potential conducted here does not allow any statements to be made about the functional properties, such as durability and workability, of the products manufactured from the biogenic resources analysed. The extent to which these properties are comparable with those of conventional papers or bio-based plastics remains an open question.

The findings thus represent only one aspect of a comprehensive assessment of future biogenic potential.

7 Conclusions and recommendations

Key facts:

Intensifying the reduction of packaging volumes essential:

- The projected reduction is not sufficient to keep the environmental impact of the increasing use of biogenic resources at the current level.
- A greater reduction achieved by avoiding packaging, the consistent use of functional reusable solutions, and an even more intensive use of recycled materials is absolutely essential.

No eco-friendly use of biomass for bioplastics in fast-moving packaging products:

- Replacing fossil-based plastics with bio-based alternatives does not lead to a holistic improvement in the environmental parameters of land and water.
- Biomass can be used more efficiently in materials with a less laborious production process, such as paper and paperboard, than in plastics.

Prioritising closed plastic loops and the use of recyclates:

- It is crucial to close the material cycle in the area of plastic packaging, particularly through the increased use of recycled materials.
- This requires recycling-orientated packaging design, improved collection and sorting processes as well as investments in recycling technologies.
- Where closed-loop solutions are not possible, new materials (e.g. via PtX technologies) can be used.

Reduction in the use of primary wood for PPC packaging:

- The use of primary wood must be drastically reduced in order to prevent overexploitation of forest areas.
- Waste wood offers great potential as a substitute here.
- Cup plant, paludiculture and crop residues are also promising, albeit not standalone, alternatives.

The following chapter summarises the key findings of the study and once again highlights the fundamental dilemma of current and future wood utilisation. Based on the elements developed over the course of the study, this chapter then draws key conclusions and derives specific recommendations for action.

Over the further course, the central conclusions are systematically developed from the study results, on the basis of which this chapter then answers the research questions formulated at the beginning of the study in a targeted manner.

7.1 Summary of the results of the study

Core messages of the study

The following bullet points summarise the key findings of the study in a compact and concise manner, providing a concentrated overview of the key statements and findings.

- **Broad range of biogenic resources identified:** In addition to established raw materials such as wood and agricultural biomass, residual materials, by-products, and biogenic waste also exhibit relevant potential for bio-based packaging. Thirteen resources were selected and described (Chapter 3), all of which differ in terms of availability, competing uses, technical feasibility, and ecological assessment.
- **Declining packaging volumes with a simultaneous increase in the share of bio-based materials:** The model calculations project a decline in total packaging consumption of almost 16% by 2045 (Chapter 5.2). At the same time, a significant increase in the share of bio-based packaging is expected – particularly as a result of an increased use of paper/paperboard/cardboard (PPC) and bio-based plastics (Chapter 5.5).
- **Decline in the use of primary materials due to an increase in recycling:** The projected reduction in packaging volumes by 2045 results in an overall decrease in both the input and output flows within the material flow. As the share of recycled materials increases significantly at the same time, the demand for primary raw materials decreases disproportionately to the decline in packaging volumes. Despite this progress, however, a considerable residual flow remains: in 2045 around 3.8 million tonnes of packaging waste will still be fed into thermal utilisation – including about 1.5 million tonnes of packaging paper and around 1.1 million tonnes of waste wood from packaging (Chapter 5.5).
- **Increasing need for land despite lower packaging volumes:** Despite the projected reduction in packaging volumes and primary material inputs, the ecological footprint increases: land consumption – measured via DNP – shows a significant increase. The reason for this is the increased use of biogenic resources, particularly in the energy-intensive field of bio-based plastics, from 2030 on; the production and processing of these plastics are associated with high resource consumption (Chapters 6.1 and 6.2).
- **Dilution of positive effects from the phasing out of fossil-based plastics:** In 2023, fossil-based plastics accounted for 58% of the assessed energy consumption of the packaging examined. Despite being phased out completely, by 2045 it is merely possible to achieve a reduction in energy consumption of 41%. The reason for this is the increasing use of bio-based plastics and PtX plastics, the production of which is also energy-intensive (Chapter 4.1).
- **Conflicting objectives between land needs and energy consumption:** The analyses carried out as part of the study show a fundamental conflict of objectives between land needs and energy consumption: measures to reduce land consumption – for example through the use of residual biomass or waste products – generally lead to higher energy consumption (Chapter 6.2).
- **Targeted and efficient utilisation of resources as a key prerequisite:** The results illustrate that the use of biogenic resources is not ecologically advantageous per se. The availability of many materials is limited and competing uses – for example in food or ecosystem services – can intensify ecological conflicts of objectives. High resource efficiency, pronounced recyclability, and a location- and context-based assessment of raw materials and areas of use are therefore crucial (Chapter 4.2).
- **Avoidance, reuse, and recycling as a key strategy:** The material flow model developed in Chapter 5.5 quantifies the effects of various substitution and recycling paths and shows

that both avoidance and recycling at the product level (e.g. through reusable products) and at the material level (e.g. through the use of recyclates) are key levers for reducing raw material needs and minimise environmental impact.

On the dilemma of wood use

- **The dilemma of wood use:** Substituting fossil fuels with renewable raw materials makes sense from a defossilisation perspective. Renewable raw materials from the forestry industry have many advantages in terms of their general availability, land efficiency, and the energy required to utilise the raw materials. However, when it comes to wood in particular, there is an increasing conflict of objectives between the ecological limits of forests and the existing and projected demand for wood – for example for packaging paper, as an energy source, and as a raw material for the construction and furniture industries. **The use of wood as a raw material for bio-based plastic packaging will exacerbate this conflict of objectives and can therefore not be recommended on the basis of this study**. In view of climate-related stress factors such as drought, pest infestation, and an increasing frequency of forest fires, Europe's forests in particular, and especially the Scandinavian forest ecosystems, are reaching the limits of their regenerative capacity. In the meantime, many forest areas are reversing their function as CO_2 sinks and becoming a source of climate-relevant emissions. A brief analysis of the key scientific publications on the assessment of current wood utilisation carried out as part of this study also shows that the intensive industrial use of wood – for example in paper production – contributes significantly to overexploitation (Chapter 4.2). Against the background of multiple competing uses, the further expansion of wood utilisation is not sustainable from an ecological point of view. A fundamental reorganisation is therefore necessary: in future, timber extraction must be strictly geared to limits of the forests. A significant reduction in utilisation in the near future seems not only sensible, but unavoidable in order to maintain the climate protection function of forests in the long term.

7.2 Conclusions derived from the results of the study

This chapter summarises the main conclusions that can be drawn from the results of the study. They will serve as the basis for an evidence-based answer to the research questions.

Reducing packaging volume as the most important ecological lever

- **Reduction of packaging volume as a key factor**: It is crucial to further intensify efforts to **reduce the packaging volume.** While the projected future packaging consumption shows a significant reduction, this will not be sufficient to keep the environmental impact of the projected access to biogenic resources at the current level. The BAU scenario shows that the **increased use of biogenic resources – especially in the production of bio-based plastics – leads to an increase in environmental impact** in terms of land and water consumption. The positive effects on energy consumption (CED_{total}) resulting from the phasing out of fossil-based plastics are largely diluted by the energy-intensive use of bio-based plastics. In order to achieve ecological targets, a much greater reduction in packaging consumption than projected is therefore required. This requires that **resource flows are reduced and slowed down overall and material cycles are consistently closed**. The far-reaching avoidance of packaging as a top priority and the development and expansion of standardised and optimised reuse solutions are essential in this context.

Priority to closed material loops

- **Prioritising the material recycling of plastics:** The results of the packaging material flows show 676 kt of plastics from packaging in Germany for 2045 as well; these will still be fed into thermal utilisation.[8] This available potential should be realised in the short to medium term, instead of tapping into bio-based resources and processing these into primary

[8] With a simultaneous demand for new plastics totalling 852 kt in 2045.

materials at great energy expense.
At the same time, one thing is clear: even a largely closed plastics cycle in the packaging sector cannot completely replace the need for primary plastics. System-related losses and uncontainable material outflows to other utilisation areas need to be replenished with primary materials. The production of new materials – for example using PtX technologies – therefore remains a necessity. Although these processes are associated with a significantly higher energy input, they can reduce the pressure from the land use discussion and the biodiversity debate. However, the use of renewable energy sources for PtX production is essential for achieving national and international environmental targets.

- **No utilisation of biomass for bioplastics as packaging material:** The analysis clearly shows that there is **no fully environmentally sustainable way to use the biomass examined in this study** as a material for the production of plastic packaging as fast-moving products. The analyses carried out as part of the study show a fundamental conflict of objectives: **a reduction in land consumption usually goes hand in hand with increased energy needs – and vice versa.** In comparison, the use of paper- and cardboard-based packaging materials proves significantly more efficient, as the processing thereof is associated with comparatively lower energy consumption (Chapter 4.1).

No environmentally sustainable use of biomass for bioplastics as packaging material

- The **use of primary wood for PPC packaging must also be significantly reduced** in order to prevent the overexploitation of forest areas and the corresponding ecological consequences. The analysis shows that there are various alternatives to biomass from forests that have a better land and energy (and water) assessment.

Reduce the use of primary wood

- Particularly worthy of emphasis is the considerable **potential of waste wood**, which is already available today as a substitute for primary wood in the packaging sector. **Cup plant**and **paludicultures are also promising alternatives** for a more sustainable raw material base. With regard to the utilisation of **leaves and crop residues,** however, it should be noted that these resources do not allow the complete substitution of biomass from forests and are therefore not a stand-alone solution.

Instead: use waste wood, cup plant, and paludiculture

7.3 Answers to the research questions

In the following, the research questions formulated in Chapter 1 are to be answered as specifically and purposefully as possible on the basis of the content derived in the text of the study and summarised in the conclusions.

- **What ecologically meaningful role can bio-based resources play in the packaging sector in the future?**
  In the packaging sector, it is primarily possible to use the examined bio-based resources in an ecologically meaningful way in the field of paper-based packaging (PPC). In other packaging areas, the use of bio-based materials is usually associated with considerable ecological disadvantages and should therefore be viewed critically.

Bio-based resources ideally in PPC packaging

- **To what extent are sufficient (sustainable) bio-based resources available to cover the projected demand for bio-based packaging in Germany?**
  The current projected demand for bio-based plastics for packaging and PPC packaging cannot be met with bio-based resources available in the long term. A further reduction in the volume of packaging is therefore absolutely essential. An additional shift from plastic to paper-based packaging is **counterproductive**, as this counteracts the goal of reducing volumes. Waste wood is a promising source for the production of PPC packaging and offers great potential as a substitute primary wood. In addition, alternative resources such as cup plant, paludiculture, and crop residues can be used as substitutes for forest-

Total demand cannot be covered sustainably ...

... therefore prioritise avoidance, reuse, and recycling!

based PPC raw materials. According to the current status of knowledge, however, for technical reasons these bio-based resources cannot replace primary wood in all applications and can only substitute it in part. The aim must therefore be to reduce the share of fibres from primary wood as much as possible and to develop alternative, more environmentally friendly sources.

- **How are the environmental challenges of the various bio-based resources to be evaluated?**
  The analyses conducted for 2045 show that any optimisation with regard to the *land* parameter is in many cases accompanied by an increase in energy needs. A key aspect of the assessment is the energy required to convert resources into packaging materials, something that becomes particularly clear when looking at bio-based plastics. Simply put: the further the biomass used in the value chain shifts towards residual or waste material, the lower the allocated land effects – at the same time, however, the energy required for its development increases considerably. When utilising bio-based resources, it is therefore important to always keep an eye on the interplay between land and energy needs. The one-sided optimisation of one parameter may have a negative impact on the other.

Energy required to convert resources into packaging materials is the biggest challenge – especially for plastics

- **What alternative carbon sources are available today and will be available in the future and how do they compare to bio-based resources?**
  From an overall ecological perspective, plastics based on Power-to-X (PtX) represent a more favourable alternative to bio-based plastics for packaging, but are associated with high energy requirements and are therefore not recommended without restriction. As a matter of priority, measures to reduce packaging and close material cycles should be pursued. As with tall oil-based plastics, PtX materials should only be used where closed-loop solutions are not possible.

PtX and tall oil as a last resort...

7.4 Derivation of recommendations for policy makers

Based on the conclusions drawn in the study, this section derives recommendations that serve to **actively** incorporate the results of the study in **political discourse**. The following areas of action in particular require ambitious political impetus in order to push ahead with the environmentally sustainable restructuring of the packaging industry in manner that is both legally compliant and provides planning security:

- Biogenic resources should not be propagated as a primary solution strategy for defossilisation in the context of the packaging debate. **Counting the share of biogenic resources in plastic packaging towards applicable minimum recycling quotas, as deliberated by some actors, is not to be recommended from an environmental perspective.**
- The previous efforts to establish and further develop a functioning circular economy for (plastic) packaging must be consistently continued. The **prevention** of packaging should be given top priority in accordance with the waste hierarchy. **Unavoidable packaging must be designed so that resources are conserved and reduced to the minimum necessary for product protection.** To effectively prevent waste, standardised reusable packaging, components, and systems should be established, implemented across the board, and specifically promoted – where appropriate, even beyond the requirements of the EU Packaging and Packaging Waste Regulation. A consistent political framework can help to remove existing barriers and increase market acceptance of reuse solutions.

Focus on avoidance, reuse, and the circular economy

- In 2023, 5.9 million tonnes of packaging were thermally utilised; the projection shows that around 3.8 million tonnes of packaging will still be fed into thermal utilisation in 2045. In order to significantly reduce this number, manufacturers and distributors must be motivated to develop resource-conserving solutions along the entire value chain today. **Rapid implementation of Section 21 of the German Packaging Act is therefore crucial** in order to create effective financial incentives for recyclable packaging design and an increased use of recyclates. In addition, the legal framework must be improved, supplemented, and, above all, implemented so that the material flows from trade and commerce as well as from residual household waste can be tapped as new sources of high-quality recyclates.

Ecological shaping of participation fees in accordance with Section 21 of the German Packaging Act necessary

- It is recommended that the required research into the **use of recycled fibres in PPC packaging with food contact** – for example in the field of pizza boxes – be specifically pursued further. In parallel, the **regulatory framework** should be reviewed and, if necessary, adapted to ensure legal compliance when using the appropriate materials.

Identify and implement required research

7.5 Derivation of recommendations for companies

The conclusions of this study also offer practical point of orientation for strategic, corporate decision-making processes in the context of a sustainable packaging industry. Against this background, the following recommendations specifically address companies.

- It is recommended that companies wanting to improve their **plastic packaging** in the interest of reducing environmental impact avoid a blanket substitution of lightweight plastic packaging with heavier paper or paper composite solutions. Such approaches often lead to a shift in environmental effects without actually reducing the overall ecological impact. Instead, the following strategies should be pursued:
  - **– Short term:** Prioritise and systematically examine and promote the potential for **avoiding packaging** and introducing **multi-use solutions**. At the same time, focus on the further development of existing plastic packaging – in particular through **material savings** ("downgauging"), the increased **use of recyclates,** and the optimisation of **recyclability**.
  - **- Medium and long term:** It is necessary to ensure a **strategic alignment throughout the entire company** that aims to **reduce** and slow down **resource flows** as well as to **close material cycles** . In particular, this includes the consistent implementation of **Design for Circularity** across all types of packaging as well as close coordination and collaboration along the entire packaging value chain in order to close material loops efficiently and sustainably.

Instead of categorically rejecting plastic packaging, optimise it:
... through downgauging,
... through reuse,
... through closed cycles

- In the analysis at hand, tall oil was categorised as a comparatively positive resource for bio-based plastic packaging. However, packaging manufacturers should **note that its use is inevitably linked to the use of forest-based biomass**. The **use of tall oil should be strictly limited for ecological reasons**, as the use of forest biomass has already reached an ecologically critical level. From a sustainability perspective, it therefore begs the question whether it makes sense to use tall oil in short-lived products such as plastic packaging. The study shows that there are equivalent alternatives, such as plastics made from packaging waste or synthetic plastics, whose effects on the *land* and *energy* parameters are associated with lower ecological impacts. Such alternatives should be prioritised, particularly in the context of closed value chains.

Take a holistic view of tall oil-based plastics in particular

- Companies in the **packaging value chain** (raw material suppliers, packaging material producers and users, retailers and recycling partners) should work together to increase the availability of recycled materials, utilise existing sources more efficiently, and tap into new sources. The decisive factor here is to consistently close the material cycle — especially in the area of plastic packaging. Designing packaging so that it can be recycled is a key prerequisite for this, as is the increased use of recyclates in production. Besides optimising the use of existing sources of recyclate, **additional input streams** need to be tapped, for example from commercial and household residual waste. This requires innovative companies that make **targeted investments in design and in collection and sorting infrastructures** as well as primarily in mechanical recycling technologies. In order to provide larger quantities and higher qualities of recyclates – including for contact-sensitive applications – segregated recyclable material streams must be expanded. The prerequisite for this is consistently recycling-orientated packaging design and more aligned systems along the entire value chain – from material development to recycling.

Targeted investments in the development of new input flows

- Companies that want to further develop their **PPC packaging** in the interest of lower environmental impact should actively monitor the market **for alternative pulp sources** and identify **suitable wood substitutes according to their product-specific requirements** and take them into account when developing packaging. In particular, this report highlights **chemically untreated crop residues, cup plant** and **paludicultures** as promising alternatives with a comparatively low environmental impact. Research should also increasingly focus on **pulp production from waste wood,** as it offers the potential to a) increase the recycling rate of wood packaging and b) strengthen the material cycle within the packaging industry.

Convert PPC packaging to largely alternative resources such as waste wood, waste products, cup plant or paludiculture

The consistent implementation of these recommendations can contribute significantly to effectively reducing the environmental impact of packaging, increasing resource efficiency along the value chains, and establishing viable strategies for a sustainable and cycle-orientated packaging industry.

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