Duni Group

Product carbon footprint

A study of Bio Dunisoft and Bio Dunicel

Summary report

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Acronyms and abbreviations

CH	Switzerland
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
EoL	end of life
FU	functional unit
GHG	greenhouse gas
GWP	global warming potential
kg	kilogram
km	kilometre
m2	square metre
PE	plastic film
PP	poly pack
ROW	rest-of-world

Executive summary

The main goal of this study was to: 1) determine the cradle-to-grave carbon footprint of Dunisoft, Bio Dunisoft, Dunicel, and Bio Dunicel; 2) compare the carbon footprints of the materials throughout the life cycle phases. This was done using a life cycle assessment based on the ISO 14067 standard.

Dunisoft tissue material is used in the manufacturing of napkins and tablecloths by Duni Group. Dunicel material is used in napkins, tablecloths, and table covers. All materials use similar feedstocks of tissue paper produced in Sweden and transported to Germany. The different products produced from the materials have different production processes, are using different amounts of input materials, and have different energy consumption per product. Dunisoft Napkins and Dunicel Placemats were chosen as representative products for the assessment.

Each material was analysed according to a European disposal scenario. The disposal scenario aimed to investigate the effect of bio-based material on the regional waste management system. Emissions at the end-of-life were reduced by introducing the bio-based material into the recipes.

When assessing the downstream benefits of and burdens that accompany the waste management scenarios, Bio Dunisoft and Bio Dunicel had more net negative GHG emissions than their counterparts. Composting was also an option, which produced net negative emissions. Landfilling remained the least-preferable option and produced net emissions in each scenario.

The results of the cradle-to-grave assessment show that Bio Dunisoft Napkins produces 8.5% less GHG emissions than Dunisoft Napkins. The low difference is mainly due to the higher amount of bio-based binder needed for Bio Dunisoft compared to the amount of fossil-based binder used in current Dunisoft. The cradle-to-grave assessment of Bio Dunicel Placemats revealed that the material produces 30.3% less GHG emissions than Dunicel Placemats. For both products the results are highly dependent on the disposal scenario, as a large number of emissions were avoided during the disposal stages for the bio-based products due to lower emissions from incineration compared to products containing plastics and the use of composting and anaerobic digestion.

1 Introduction

Duni Group (Duni) produces various products for food packaging and sanitation packaging. These include, but are not limited to, napkins, table covers, placemats, and cutlery.

Traditionally, Duni has manufactured its line of Dunisoft and Dunicel materials with plastic-based binding agents. The new recipes for these two materials use bio-based components instead. The bio-based materials are seen as a more sustainable product than their former recipes. The packaging materials have also shifted to be completely paper-based instead of plastic-based.

To evaluate the sustainability pathways for new products, Duni has asked South Pole to assess and compare the carbon footprint of its current products those of its future bio-based products using the new recipes.

1.1 Goal of the study

The goal of this study is to account for the cradle-to-grave carbon footprint of Duni's current paper-based products Dunisoft and Dunicel with plastic-based binding, and compare this to the new products Bio Dunisoft and Bio Dunicel which use bio-based binding alternatives, including the products associated packaging. Products are evaluated for production in the year 2021.

The reason for conducting the study is to evaluate whether the new bio-based products are better from a climate-impact perspective than the old products that use plastic binding. The results will be used by Duni as the basis for taking an internal strategic decision on whether to switch the production to bio-based products.

The secondary aim of the study is to identify the carbon emission hotspots (global warming potential, or GWP) in the production of new materials, especially in the disposal phase. The disposal phase is key to understanding the best practice for end-of-life management for the products. The products' carbon emissions from disposal were assessed on the basis of common waste management methods in Europe.

As part of the secondary goal of the study, a scenario analysis was performed. The analysis used a total allocation of waste for each pathway to determine the best waste management method based on any benefits or burdens from disposal. The system expansion is not included in the overall cradle-to-gate results, but rather as an additional analysis.

This study is based on the ISO 14067 standard for the quantification of the carbon footprint of products. As a next step, the scope of the study could be extended to include the analysis of additional impact categories aligned with the ISO 14040 and ISO 14044 series standards.

1.2 Products under study

The Dunisoft and Dunicel materials are used for a range of different products with different material input and energy consumption in the final production phase depending on production method and layering. The materials are produced as large rolls, which are later sheared and layered into the appropriate size for various products.

This study evaluates the final products of Dunisoft Napkins and Bio Dunisoft Napkins as well as Dunicel Placemats and Bio Dunicel Placemats. The products are evaluated for their carbon footprint within the European market.

The first material, Dunisoft, is mainly used in tissues and napkins. The Dunisoft material is compared here with the newer, bio-based material called Bio Dunisoft. Dunisoft contains a binding agent derived from a copolymer EVA dispersion, which is used to produce the final material. Bio Dunisoft uses a new recipe, which is completely bio-based. The EVA binder is not used in Bio Dunisoft, but a bio-based binder from a company in Sweden is used for a similar effect.

The second material, Dunicel, has similar uses to Dunisoft but is also used for the production of tablecloths. Dunicel is here compared to the new bio-based material, Bio Dunicel. Dunicel also uses a copolymer EVA dispersion as binding agent to produce the material, whereas the recipe for Bio Dunicel uses bio-based ingredients in the tissue-binding process.

In addition to the material and its components, the packaging for the material was also evaluated. The packaging for Dunisoft Napkins and Dunicel Placemats comprises a matrix of plastic and paperboard layers. The packaging was also changed for the new Bio Dunisoft Napkins and Bio Dunicel Placemats to be completely bio-based. Bio Dunisoft Napkins and Bio Dunicel Placemats use a matrix of paperboard and kraft paper instead of plastics.

1.2.1 Functional unit

The functional unit (FU) chosen for the comparison of each material under study was 1 m^2 of finished Dunisoft Napkins, Bio Dunisoft Napkins, Dunicel Placemats, and Bio Dunicel Placemats. The packaging was also included within the system. The lifetime of the material is considered for one use since the material is only directed for single-use.

This FU was chosen since the material is used for several purposes (tablecloth and napkins). The defined FU includes the function (service) the product fulfils, the duration or service life and the expected quality level. There is also no difference in the thickness or other functional parameters (mechanical strength, absorption, etc.) of the different products.

It should also be noted that the products under study are higher at the higher end of the quality spectrum, which may explain the higher GWP values per FU compared to similar products.

1.2.2 System boundary

The system boundary for the assessment of the products under study covers the life cycle from cradle to grave (Figure 1). This includes the production of kraft pulp and other raw materials, the manufacturing process, the production of packaging materials, transportation between stages, and waste outputs.

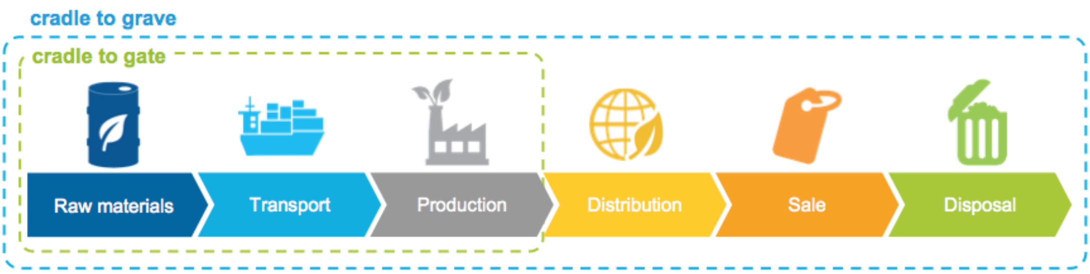

Figure 1: System boundary

The production and disposal scenarios were evaluated for the European market, uing data and statistics based on this region. A detailed description of the system boundary is shown in Table 1 below.

The use-phase for the product under study was not evaluated. The goals of the study are to determine the carbon emissions from the cradle-to-gate manufacturing process and the effects of waste management options. It was assumed that the use-phase for the material does not have a significant impact, if any, on the carbon emissions.

The distribution of the final product was estimated based on average transportation distances from freight in Europe, derived from Eurostat.

Table 1: System boundary detailed description

Stage	Description	Attributable processes
Raw materials	The stage starts when raw materials, which include kraft pulp and packaging materials, are acquired from each source, and ends when raw materials are ready for use.	• Acquisition • Pre-processing including the production of the two different binders

Stage	Description	Attributable processes
Transportation of raw materials	The stage starts when raw materials leave the raw materials/intermediate products' manufacturing facilities, and ends when the raw materials arrive at the processing facility in Sweden.	Road transportation from the source of the raw materials to the mill in Sweden
Processing	The stage starts when raw materials arrive at the processing facility and end when the final product is ready to leave the factory.	• Airlaid process • Pulp and binding • Converting • Packaging assembly • Production waste's transportation and treatment
Distribution	The stage starts when products leave the factory gate and ends when products arrive at the point of sale	Estimated based on European freight statistics
Use	The stage starts when the product arrives at consumers' homes and ends when the product has served its function	*No impact is considered for this phase*
Disposal	The stage starts when the product and packaging leaves consumers' homes and ends when the waste has been treated.	Packaging transportation and end-of-life treatment

The detailed system boundaries for the Dunisoft and Dunicel products are presented in Figure 2.

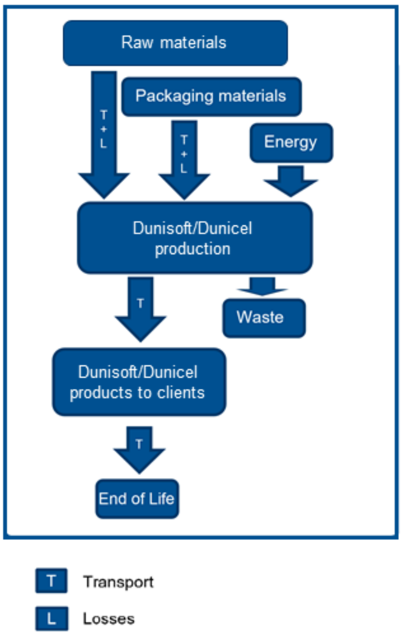

Figure 2: Detailed system boundaries

1.2.3 Impact categories and methodology

The impact category chosen for this assessment is climate change, expressed in kilograms of carbon dioxide equivalents (kgCO_2e), since the objective is to estimate a carbon footprint. The assessment is based on ISO 14067. The ISO 14067 standard generally is also aligned with PAS2050 the Greenhouse Gas (GHG) Protocol: A Product Life Cycle Accounting and Reporting

Standard. The GHG Protocol standard has been developed by the World Resources Institute and the World Business Council for Sustainable Development and is one of the most used international standards for understanding, quantifying and addressing GHG emissions.

The accounting was based on the principles of the 'GHG Protocol':

- **Relevance:** an appropriate inventory boundary that reflects the GHG emissions of the company and serves the decision-making needs of users.
- **Completeness:** accounting includes all emission sources within the chosen inventory boundary. Any specific exclusion is disclosed and specified.
- **Consistency:** meaningful comparison of information over time and transparently documented changes to the data.
- **Transparency:** data inventory sufficiency and clarity, where relevant issues are addressed in a coherent manner.
- **Accuracy:** minimised uncertainty and avoided systematic over- or under-quantification of GHG emissions.

The IPCC 2013 GWP impact methodology was used to characterise the environmental impacts into global warming potential (GWP).

1.2.3.1 Impact category: global warming potential

Within the scope of this assessment, the product's impact on climate change has been analysed. The chosen indicator is the GWP for a 100-year time horizon (IPCC, 2014). The GWP emissions are expressed in kilogram carbon dioxide equivalent ($kgCO_2e$).

Emissions from biogenic sources are not evaluated in this study due to the short lifetime of the product, the general complexity of accounting for biogenic carbon, and the lack of consensus on proper accounting methodologies. This aligns with the PAS 2050 recommendation to omit biogenic sources of carbon along the life cycle.

The GWP is a measure of the climate impact of a GHG compared to carbon dioxide over a time horizon. GHG emissions have different GWP values depending on their efficiency in absorbing longwave radiation, and on the atmospheric lifetime of the gas. The GWP values used in GHG accounting include the six GHGs covered by the United Nations Framework Convention on Climate Change and Kyoto Protocol and combinations of these, as presented in Table 3. These are the GWP based on the 'Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5)'.

Table 2: Applied GWP factors

GHG	GWP (100 years)
Carbon dioxide (CO_2)	1
Methane (CH_4)	28
Nitrous oxide (N_2O)	265
Hydrofluorocarbons (HFCs)	See IPCC AR6 p.73-79
Perfluorocarbons (PFCs)	See IPCC AR6 p.73-79
Sulphur hexafluoride (SF_6)	23,500

(Source: IPCC AR5, 2013)

1.2.4 Allocation of impacts

The impacts along the material life cycle are allocated based on the component mass. This is especially relevant for the transportation of ingredients and packaging to the manufacturing facilities. The end-of-life of the material used a cut-off approach. All impacts associated with disposal of the product are allocated to the product system.

Table 3: Allocation rules

Process	Allocation rule
Transportation of components	Mass allocation
Manufacturing	Mass allocation
Distribution	Mass allocation
End-of-life (disposal)	Cut-off
End-of-life (disposal) expanded scenarios	Consequential

1.2.5 Data requirements and quality

Duni Group has provided South Pole with primary data for the production processes of each material, including sub-level inputs and transportation distance for raw material and product distribution.

Generic data was used for calculating the carbon footprint of raw material inputs, such as kraft pulp. The background data for the upstream and downstream processes including raw material extraction, energy production, water preparation, wastewater treatment and end-of-life treatment are based on the Ecoinvent database V3.7 (Wernet et al., 2016). When no dataset was available for an input, a suitable proxy dataset was chosen based on the closest representative match. Proxy data was only used for processes that were determined to be of low contribution to the overall result.

Where assumptions have been made, this is explained in the report and the basis for the assumption is referenced.

Table 4: List of assumptions used in the assessments

Assumption area	Comment
Disposal	The end-of-life for the benchmark products is meant to reflect the management of fossil-based materials, such as the copolymer EVA dispersion binder. This scenario includes only the incineration, recycling and landfilling of the material, based on European statistics on municipal solid waste treatment. A cut-off approach was used.
Disposal – bio-based	The end-of-life for the bio-based products is meant to reflect the expanded options for the waste management of bio-based materials. This scenario includes the incineration, recycling, landfilling, composting and anaerobic digestion based on European statistics on municipal solid waste treatment. A cut-off approach was used.
Disposal scenarios	The end-of-life scenarios were built on the assumption that the final product and packaging are completely allocated to one waste management pathway. This implies that no sorting takes place, as the materials will either be 100% incinerated, landfilled, or anaerobically digested when available. The expanded system attributes any energy or by-product burdens or credits to within the system boundary.

Assumption area	Comment
Data quality – regional factors	A number of datasets do not belong to the European region, but either reside within Europe or were investigated for their likeness to European regional datasets. This is mainly seen for the expanded disposal scenarios, where datasets came from Rest-of-World (RoW) regional factors. Based on the dataset descriptions, they were assumed to be sufficiently appropriate to the scenario analysis to capture the downstream impacts from waste.

2 Inventory and results

2.1 Life cycle inventory analysis

The production data for the products were given to South Pole directly from Duni Group and its suppliers for production in 2021. The main supplier of tissue materials for Dunicel and Bio Dunicel was Rexcell in Sweden. This same supplier manufactures the airlaid materials for Dunisoft and Bio Dunisoft. Materials are shipped from Sweden to the converting facilities in Germany. The converting facility processes all four items covered by this assessment. Distribution begins at the gate of the facility and ends at the customer. The end-of-life is considered within the boundaries of Europe.

2.1.1 Raw materials

Ingredient information was provided by Duni Group for the recipes of each material under study. Where possible, supplier data were also given. The key ingredients and recipes are non-disclosable and therefore are not detailed in this public report.

All emissions factors were derived from the Ecoinvent database to ensure consistenccy in the model. The main ingredient in the paper-based products is wood pulp. The pulp is sourced from pulp mills in Sweden. The main product at this facility is softwood bleached pulp, which is then delivered as tissue rolls. The rolls are shipped to Bramsche, Germany where they are converted. All converting of final materials takes place in Bramsche.

2.1.2 Packaging materials

The packaging materials also use emissions factors from the Ecoinvent database. The components are listed in **Error! Reference source not found.** below. Packaging film is used to d eliver the pulp rolls mentioned in the section above. Dunisoft is packaged using a combination of polypropylene-based poly packs and corrugated board. Dunicel uses a polyethylene-based film with corrugated board for packaging.

The new materials, Bio Dunisoft and Bio Dunicel, use bio-based packaging instead of the plastic films. Bio Dunisoft and Bio Dunicel material is packaged using a combination of corrugated board and transparent paper.

2.1.3 Manufacturing and distribution

Production resource and waste information were provided to South Pole by Duni Group and their suppliers.

The manufacturing stages for the four materials under study occur in Sweden and Germany. Electricity values were assumed to be from a medium-voltage source rather than medium-voltage.

Production of pulp rolls and Rexcell Airlaid takes place in Sweden. This process produces small amounts of waste in the form of sheared tissue material, wastewater, and the plastic packaging film for the delivered pulp. Electricity, liquid propane gas, and boiler steam from pulp residue are all used in the production process in Sweden.

A Swedish company manufactures the binding agent used in the Bio Dunisoft material. The binder is shipped to the production facility in Sweden. The ingredients for the bio-based binder are received in large polyethylene bags and IBC-containers. The IBC-containers are typically reused in shipping.

Rexcell manufactures the Airlaid material to be used in the Dunisoft and Bio Dunisoft materials. The material is a combination of pulp, binder and water. Bio-based binder is used for the bio-based Airlaid material, while a copolymer EVA dispersion binder is used for the current Airlaid material. Small amounts of waste occur in this step, which is incinerated.

Rexcell manufactures the tissue to be used in Dunicel and Bio Dunicel material. The tissue is a combination of pulp and water. Small amounts of waste occur in this step, which is incinerated.

All rolls are distributed by truck for 1,021 km from Sweden to Germany where all the converting units are located.

Dunisoft and Bio Dunisoft are sheared into different final products in a converting process using electricity. Waste is generated from the shearing of the finished material and the packaging, which is then incinerated.

For Dunicel, the tissue is mixed with either bio-based binding and preservative agents, as is the case for Bio Dunicel, or it is mixed with polymer binding agents in the case of Dunicel. The polymer binding and the bio-binding take place at the same facility in a converting process using electricity and natural gas for heating. When it is ready, the material is then sheared into different final products in a converting process using electricity. Waste is generated from the shearing of the finished material and the packaging, which is then incinerated.

2.1.4 End-of-life

The final materials and associated packaging are disposed of by the consumer. The typical consumer is assumed to be a restaurant, caterer, household, or other dining establishment. The end-of-life treatment of the materials is modelled based on European waste management statistics from Eurostat.

The material disposal of Dunisoft and Dunicel could either be incineration or landfill, depending on the country. The material for Bio Dunisoft and Bio Dunicel could be incinerated, landfilled, or sent to anaerobic digestion. Dunisoft and Dunicel are not considered for anaerobic digestion because of the polymers used in production. Anaerobic digestion would be an advantage of switching to the new bio-based materials; it was part of the goal of this report to explore this. Recycling of the product materials was not considered on the basis of the average use of the product by the customer. Most of the used material will include food waste, which means that the product cannot be recycled. The model relied on the assumption that the recycling fraction of waste statistics was allocated instead towards incineration.

The packaging material for Dunisoft, Bio Dunisoft, Dunicel and Bio Dunicel could either be incinerated, recycled or landfilled.

Table 5: Waste management methods used in the disposal scenarios of each material

Disposal scenario	Waste management method	% Composition
Average disposal scenario for current products	Landfilled waste (sanitary)	24.3%
	Incineration	75.7%
Average disposal scenario for bio-based products	Landfilled waste (sanitary)	24.3%
	Composting	9.8%
	Anaerobic digestion	7.9%
	Incineration	58.0%
Average disposal scenario for paper packaging	Landfilled waste (sanitary)	26.0%
	Recycling	66.3%

	Incineration	7.7%
Average disposal scenario for plastic packaging	Landfilled waste (sanitary)	21.5%
	Recycling	41.4%
	Incineration	37.1%

(Source: Eurostat, 2019; European Environment Agency, 2020)

The waste management methods were an important part of the study goal. Duni Group would like to understand the best way to manage its waste with regard to GWP. Therefore, scenarios were built that modelled 100% of the material waste being allocated to incineration, landfilling or anaerobic digestion. This model was not used in the final results, but only developed to evaluate the GWP of each pathway. The final results use a combination of waste pathways based on the statistics used.

2.1.5 End-of-life with expanded system scenarios

Part of the study's secondary goal was to explore the GWP of each waste management pathway. A scenario was built for each product under study based on the waste pathways of landfilling, anaerobic digestion, and incineration. These scenarios use a system expansion, which includes any burdens or benefits that arise from processing the waste. In the case of incineration, this includes energy credits through electricity or heat production. Combined heat and power facilities commonly use this energy within Europe. Anaerobic digestion includes the biogasification of waste, which also receives energy credits. The landfilled waste includes some types of leachate gas recovery and burning but results in net emissions rather than avoided emissions as in the case of incineration and biogasification.

The European Production Environmental Footprint Category Rules recommends a Circular Footprint Formula to capture any downstream energy credits for disposal. This formula was explored but not used within the assessment because it does not capture the benefits of composting or biogasification, which was especially interesting for this study. Therefore, the Circular Footprint Formula was not chosen.

The datasets used for the waste scenarios were chosen based on their representation of the most similar waste management process. A number of datasets used a larger regional representation than Europe and were therefore further investigated. The resulting datasets used were considered to be appropriate based on the disposal method and energy credits used. Datasets that only covered Switzerland (CH) were considered not to be representative of the region because of the low carbon intensity of energy produced in the country.

2.2 Life cycle impact assessment

2.2.1 GHG emissions for Dunisoft Napkins and Bio Dunisoft Napkins

The cradle-to-grave GHG emissions for the production of Dunisoft Napkins and Bio Dunisoft Napkins in 2021 are listed below in Table 6. The total life cycle GHG emissions for 1 m^2 of Dunisoft Napkins is 101.6 gCO_2e and 93.0 gCO_2e for Bio Dunisoft Napkins.

Table 6: Life cycle impact assessment data for the production of 1 m^2 of Dunisoft and Bio Dunisoft material

Unit process	Dunisoft emissions (gCO_2e)	Bio Dunisoft emissions (gCO_2e)
Raw material input	**55.8**	**59.8**
Rexcell Airlaid	55.8	59.8
Raw material input		
Pulp	6.6	6.2
Water	0.0	0.0
Binder: - Dunisoft = copolymer EVA dispersion - BioDunisoft = bio-based	18.9	25.3
Packaging material input	0.2	0.2
Input material transport	3.3	1.3
Converting energy and process waste	26.8	26.8
Packaging material input	**1.7**	**1.3**
- Dunisoft = cardboard and plastic matrix - Bio Dunisoft = cardboard and paper matrix	1.7	1.3
Transport, supplier to factory, including materials	**9.3**	**9.1**
Converting	**1.5**	**0.8**
Electricity (grid, Germany)	0.7	0.7
Waste	0.8	<0.1
Distribution from factory to clients	**5.2**	**5.2**
Use	**Not applicable**	**Not applicable**
End-of-life	**28.1**	**16.8**
Disposal of product	27.3	16.4
Disposal of packaging	0.9	0.4
Total GHG emissions[1]	**101.6**	**93.0**

[1] Total emissions may not add up completely due to rounding used in the figures above. Waste scenarios with 100% allocation are not included in the total. All transport includes transport losses.

2.2.2 GHG emissions for Dunicel and Bio Dunicel

The cradle-to-grave GHG emissions for the production of Dunicel Placemats and Bio Dunicel Placemats in 2021 are listed below in Table 7. The total life-cycle GHG emissions for 1 m^2 of Dunicel Placemats is 298.3 gCO_2e and 207.8 gCO_2e for Bio Dunicel Placemats.

Table 7: Life cycle impact assessment data for 1 m^2 of Dunicel and Bio Dunicel

Unit process	Dunicel emissions (gCO_2e)	Bio Dunicel emissions (gCO_2e)
Raw material input	**110.6**	**102.8**
Rexcell tissue	26.6	26.6
Raw material input	8.7	8.7
Packaging material input	0.2	0.2
Input material transport	1.3	1.3
Converting energy and process waste	16.5	16.5
Dunicel binder	96.9	76.2
Raw material input	42.5	16.3
Input material transport	2.2	1.5
Converting energy and process waste	52.2	58.4
Packaging material input	**25.3**	**17.9**
Dunicel = cardboard/plastic matrix Bio Dunicel = cardboard/paper matrix	25.3	17.9
Input material transport	**12.1**	**11.7**
Converting	**17.9**	**13.6**
Electricity	15.8	13.4
Waste	2.2	0.2
Distribution	**13.4**	**14.2**
Use	**Not applicable**	**Not applicable**
End-of-life	**106.2**	**47.5**
Disposal of product	95.2	38.9
Disposal of packaging	10.9	8.6
Total GHG emissions[2]	**298.3**	**207.8**

[2] Total emissions may not add up completely due to rounding used in the figures above. Waste scenarios with 100% allocation are not included in the total. All transport includes transport losses.

3 Analysis

The results from the assessment of each bio-based material and respective benchmark material are presented in Figure 3 to Figure 8 in the sections below. Waste scenarios are evaluated below each comparison.

3.1 Comparison of Dunisoft and Bio Dunisoft

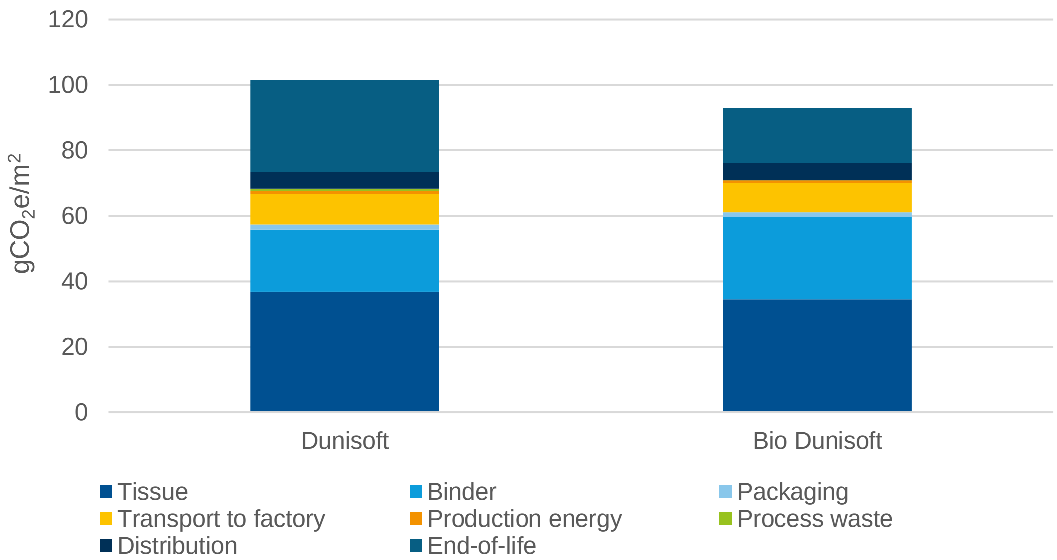

Figure 3: Life cycle GHG emissions comparison of Dunisoft and Bio Dunisoft

The Bio Dunisoft material performs better when comparing GHG emissions per m^2 of material. Over the life cycle, Bio Dunisoft Napkins produces 8.5% less GHG emissions, or 8.6 gCO_2e, compared to the benchmark Dunisoft Napkins. See details in Table 12 below.

Table 8: Comparison of Dunisoft and Bio Dunisoft

Unit process	Dunisoft emissions (gCO_2e)	Bio Dunisoft emissions (gCO_2e)	Difference (%)
Tissue	36.9	34.4	-6.7%
Binder	18.9	25.3	33.9%
Packaging	1.7	1.3	-22.2%
Transport to factory	9.3	9.1	-1.7%
Production energy	0.7	0.7	0.0%
Process waste	0.8	<0.1	-94.2%
Distribution	<5.2	5.2	1.4%
End-of-life	28.1	16.8	-40.3%
Total GHG emissions[3]	**101.6**	**93.0**	**-8.5%**

[3] Total emissions may not add up completely due to rounding used in the figures above. Waste scenarios with 100% allocation are not included in the total. All transport includes transport losses.

During the Airlaid production, a binding agent is introduced along with water and pulp. Dunisoft material uses a copolymer EVA dispersion agent whereas Bio Dunisoft uses a bio-based agent. The bio-based binder produces 38.2% less GHG emissions than the copolymer EVA dispersion binder compared on a weight-by-weight basis (kg/kg). However, approximately two times more bio-based binder is required in the Bio Dunisoft recipe, which leads to slightly higher emissions from binder in the bio-based product. This is compensated by lower transport distance for the bio-based binder and the use of renewable fuels for this transport, as well as the lower emissions from waste management for the bio-based product.

3.1.1 Waste scenarios with system expansion

The waste scenarios for Bio Dunisoft performed better than Dunisoft in terms of GWP. Bio Dunisoft produced less end-of-life emissions during incineration and showed more net negative emissions than Dunisoft.

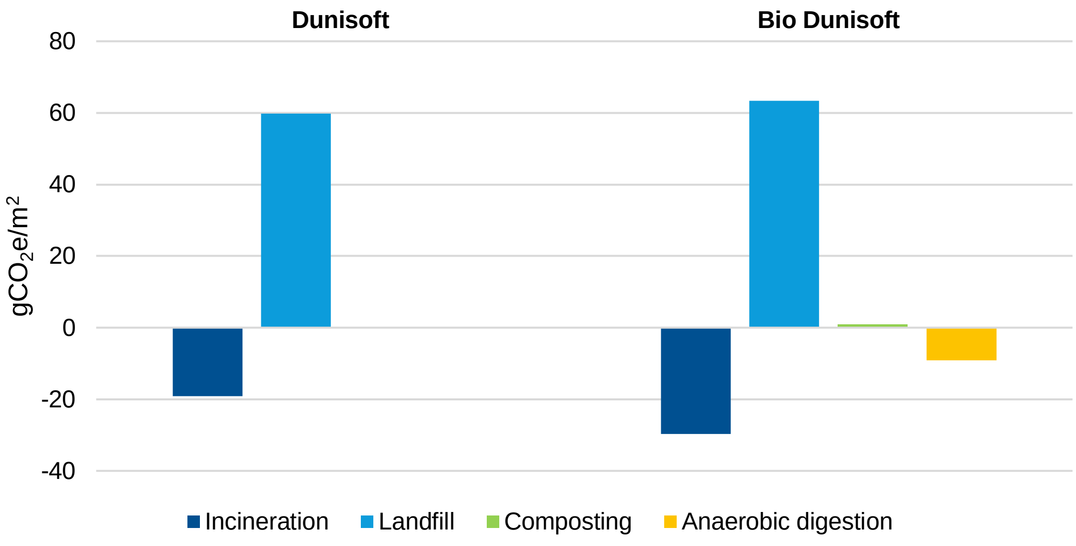

Figure 4: European waste scenario comparison between Dunicel and Bio Dunicel materials with system expansion for the end-of-life phase

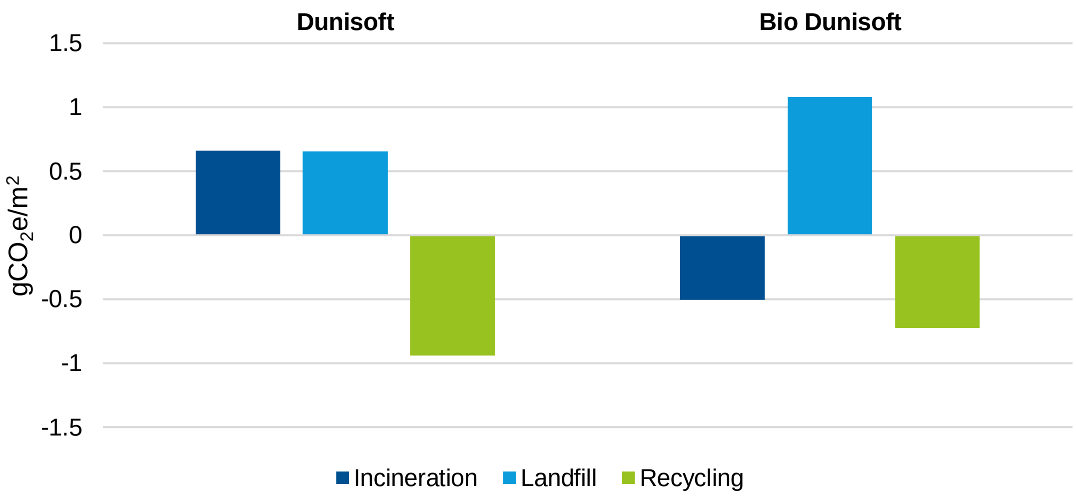

Figure 5: European waste scenario comparison between Dunicel and Bio Dunicel packaging with system expansion for the end-of-life phase

The net negative emissions from Dunisoft and Bio Dunisoft are seen in the energy credits from incineration and anaerobic digestion. Bio Dunisoft had more embodied bio-based materials, which released less fossil emissions while still providing energy. Dunisoft material contains small amounts of plastics, including in the packaging. Plastics have a high energy value for incineration, but also produce high GHG emissions. The higher emissions from the landfill scenario for Bio Dunisoft stem partly from the fact that the binder consists of more material and partly from the fact that the packaging is made from paper, which has a higher GWP compared to plastics when disposed of in landfill. Given that the study covers the 100-year time horizon, only a couple of percent of the plastic will have been broken down during the time period. Hence there are additional GWP emissions not covered in this study that will be released in the landfill scenario over the next centuries.

Table 9: Inventory results of waste scenarios for 1 m^2 of Dunisoft and Bio Dunisoft materials, including packaging

Waste management method	Dunisoft emissions (gCO_2e)	Bio Dunisoft emissions (gCO_2e)
Landfilled waste (sanitary)	**60.4**	**63.3**
Product	59.7	62.2
Packaging	0.7	1.1
Incineration	**-18.6**	**-29.7**
Product	-19.2	-29.2
Packaging	0.7	-0.5
Recycling	**-0.9**	**-0.7**
Product	N/A	N/A
Packaging	-0.9	-0.7
Composting	**N/A**	**0.9**
Product	N/A	0.9
Packaging	N/A	N/A
Anaerobic digestion	**N/A**	**-9.1**
Product	N/A	-9.1
Packaging	N/A	N/A

3.2 Comparison between Dunicel and Bio Dunicel

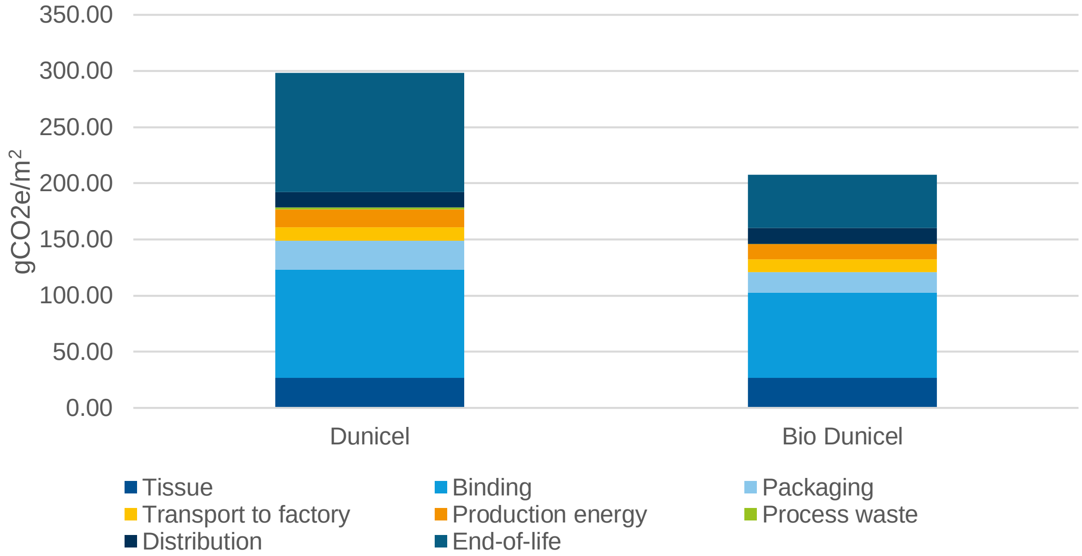

Figure 6: Lifecycle GHG emissions comparison of Dunicel and Bio Dunicel

The bio-based material, Bio Dunicel, performed better than Dunicel when comparing GWP emissions. Bio Dunicel released 30.3% less GWP emissions, or 90.5 g CO_2e, when evaluating the entire life cycle. See details in Table 14 below.

Table 10: Comparison of Dunicel and Bio Dunicel

Unit process	Dunicel emissions (gCO_2e)	Bio Dunicel emissions (gCO_2e)	Difference (%)
Tissue	26.6	26.6	-0.0%
Binder	96.9	76.2	-21.3%
Packaging	25.3	17.9	-29.0%
Transport to factory	12.1	11.7	-2.9%
Production energy	15.8	13.4	-15.1%
Process waste	2.2	0.2	-88.6%
Distribution	13.4	14.2	5.7%
End-of-life	106.2	47.5	-55.2%
Total GHG emissions[4]	**298.3**	**207.8**	**-30.3%**

3.2.1 Waste scenarios with system expansion

The waste scenario for Bio Dunicel performed better than Dunicel when there was proper waste management. Bio Dunicel showed a higher impact of net negative emissions through incineration and anaerobic digestion.

[4] Total emissions may not add up completely due to rounding used in the figures above. Waste scenarios with 100% allocation are not included in the total. All transport includes transport losses.

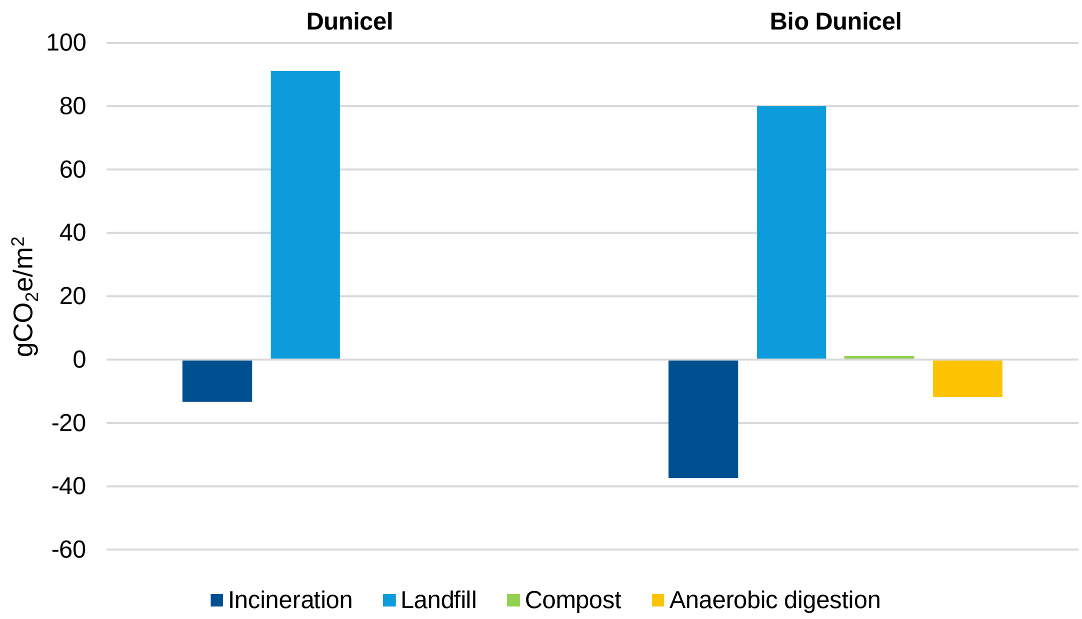

Figure 7: European waste scenario comparison between Dunicel and Bio Dunicel materials with system expansion

The credits given in the incineration scenario stem from the energy recovery from waste incineration. The recovered energy avoids the heat and electricity generation from fossil fuels. The type of avoided fuel is different depending on the market. In this study, a European average based on the Ecoinvent database was modelled.

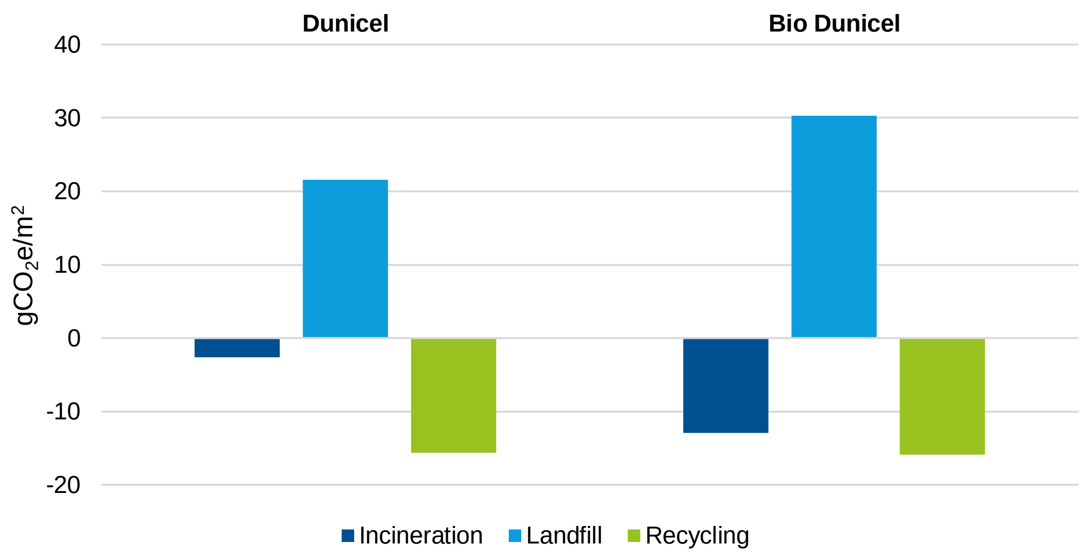

Figure 8: European waste scenario comparison between Dunicel and Bio Dunicel packaging system expansion

Bio Dunicel had a largest GWP when landfilled due to the higher fraction of bio-based materials used and because only a fraction of the plastic is broken down during 100 years. Similar to most biowaste, anaerobic digestion is the preferred option for waste disposal to capture gases released during the gasification of materials. At landfill, these gases are largely released back into the atmosphere. In this assessment, using a European energy mix, incineration has the best overall performance for Bio Dunicel.

Table 11: Inventory results of waste scenarios for 1 m^2 of Dunicel and Bio Dunicel materials and packaging

Waste management method	Dunicel emissions (gCO_2e)	Bio Dunicel emissions (gCO_2e)
Landfilled waste (sanitary)	**112.9**	**110.1**
Product	91.2	80.0
Packaging	21.6	30.0
Incineration	**-15.9**	**-50.3**
Product	-13.3	-37.5
Packaging	-2.6	-12.8
Recycling	**-15.6**	**-15.8**
Product	N/A	N/A
Packaging	-15.6	-15.8
Composting	**N/A**	**1.1**
Product	N/A	1.1
Packaging	N/A	N/A
Anaerobic digestion	**N/A**	**-11.7**
Product	N/A	-11.7
Packaging	N/A	N/A

3.3 Comparison of material packaging

The inventory results for each product associated with packaging are listed in Table 12. The packaging is based on the expectations for products that are manufactured from 1 m^2 of final material. Packaging is prepared in the same dimensions as the final product.

Table 12: Comparison of packaging life cycle GHG emissions for 1 m^2 of each material

Unit process	Dunisoft (gCO_2e)	Bio Dunisoft (gCO_2e)	Dunicel (gCO_2e)	Bio Dunicel (gCO_2e)
Corrugated board	0.18	0.21	17.08	27.06
Plastic film (PP)	2.79	-	-	-
Paper	-	1.62	-	1.16
Plastic film (PE)	-	-	22.08	-
Total GHG emissions	**2.97**	**1.83**	**39.16**	**28.22**

Table 13: Comparison of packaging life cycle GHG emissions per life cycle phase for 1 m² of material

Unit process	Dunisoft (gCO_2e)	Bio Dunisoft (gCO_2e)	Dunicel (gCO_2e)	Bio Dunicel (gCO_2e)
Packaging materials	1.82	1.29	26.42	17.92
Packaging transport and losses	0.18	0.03	0.65	0.31
Distribution	0.11	0.12	1.13	1.27
Packaging EoL	0.86	0.40	10.95	8.72
Total GHG emissions	**2.97**	**1.83**	**39.16**	**28.22**

4 Conclusions

The life cycle assessment has evaluated 1 m^2 of Bio Dunisoft and Bio Dunicel and determined that they both have a lower carbon footprint compared to their conventional alternatives, Dunisoft and Dunicel.

Bio Dunisoft Napkin produces 8.5% less carbon dioxide-equivalent emissions throughout the product's life cycle. The bio-based binder produced 38.2% less GHG emissions than the copolymer EVA dispersion binder on a weight by weight basis. However, more bio-based binder is needed for the final product than for the current product and the total emission from binder are thus slightly higher for Bio-Dunisoft. This is compensated by significantly lower transport and waste management emissions. The bio-based content of the Bio Dunisoft material allowed for a better end-of-life performance.

Bio Dunicel Placemat produces 30.3% less emissions than Dunicel Placemats from a life-cycle perspective. The bio-based binder produced 25.6% less GHG emissions than the current binder on a weight by weight basis. The GHG reductions from Bio Dunicel are highly dependent on the disposal scenario. GHG emissions from the end-of-life can vary based on the disposal method but were found to be considerably lower for Bio-Dunicel than for Dunicel.

The end-of-life disposal method had a large impact on the total life-cycle emissions for both materials. The high-level assumption of average European waste management methods and the large share of landfill used may affect this result in a negative way if the product is not actually sold on an average European market. It is recommended that the actual market shares be further analysed.

The system expansion for disposal analysis showed mixed results for the performance of each material. The incineration of materials showed the most negative, or avoided, GHG emissions in all products. Anaerobic digestion was also a promising option when available, as well as recycling the packaging materials. Landfill is the least-preferable option due to the bio-based content used in the final materials. These results are dependent on region and the carbon intensity of energy production. In many cases, biogasification is a better option because it can be used in transport infrastructure or heat production. Incineration can also be a good option if a region has a particularly high carbon intensity for energy production, if the produced heat and electricity can be used.

South Pole recommends that Duni Group perform further analysis on disposal scenarios for the global market in which it operates. The expanded scope could reveal how the bio-based materials interact with other systems, especially with less-developed waste management infrastructure. This is relevant given the current issues of persistent plastic and microplastic pollution into the environment.

It is understood that the modification of these recipes requires a significant upfront investment of capital to change current production. The true benefits of this investment could be realised when using a cost-benefit analysis combined with future waste and production scenarios. For example, biological composting systems could become more common and efficient in the future, which would mean significant returns on investment for Duni's shift to bio-based materials. The credits given in the compost scenario stem from carbon sequestration in soil and fertiliser replacement. This avoids emissions that would be released from the material and from fertiliser production. The avoided emissions are based on the Ecoinvent database.

In the case of this study, two existing products have been compared with equivalent products with an improved environmental performance. It is important to observe the limitations in the existing products in relation to the innovative solutions that perform better. An analysis of the development trends in the industry and competitor analyses could be an advantage in such a decision-making process.

As mentioned above, the benefits of the bio-based materials could go further than GWP emissions reductions. A full analysis is recommended to account for other environmental load and social factors, particularly in the production process. An expanded assessment of Bio Dunisoft and Bio Dunicel could address other positive or negative aspects in the modified recipe.

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