Environmental footprint

Underlay 5156 VB and Underlay Nature 8210

Amorim Cork Composites

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Building a better working world

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EY LCA analysis is based on ISO Standard 14040 and on Corticeira Amorim data and business assumptions. The results presented are preliminary and not third-party verified.

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Executive Summary

Corticeira Amorim is the largest world producer of cork products, championing the sector since 1870. The company has a portfolio of products with applications in multiple industries, such as wine, construction, flooring, aeronautical, automobile, footwear, among others. It has implemented an integrated production process that ensures that no cork is wasted. Amorim Cork Composites (ACC), a subsidiary of Corticeira Amorim is focused in producing innovative solutions with combinations of cork and other materials, by recycling, reusing and reinventing natural and organic materials. The composite cork industry requires high levels of physical and chemical performance, providing adequate solutions to the needs of several industries such as the automotive, aerospace and aeronautical industries, the construction sector, as well as the shoe and interior design industries.

The main purpose of this study is to quantify the potential environmental impacts related to the production of Underlays 5156 VB and Nature 8210. These underlays provide confort, protection and longevity to floors, further contributing to energy efficiency and acoustic insulation. Furthermore, these underlayments are made from recycled and natural materials, by Amorim Cork Composites. The assessment is focused on a functional unit of 1 m^2 of Underlay 5156 VB, an underlayment for flooring composed by cork, recycled ethylene-vinyl acetate (EVA), polyurethane binders and a polyethylene film layer, and 1 m^2 of Underlay Nature 8210, composed by cork, recycled cork and polyurethane binders. The life cycle stages under a cradle-to-gate approach, included in the inventory boundary of Underlay 5156 VB are: forest management activities, cork granulate production, grinding white EVA, grinding colored EVA, agglomeration, transformation and packaging, as well as transport of raw materials from suppliers, while the inventory boundaries for Underlay Nature 8210 include: forest management activities, cork granulate production, grinding cork, agglomeration, transformation and packaging, as well as transport of raw materials from suppliers.

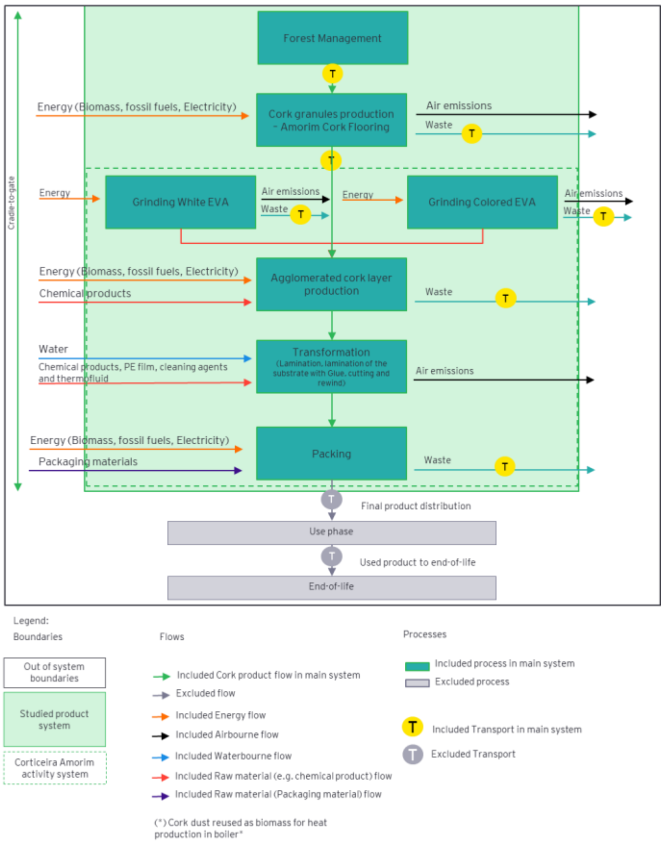

Figure A - System boundaries for the Underlay 5156 VB's studied system, relevant flows and processes

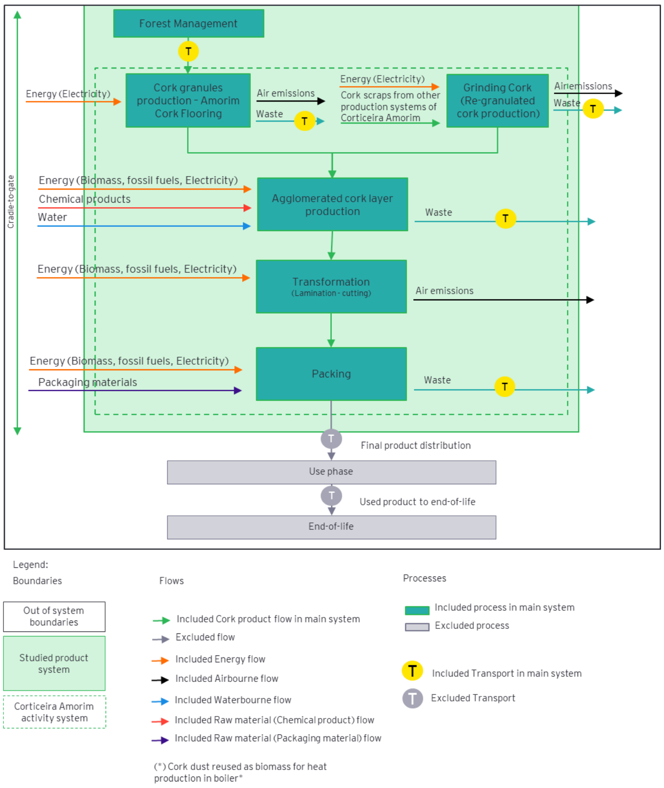

Figure B - System boundaries for the Underlay Nature 8210's studied system, relevant flows and processes

Methods

This report analyses the environmental footprint regarding the production of Underlays 5156 VB and Nature 8210, through a life cycle analysis (LCA) approach. The study was based on the ISO 14040/44 standards (ISO, 2006), complemented with the guidelines from International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance (EC-JRC, 2010).

To assess the environmental footprint on a full year of operation basis (2020), energy, material user, air emissions, waste and water treatment data was collected for each stage. Potential environmental impacts were allocated to Underlays 5156 VB and Nature 8210 and their by-products using mass allocation (i.e. allocation based on the proportional mass of each of the products), when no further subdivision of unit processes was deemed feasible.

Impacts related to Underlays 5156 VB and Nature 8210 production were assessed and the following impact categories were selected: Climate Change (CC), Ozone Depletion (OD), Human Toxicity: Cancer Effects (HTC), Human Toxicity: Non-Cancer Effects (HTCN), Photochemical Ozone Formation (POF), Acidification (A), Terrestrial Eutrophication (TEu), Freshwater Eutrophication (FEu), Marine Eutrophication (ME), Freshwater Ecotoxicity (FEc), Mineral and Fossil Resource Depletion (MFRD), Water Use (WU) and Total Cumulative Energy Demand (CEDt).

Main results

The life cycle assessment of Underlay 5156 VB is shown in Table A and Figure C per stage. As observed, forest management and cork granulate production have a very low impact in the overall impacts considered. In contrast, Underlay 5156 VB agglomeration and grinding colored EVA stages show the highest level of potential impacts in the studied system. These stages include the main transformation and transport activities. The use of polyurethane binders and a polyethylene film layer in the agglomeration and transformation and packaging processes are the main contributor for the observed potential impacts. The impacts stemming from the transport of raw materials, namely the transport of colored EVA, are also especially relevant in the grinding white EVA and grinding colored EVA stages.

Table A – Overall results of the analysis and absolute values per stage of Underlay 5156 VB

Impact category	Unit*	Stored carbon (cork)	Stored carbon (packaging)	Forest management	Grinding White EVA MD	Grinding Colored EVA MD	Cork granulate production (ACF)	Agglomeration	Transformation and Packaging	Total Cradle-to-gate
CC	kg CO_2 eq	-1,66E-01	-7,10E-02	1,33E-03	6,82E-02	1,82E-01	9,54E-03	3,96E-01	2,23E-01	6,44E-01
OD	kg CFC-11 eq			2,59E-10	1,01E-08	3,06E-08	1,14E-09	8,96E-09	6,86E-09	5,79E-08
HNTC	CTUh			3,79E-11	8,68E-09	4,84E-08	2,37E-09	4,54E-08	2,86E-08	1,34E-07
HTC	CTUh			3,85E-11	2,27E-09	8,45E-09	4,28E-10	2,98E-08	1,22E-08	5,32E-08
POF	kg NMVOC eq			4,82E-05	8,66E-04	8,79E-04	4,22E-05	1,29E-03	8,50E-04	3,97E-03
A	molc H+ eq			1,13E-05	1,43E-03	9,21E-04	6,71E-05	1,94E-03	1,00E-03	5,37E-03
TEu	molc N eq			4,94E-05	3,14E-03	3,00E-03	1,54E-04	3,84E-03	2,17E-03	1,24E-02
FEu	kg P eq			7,94E-08	1,18E-05	2,30E-05	2,43E-06	7,38E-05	3,00E-05	1,41E-04
ME	kg N eq			5,03E-06	2,83E-04	2,75E-04	1,42E-05	4,75E-04	2,38E-04	1,29E-03
FEc	CTUe			2,73E-03	2,40E-01	1,20E+00	6,81E-02	1,96E+00	9,81E-01	4,45E+00
MFRD	kg Sb eq			2,60E-08	1,32E-06	2,17E-05	5,28E-07	2,95E-06	5,27E-06	3,18E-05
WU	m^3			3,08E-04	1,06E-02	2,00E-02	3,04E-03	4,52E-01	1,30E-01	6,16E-01
CEDt	MJ			2,34E-02	1,06E+00	2,80E+00	1,69E-01	9,91E+00	6,45E+00	2,04E+01

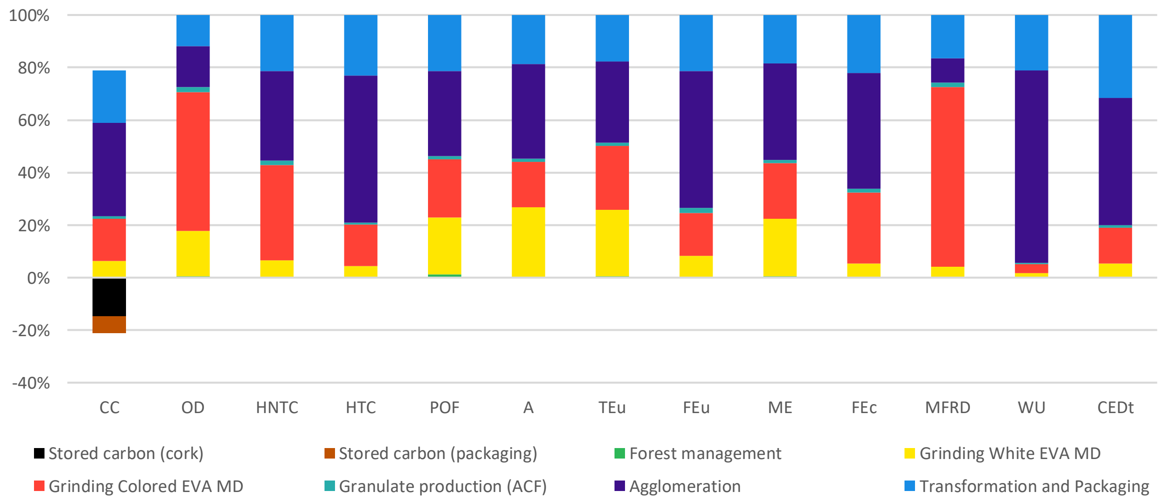

Figure C - Overall relative results per stage of Underlay 5156 VB

The life cycle assessment of Nature 8210 is shown in Table B and Figure D, per stage. As observed, forest management, cork granulate production, grinding cork and transformation and packaging stages have a very low impact in the overall impacts considered. In contrast, Underlay Nature 81210 agglomeration stage shows the highest level of potential impacts in the studied system. This stage includes the main production activities, such as agglomeration of the main underlay components. The use of polyurethane binders for the agglomeration process is the main contributor for the observed potential impacts. The impacts stemming from energy consumption, namely electricity, are also especially relevant in the grinding stages.

Table B – Overall results of the analysis and absolute values per stage of Underlay 8210

Impact category	Unit*	Stored carbon (cork)	Stored carbon (packaging)	Forest management	Cork granulate production (ACF)	Grinding Cork	Agglomeration	Transformation and packaging	Total Cradle-to-gate
CC	kg CO_2 eq	-3,30E-01	-3,40E-02	2,44E-03	1,74E-02	1,53E-03	2,77E-01	2,10E-02	-4,52E-02
OD	kg CFC-11 eq			4,74E-10	2,09E-09	7,90E-11	6,69E-09	9,44E-10	1,03E-08
HNTC	CTUh			6,92E-11	4,34E-09	3,93E-10	3,50E-08	4,27E-09	4,41E-08
HTC	CTUh			7,04E-11	7,83E-10	8,24E-11	2,03E-08	1,03E-09	2,23E-08
POF	kg NMVOC eq			8,81E-05	7,72E-05	1,16E-03	9,11E-04	8,14E-05	2,32E-03
A	molc H+ eq			2,06E-05	1,23E-04	2,74E-04	1,46E-03	8,82E-05	1,97E-03
TEu	molc N eq			9,03E-05	2,81E-04	4,17E-03	2,78E-03	2,11E-04	7,53E-03
FEu	kg P eq			1,45E-07	4,43E-06	6,68E-07	5,78E-05	3,63E-06	6,66E-05
ME	kg N eq			9,20E-06	2,60E-05	2,09E-06	3,35E-04	1,97E-05	3,92E-04
FEc	CTUe			4,99E-03	1,25E-01	1,33E-02	1,46E+00	9,07E-02	1,69E+00
MFRD	kg Sb eq			4,75E-08	9,65E-07	2,11E-08	2,13E-06	7,08E-07	3,87E-06
WU	m^3			5,62E-04	5,56E-03	8,97E-04	3,04E-01	8,67E-03	3,20E-01
CEDt	MJ			4,27E-02	3,09E-01	3,12E-02	7,25E+00	8,05E-01	8,43E+00

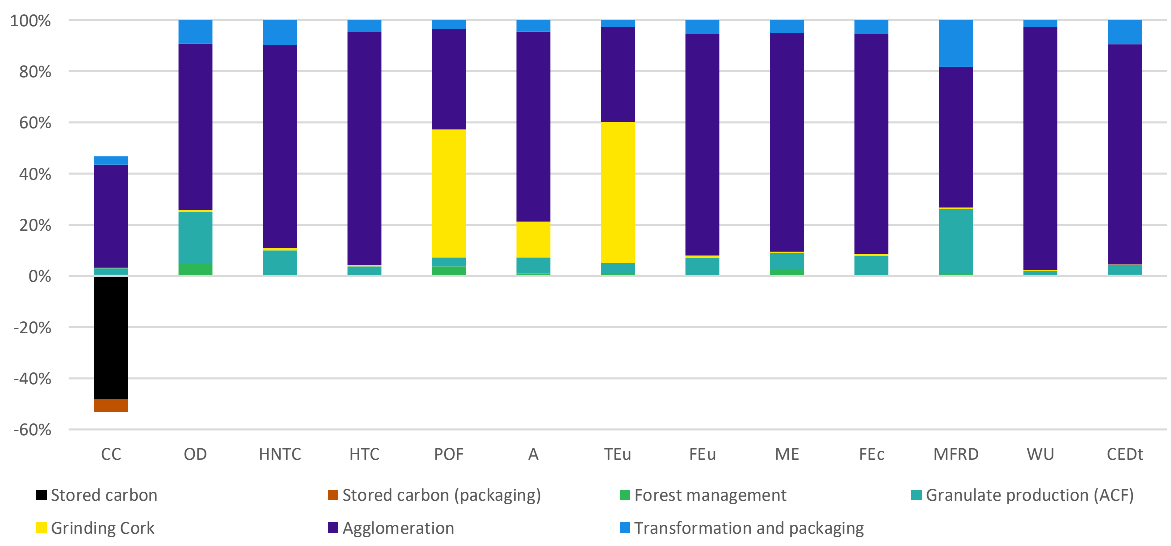

Figure D - Overall relative results per stage of Underlay Nature 8210

Carbon footprint

Figure E shows the carbon footprint results for Underlay 5156 VB production. As observed, the carbon stored in the product represents -0,17 $kgCO_{2eq}$ per $1m^2$ of Underlay 5156 VB, from cork composition, and -0,07 $kgCO_{2eq}$ per $1m^2$ of Underlay 5156 VB, from the packaging materials, with the overall impacts of the transformation stages representing a total sum of 0,88 $kgCO_{2eq}$ per $1m^2$ of Underlay 5156 VB. As a result, the carbon footprint has a total value of +0,64 $kgCO_{2eq}$ per $1m^2$ of Underlay 5156 VB packed under a cradle to gate approach. As so, considering a cradle-to-gate approach, the stored carbon per $1m^2$ of Underlay 5156 VB is lower than potential climate impacts of the assessed industrial stages.

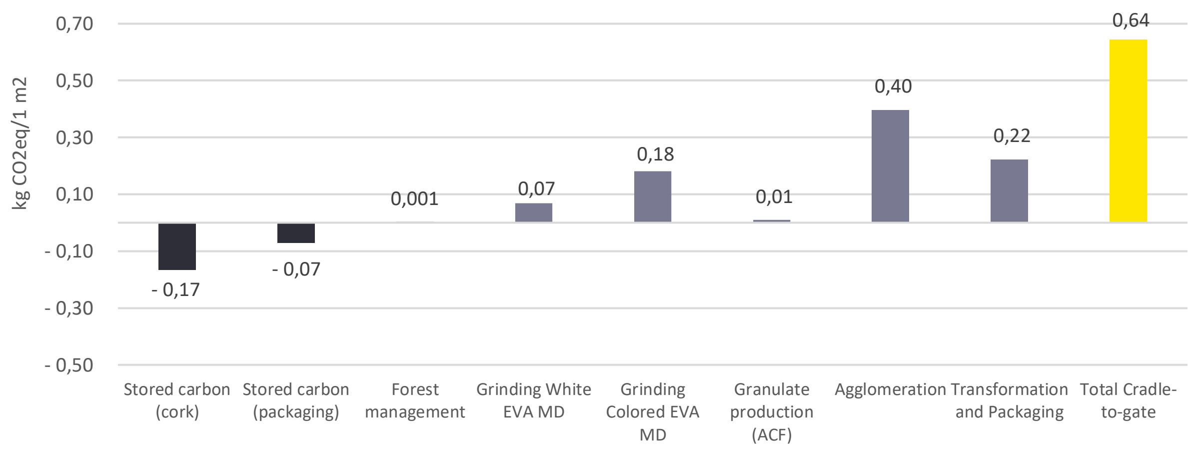

Figure E – Carbon footprint of Underlay 5156 VB per stage

Figure F shows the carbon footprint results for Underlay Nature 8210 production. As observed, the carbon stored in the product represents -0,33 $kgCO_{2eq}$ per $1m^2$ of Underlay Nature 8210, from cork composition, and -0,03 $kgCO_{2eq}$ per $1m^2$ of Underlay Nature 8210, from the packaging materials, with the overall impacts of the transformation stages representing a total sum of 0,32 $kgCO_{2eq}$ per $1m^2$ of Underlay Nature 8210. As a result, the carbon footprint has a total value of -0,05 $kgCO_{2eq}$ per $1m^2$ of Underlay Nature 8210 packed under a cradle to gate approach. As so, considering a cradle-to-gate approach, the stored carbon per $1m^2$ of Underlay Nature 8210 is higher than potential climate impacts of the assessed industrial stages.

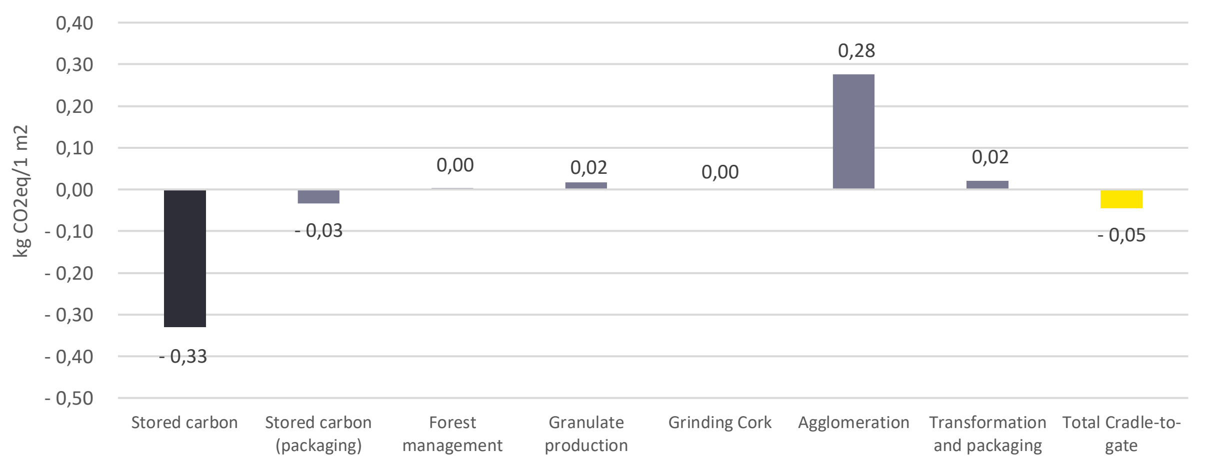

Figure F – Carbon footprint of Underlay Nature 8210 per stage

Scenario analysis for carbon sequestration of the cork oak forest

In past studies, the assumption that carbon sequestration of the cork oak forest can indirectly be attributed to cork products was simulated, as the cork transformation industry contribute to the exploitation and maintenance of the cork oak forest. This link is explored by a means of a scenario analysis of how much carbon retention by forest can be linked to an amount of cork produced PwC/Ecobilan 2008; Rives et al., 2013, EY, 2019a,b).

Since 2018, the Product Environmental Category Rules (PEFCR) for still and sparkling wine, published by the European Commission (EC), states that carbon stored by cork oak trees could be included in environmental footprints as additional environmental information, if carbon storage goes beyond 100 years, which is the case for cork. The PEFCR are applicable to wine companies that aim to conduct a Product Environmental Footprint (PEF) to a functional unit of "0,75 liters wine".

In this scenario analysis, the GHG emissions of the studied cradle-to-gate system are compared to the carbon uptake by the cork oak forest, considering the cork weight in the functional unit. The resulted carbon balance is here presented as additional environmental information, as should not be confused with the carbon footprint analysis, where GHG emissions and biogenic stored carbon by cork are addressed. Carbon stored in the product was excluded for this scenario to avoid double counting. Allocation of CO_2 uptake to the cork extracted from the cork oak stands follows the same premises of allocating environmental impacts in Dias et al. (2014a). Two perspectives were considered:

1. **Weight-based perspective:** All CO_2 uptake by the cork oak forest is allocated to extracted cork as cork production is the main economic activity of cork oak forest;

2. **Mass perspective:** CO_2 uptake by the cork oak forest is allocated to extracted cork considering the physical system of the cork oak stand (tree + cork), where, during the tree life cycle, cork mass represents about 31% of dry basis weight when compared to wood.

The analyzed scenarios consider carbon sequestration in well-managed cork oak forests, with a high tree coverage and good soil and climate conditions, with an average CO_2 uptake of 11 t CO_2/ha[1], reaching a maximum of 14,7 t CO_2/ha. Translating[2] these values in function of cork extraction, there is a CO_2 uptake of 55 t CO_2/t of cork extracted, reaching up to 73 t CO_2/t of cork extracted.

Taking into account both allocation perspectives, for Underlay 5156 VB:

- When considering the **weight-based perspective** of allocation procedure (1), a forest uptake of -4,8 kg CO_2/1 m^2, up to -6,4 kg CO_2/1 m^2, is attributed to the product and a carbon balance[3] of -4,0 kg CO_2/1 m^2, up to – 5,6 kg CO_2/1 m^2.

- When considering the **mass perspective** (2), there is a lower forest uptake attributed to the product of -1,5 kg CO_2/1 m^2, up to -2,0 kg CO_2/1 m^2, and a carbon balance of -0,7 kg CO_2/1 m^2, up to – 1,2 kg CO_2/1 m^2, as a lower fraction of CO_2 uptake is allocated to the extracted cork.

[1] Figures considered in the "The value of cork oak montado ecosystem services" (EY, 2019c). Average ecosystem CO_2 uptake (11 t CO_2/ha) considers wet and dry years in well managed forests, with a maximum of 14,7 t CO_2/ha registered in optimal climatic conditions (Costa-e-Silva et al., 2015).

[2] Conversion of forest ecosystem uptake per tonne of extracted cork considers the total cork oak occupation area in Portugal (719 937 ha) (ICNF, 2019) and an average value of cork production (145 000 t cork) based on a nine-year series (2003-2011) (APCOR, 2011).

[3] Considering 0,8 kg CO_{2eq}/1 m^2 of Underlay 5156 VB emitted during the production of Underlay 5156 VB.

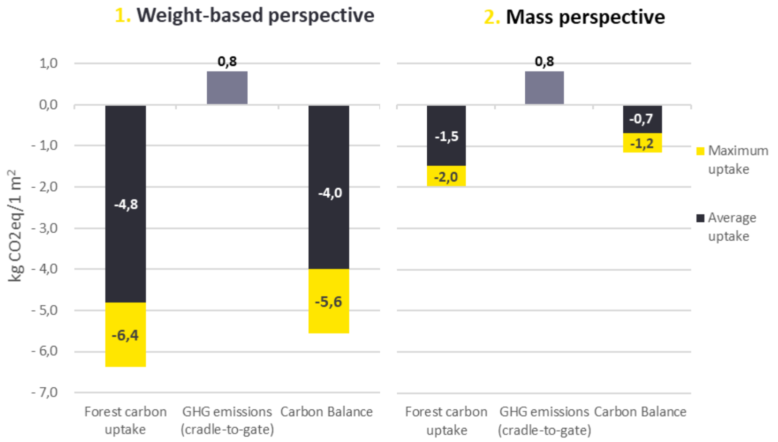

Figure G - Forest carbon uptake and carbon balance with product GHG emissions for Underlay 5156 VB

Taking into account both allocation perspectives, for Underlay Nature 8210:

- When considering the **weight-based perspective** of allocation procedure (1), a forest uptake of -9,6 kg CO_2/1 m^2, up to -12,7 kg CO_2/1 m^2, is attributed to the product and a carbon balance[4] of -9,3 kg kg CO_2/1 m^2, up to –12,4 kg kg CO_2/1 m^2.
- When considering the **mass perspective** (2), there is a lower forest uptake attributed to the product of -3,0 kg CO_2/1 m^2, up to -3,9 kg kg CO_2/1 m^2, and a carbon balance of -2,7 kg CO_2/1 m^2, up to – 3,7 kg CO_2/1 m^2, as a lower fraction of CO_2 uptake is allocated to the extracted cork.

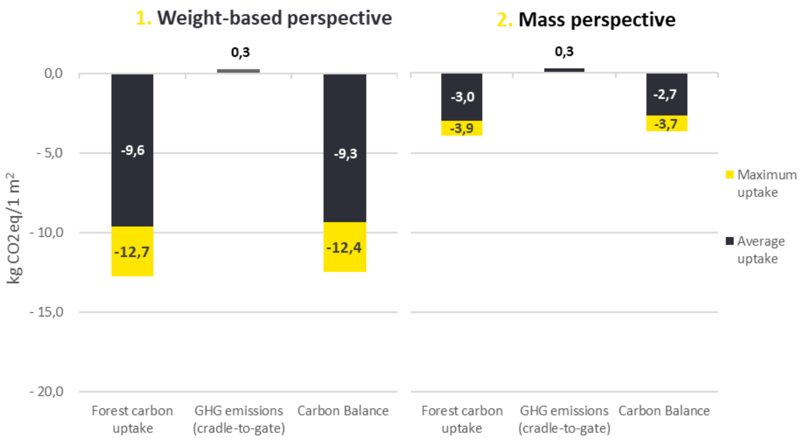

Figure H - Forest carbon uptake and carbon balance with product GHG emissions for Underlay Nature 8210

These results (Figures G and H) illustrate the differentiating factor between cork and other forest-based products. As the cork oak tree retains carbon for over 100 years, regardless of cork harvesting (Bugalho et al., 2011), cork exploitation supports the maintenance of the ecosystem, thus having a positive contribution to global climate regulation. As stated above, it is important to note that this result should solely be considered as an additional environmental information to the carbon footprint presented in this study.

[4] Considering 0,3 kg CO_{2eq}/1 m^2 of Underlay Nature 8210 emitted during the production of Underlay Nature 8210.

Conclusions

Main results (Table A and Figure C) show that overall the highest environmental impacts of Underlay 5156 VB are associated with the processes where the use of chemical products is higher and where the long distance transport of raw materials from suppliers take place, as a result, the impact of grinding colored EVA and agglomeration stages across all LCA impact categories is significant.

Main results (Table B and Figure D) show that overall the highest environmental impacts are associated with the processes where the use of chemical products and energy consumption is higher, as a result, the impact of Underlay Nature 8210 agglomeration process all LCA impact categories is significant. To lower the impact from these activities, more efficient and less environmental harmful options should be studied when selecting materials to be included in the process. Renewable energy generation and energy efficiency measures can also be studied and implemented. These actions could substantially improve overall performance of the studied system.

By using natural raw materials, such as cork and recycled materials such as EVA and cork scrap, that would otherwise be disposed, Amorim Cork Composites is able to lower the potential environmental impacts stemming from its product, opposed to a scenario where these main inputs would be sourced in the transformation industry, as they are the sole main components of the final product. Hence, here this recycled materials enter the system with no environmental burdens other than its transport to the industrial facilities. By putting the concepts of bio-based products and circular economy into practice, a reduction of expected potential impacts in the final product is observed.

For Underlay 5156 VB, total emissions account for an overall climate change impact of 0,9 kg CO_{2eq} per 1 m^2. Considering the carbon stored in the cork and packaging materials used to produce Underlay 5156 VB (0,2 $kgCO_2$/ 1 m^2), the carbon footprint of the product is +0,6 $kgCO_{2eq}$ per 1 m^2, under a cradle-to-gate approach. For Underlay Nature 8210, total emissions account for an overall climate change impact of 0,32 kg CO_{2e}q per 1 m^2. Considering the carbon stored in the cork and packaging materials used to produce Underlay Nature 8210 (0,36 $kgCO_2$/ 1 m2), the carbon footprint of the product is -0,05 kgCO2eq per 1 m^2, under a cradle-to-gate approach.

Considering a scenario analysis in Underlay 5156 VB, where the carbon sequestration of the cork oak forest can indirectly be attributed to cork products, based on well-managed cork oak forests, a forest carbon uptake up to -6,4 kg CO_2 per 1 m2 can be observed. Considering both the forest carbon uptake and the GHG emissions of maximum weight Underlay 5156 VB production (0,8 $kgCO_2$/ 1 m2), there is a carbon balance up to -5,6 kg CO_{2eq} per 1 m^2. In Underlay Nature 8210, a forest carbon uptake up to -12,7 kg CO_2 per 1 m^2 can be observed. Considering both the forest carbon uptake and the GHG emissions of maximum weight Underlay Nature 8210 production (0,3 $kgCO_2$/ 1 m^2), there is a carbon balance up to -12,4 kg CO_{2eq} per 1 m^2. This balance illustrates the differentiating factor between cork and other products.

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1. Introduction

1.1 The cork oak sector

Corticeira Amorim is the largest world producer of cork products, championing the sector since 1870. It is a Portuguese company, which activities spread in over 100 countries in all continents. The company has a portfolio of products with applications in multiple industries, such as a wine, construction, flooring, aeronautical, automobile, footwear, among others. The production process of their products is a true example of circular economy and industrial ecology, since most cork byproducts are used in multiple end-products. When unsuitable to be included in end-products, the remaining cork and cork dust can be used as biomass to produce energy, considerably reducing waste production and energy consumption of the industrial process. Corticeira Amorim has been placing a higher importance on sustainability in its activities as the business is ever more structured around the adoptions of sustainable development practices, being also an important knowledge spillover vector of best cork oak ecosystem management practices to cork producers.

Amorim Cork Composites (ACC), a subsidiary of Corticeira Amorim is focused in producing innovative solutions with combinations of cork and other materials, by recycling, reusing and reinventing natural and organic materials. The composite cork industry requires high levels of physical and chemical performance, providing adequate solutions to the needs of several industries such as the automotive, aerospace and aeronautical industries, the construction sector, as well as the shoe and interior design industries.

Cork oak forests cover approximately 2.2 million hectares in the West Mediterranean basin, where it grows in countries such as Portugal, Spain, France, Italy, Morocco, Algeria and Tunisia. Portugal has the largest cork oak woodland area (also known as montado in Portugal), representing 34 percent of the world area of cork oak forests, with an area of 720 thousand hectares (23% of total national forest area) (APCOR,2019). It also has a share of about 50% of the worldwide raw cork production.

The cork oak montado is an agroforestry multifunctional system, with a high socioeconomic importance as cork is used to produce various products in a wide range of sectors due to its versatility, providing also thousands of direct and indirect jobs. Moreover, the montado ecosystem provides a range of services, such as carbon sequestration, habitat maintenance for species and hydrological regulation (Godinho et al., 2016), which contribute to human welfare. As environmental impacts associated to cork extraction are minimal, the cork oak montado ecosystem provides a sustainable source of resources to human welfare (Rives et al., 2011).

Cork is a raw material extracted from the outer bark of the cork oak tree (Quercus Suber L.). It is a renewable resource since (1) cork harvesting is a process where the tree is not cut down and (2) the cork oak tree has the capacity to regenerate its outer bark. This allows multiple periodical extractions for more than 200 hundred years (average life span of a cork oak tree). Cork is a flexible and compressible material, with impermeability to liquids and gases, noise and heat insulating properties, resistance to bacterial growth and many other features that make it impossible to mimic simultaneously. Depending on its characteristics, cork is an appropriate resource with different applications such as natural and agglomerated cork stoppers, insulators, floor and wall coverings, composite products, among others. In Portugal, the first extraction of cork (virgin cork), which takes place when the trees trunk's circumference reaches 70cm, measured at 1.3 meters from the ground (at around 20-30 years old), usually is used in the manufacture of agglomerates once it doesn't have the quality required for producing cork stoppers. Afterwards, cork harvesting takes place every 9 years. The cork obtained from the second harvesting, called second cork, is also only suitable to the agglomerate industry. The cork stripped in third harvesting onwards, called reproduction cork has the higher quality, and is more likely to be suitable to cork stoppers.

1.2 Context of this study

This report is focused on the environmental impacts and carbon footprint of the production system of the Undelay 5156 VB and Nature 8210, through a life cycle approach. The production systems and main characteristics of the studied products can be observed in section 2.3 and 2.4.

1.3 Study design

Environmental impacts of the production of Underlay 5156 VB and Nature 8210 can be assessed within a lifecycle thinking approach. Life cycle assessment (LCA) is a technique that assesses potential impacts of a product at different stages of its life. We detail the goal and scope of the study in the following chapter 2. *Goal and Scope Definition*.

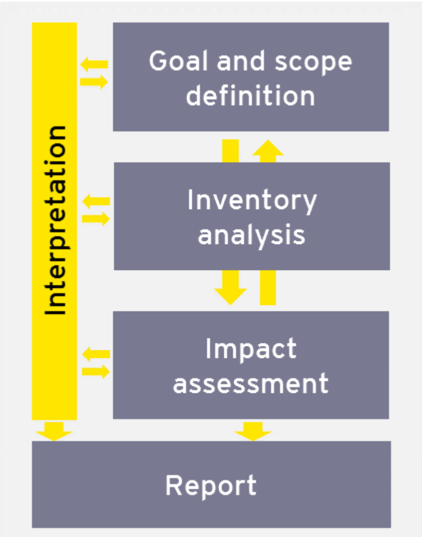


Figure 1 - Figure

This study was based on ISO 14040/44 standards (ISO, 2006) that describe the four basic steps of an LCA assessment procedure:

- Goal and scope definition,
- Life cycle inventory (LCI),
- Life cycle impact assessment (LCIA) and
- Life cycle interpretation;

The structure and contents of this report follow ISO 14040/44 series of standards, complemented with the guidelines from International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance (EC-JRC, 2010).

The report is structured as follows:

- Goal and Scope definition: outlines the goal of the study, describes Underlays 5156 VB and Nature 8210 products, functional units considered, studied systems and their boundaries, modelling framework and allocation procedures, and environmental impacts studied.
- Life Cycle Inventory analysis: describes the data collection procedures.
- Results and Discussion: presents the impact assessment results, their interpretation and conclusions.
- Conclusions: highlights the main conclusions of this study.

2. Goal and scope definition

2.1 Goal of the study

The main purpose of this study is to quantify the environmental impacts of Underlays 5156 VB and Nature 8210. These underlayments provide confort, protection and longevity to floors, further contributing to energy efficiency and acoustic insulation, these are produced from recycled and natural materials, by Amorim Cork Composites. The study aims to determine which stages of the production have higher impacts considering the product lifecycle, within a determined scope.

As so, the main objectives of the study can be summarized as follows:

- To provide data to Amorim Cork Composites to understand and manage the environmental impacts of its products;

- To provide relevant information to the shoe materials industry regarding environmental impacts and benefits of cork use.

2.2 Scope of the study

The study was carried on a cradle-to-gate approach, to quantify and compare potential environmental impacts in the main stages of Underlays 5156 VB and Nature 8210 production.

The activities performed by Corticeira Amorim in Portugal, begin in the raw cork treatment stage, including its transport from the cork oak forest. In spite of not being performed by Amorim Cork Composites, the oak forest management activities (see section 2.4) at cork providers/suppliers are also considered and assessed. Cork is then transformed into cork granulate at Amorim Cork Flooring and then transported to Amorim Cork Composites.

Ethylene-vinyl acetate (EVA) is sourced from suppliers, that would otherwise dispose this materials as they were considered as wastes from their activities. Once transported to Corteceira Amorim, these materials are grinded to be introduced in the composite material production. The granulated cork, together with the grinded EVA, are molded and compressed into an agglomerated panel, through the use of polyurethane (PU) binders, to which a polyethylene film is then applied, using a vapor barrier technology. The Underlay 5156 VB is ultimately packed and stored to be ready for shipment.

The production of Underlay Nature 8210 includes solely cork, water and polyurethane (PU) binder. The cork granulate includes both Amorim Cork Flooring granulate as well as regranulate resulting from the grinding of cork scraps, that would otherwise be disposed as waste. The granulated and regranulated cork are molded, through the use of polyurethane binders, and compressed into an agglomerated panel. The Underlay Nature 8210 is ultimately packed and stored to be ready for shipment.

The cork oak forest management activities (see section 2.4) that provide the raw cork are also assessed and included, although not being performed by Corticeira Amorim. The use phase and its impacts, as well as main transport activities between those stages are excluded from the scope of this study, as there are no reliable sources of data that allow an estimation of the environmental impacts of these stages.

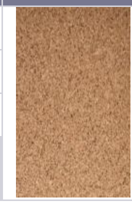
2.3 Product description and functional unit

The products under study are the Underlay 5156 VB, product made from agglomerated cork and composite materials such as recycled ethylene vinyl acetate and Nature 8210, product made from agglomerated cork and recycled cork, and EVA foam at Amorim Cork Composites. The main characteristics of the studied product Underlay 5156 VB are presented in Table 1, while the main characteristics of Nature 8210 are presented in Table 2.

Table 1 - General product information on Underlay 5156 VB

Material	% weight	Components	% weight	Picture
Underlay 5156 VB	88,16%	White EVA MD	37%	
		Coloured EVA MD	37%	
		Cork	13%	
		Costumization products	13%	
Packaging	11,84%			

Table 2 – General product information on Nature 8210

Material	% weight	Components	% weight	Picture
Nature 8210	95,5%	Cork	87,32%	
		Recycled cork	53%	
		Costumization products	13%	
Packaging	4,46%			

The functional unit established for this study is 1 m^2 both for Underlay 5156 VB as well as for Underlay Nature 8210, as it is a regular unit of sale of these products. The characteristics of volume and weight of the functional unit can be observed in Table 3.

Table 3 - Functional unit and characteristics of Underlays 5156 VB and Nature 8210

Product	Functional unit	Thickness (mm)	Weight-packed (kg)	Average specific weight (kg/m3)
Underlay 5156 VBVB	1 m^2	1,8	0,76	375
Underlay Nature 8210	1 m^2	2,0	0,52	250

2.4 System description and boundaries

The aim of the current section is to present the studied systems, detailing the processes within each stage, their main inputs and outputs, as well as the main assumptions considered when estimations were needed. Figure 2 and Figure 3 present the system boundaries of the studied systems, the boundaries for the activities performed by Amorim Cork Composites and main inputs and outputs per stage. A brief description of the processes and activities included in each stage is presented below, distinguishing stages and flows included in the main system of study.

Underlay 5156 VB

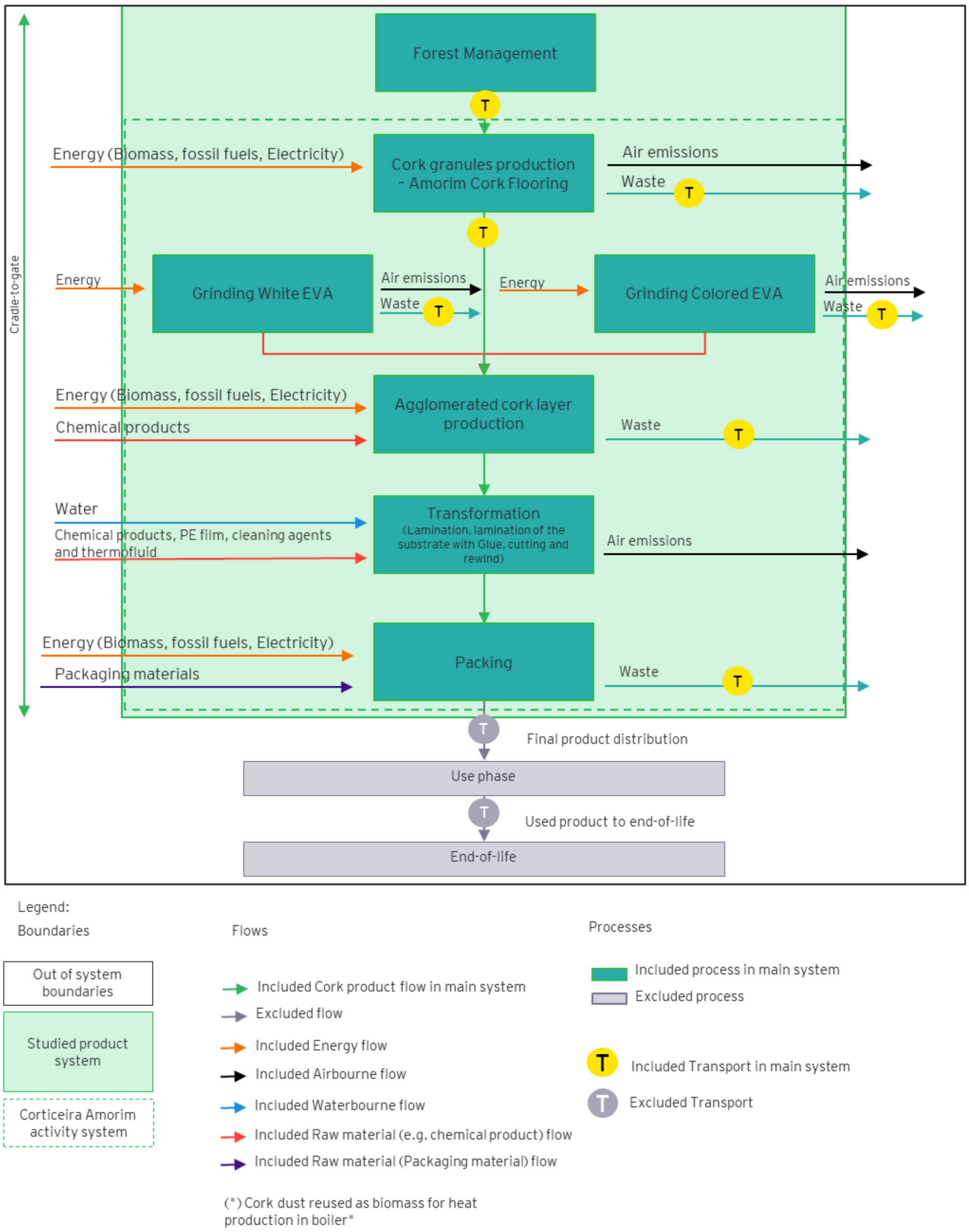


Figure 2 - System boundaries for the Underlay 5156 VB's studied system, relevant flows and processes

Stage 1 – Forest management and cork harvesting

From a life cycle perspective, the cork oak forest management typically includes the following activities (Dias et al., 2014a): stand establishment either by plantation or natural regeneration; stand tending, which includes motor-manual processes such as cleaning of spontaneous vegetation, pruning, thinning and fertilizing; manual harvesting of the cork (every 9 years) when the trees are 20-30 years old; final cutting when the tree approaches the end of its life (when approximately 170 years old); transport of cork slabs up to the storage place; transport of workers and materials used during cork oak tree forestry activities; and production of fuels and chemical consumed during the tree life-cycle.

The datasets used to model these activities covers cork production in a silvipastoral extensive management system as common in Portugal (Werner, et al., 2016). The dataset refers to the yield of 1 hectare over the rotation period of 140 years as the maximum rotation period in commercial cork production in Portugal. It includes manual harvesting of the cork (every 9 years) and motor-manual processes for thinning and final cutting of the trees. Also included are the transport of the workers to the forests for harvesting cork and the transport of the products to the nearest forest road.

Stage 2 – Cork granulate production (ACF)

This stage takes place at Amorim Cork Flooring, a subsidiary of Corticeira Amorim, that receives raw cork from Amorim Florestal. It was assumed that all cork raw material had been initially transported from Amorim Florestal, in Coruche, to Amorim Cork Floring, in Lourosa, thus assuming a distance of 253 km for transport by truck. The cork received then goes through a mechanical grinding and vibrating screening process, producing granulated cork that is then sent to Amorim Cork Composites for the production of Underlay 5156 VB.

Stage 3 and 4 – Grinding White and Colored EVA

For EVA grinding processes, taking place at Amorim Cork Composites, in Mozelos, ethylene-vinyl acetate (EVA) both white and colored are received from several external suppliers. The EVA foams sourced were considered as waste of production during manufacturing of products for different industries. White EVA foam is sourced from Vietnam, being transported by over 16 000 km, mainly through intercontinental maritime transport. Colored EVA foam is sourced from Spain and France, being transported by approximately 2 500 km, mostly by road. These materials are then grinded in Amorim Cork Composites facilities. After grinding, the EVA granulates enter the next stage as an input to produce the Underlay 5156 VB.

Stage 4 – Agglomeration

In the Underlay 5156 VB production, granules and the ethylene-vinyl acetate (EVA) grinded material are binded together, to produce an agglomerated panel, using polyurethane (PU) binders, as binding agents, pressure and heat. The panels are rolled in large cylinders, with a cardboard tube inside. Once the agglomerated panel is produced, it goes through an additional transformation process.

Stage 5 – Transformation and packaging

The agglomerated panels are then subjected to a transformation process where they are laminated, a polyethylene film is applied, with polyurethane (PU) binder, using a vapor barrier technology and the final cilinders are transversally cut and rewinded. By the end of the production process, the Underlay 5156 VB panels are packed and stored in the warehouse in a cylindrical form and are ready for shipment.

Underlay Nature 8210

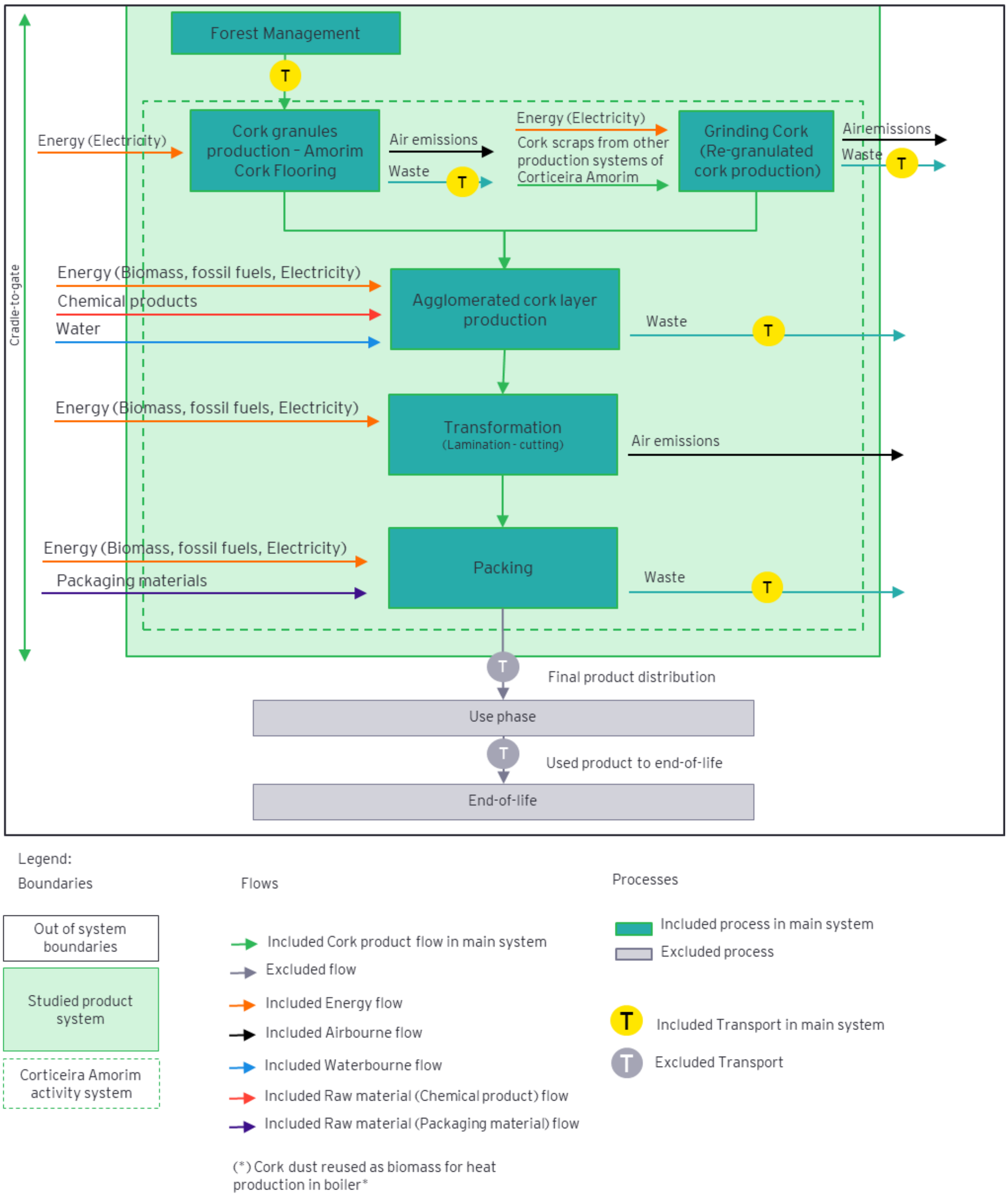


Figure 3 - System boundaries for the Underlay Nature 8210's studied system, relevant flows and processes

Stage 1 – Forest management and cork harvesting

The forest management and cork harvesting process is the same as described for Underlay 5156 VB.

Stage 2 – Cork granulate production (ACF)

This stage takes place at Amorim Cork Flooring, a subsidiary of Corticeira Amorim, that receives raw cork from Amorim Florestal. It was assumed that all cork raw material had been initially transported from Amorim Florestal, in Coruche, to Amorim Cork Floring, in Lourosa, thus assuming a distance of 253 km for transport by truck. The cork received then goes through a mechanical grinding and vibrating screening process, producing granulated cork that is then sent to Amorim Cork Composites for the production of Underlay 5156 VB.

Stage 3 – Grinding Cork (Re-granulated cork production)

The cork griding process occurs in Amorim Cork Composites facilities, where cork scraps, acquired or gerated as by-products of other products systems by Amorim Cork Composites, that would otherwise be disposed as waste, go through a grinding process. After grinding, the regranulated cork enter the next stage as an input to produce the Underlay Nature 8210.

Stage 4 – Agglomeration

In the Underlay Nature 8210 production, the granulated cork, produced in Amorim Cork Flooring, and the regranulated cork produced in Amorim Cork Composites, is binded together, with the use of polyurethane binders, to produce an agglomerated panel, using a polyurethane (PU) binders, as binding agents, pressure and heat.

Stage 5 – Transformation and packaging

The panels are rolled in large cylinders, with a cardboard tube inside. Once the agglomerated panel is produced, it goes through a cutting process. By the end of the production process, the underlay rolls are packed and stored in the warehouse in a cylindrical form and are ready for shipment.

Excluded activities:

The following operations were excluded from the studied system:

- Construction of industrial buildings and machinery
- Administrative, laboratory, business and maintenance activities

2.5 Impact assessment methods

Inventory results are calculated using the SimaPro software (version 9.1) (PRé Consultants, 2020). To evaluate the potential environmental impacts of each stage, the midpoint characterization factors recommended by the International Reference Life Cycle Data System (ILCD) were selected (

Table 4), as these factors are considered by scientific experts and stakeholders as the best available (Hauschild et al., 2013).

The following impact categories were selected: Climate Change (CC), Ozone Depletion (OD), Human Toxicity: Cancer Effects (HTC), Human Toxicity: Non-Cancer Effects (HTCN), Photochemical Ozone Formation (POF), Acidification (A), Terrestrial Eutrophication (TEu), Freshwater Eutrophication (FEu), Marine Eutrophication (ME), Freshwater Ecotoxicity (FEc), and Mineral and Fossil Resource Depletion (MFRD). This selection considered impact categories usually used in cork products LCA assessments (Rives et al., 2011; Dias et al., 2014a; Demertzi et al., 2015).

Table 4 - ILCD Midlpoint+ Impact Categories (EC-JRC, 2011), adapted from PRé Consultants, 2018

Impact category	Unit	Description	Reference
Climate Change (CC)	kg CO_2 eq	Global Warming Potential calculating the radiative forcing over a time horizon of 100 years.	IPCC 2007
Ozone Depletion (OD)	kg CFC-11 eq	Ozone Depletion Potential (ODP) calculating the destructive effects on the stratospheric ozone layer over a time horizon of 100 years.	World Meteorological Organization (WMO) 1999
Human Toxicity: Cancer Effects (HTC)	CTUh	Comparative Toxic Unit for humans (CTUh) expressing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted (cases per kilogramme). Specific groups of chemicals require further works.	USEtox
Human Toxicity: Non-Cancer Effects (HTCN)	CTUh	Comparative Toxic Unit for humans (CTUh) expressing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted (cases per kilogramme). Specific groups of chemicals require further works.	USEtox
Photochemical Ozone Formation (POF)	kg NMVOC eq	Expression of the potential contribution to photochemical ozone formation. Only for Europe. It includes spatial differentiation.	van Zelm et al. 2008.
Acidification (A)	mole H^+ eq	Accumulated Exceedance (AE) characterizing the change in critical load exceedance of the sensitive area in terrestrial and main freshwater ecosystems, to which acidifying substances deposit. European-country dependent.	Seppälä et al. 2006 and Posch et al. 2008.
Terrestrial Eutrophication (TEu)	mole N eq	Accumulated Exceedance (AE) characterizing the change in critical load exceedance of the sensitive area, to which eutrophying substances deposit. European-country dependent.	Seppälä et al. 2006 and Posch et al. 2008.
Freshwater Eutrophication (FEu)	kg P eq	Expression of the degree to which the emitted nutrients reaches the freshwater end compartment (phosphorus considered as limiting factor in freshwater). European validity. Averaged characterization factors from country dependent characterization factors.	ReCiPe version 1.05
Marine Eutrophication (ME)	kg N eq	Expression of the degree to which the emitted nutrients reaches the marine end compartment (nitrogen considered as limiting factor in marine water). European validity. Averaged characterization factors from country dependent characterization factors.	ReCiPe version 1.05
Freshwater Ecotoxicity (FEc)	CTUe	Comparative Toxic Unit for ecosystems (CTUe) expressing an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per unit mass of a chemical emitted (PAF m3 year/kg). Specific groups of chemicals require further works	USEtox (recommended + interim)
Mineral and Fossil Resource Depletion (MFRD)	kg Sb eq	Scarcity of mineral resource with the scarcity calculated as 'Reserve base'. It refers to identified resources that meets specified minimum physical and chemical criteria related to current mining practice. The reserve base may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics	van Oers et al. 2002

"The normalization factors are based on "Normalization method and data for Environmental Footprints; 2014; Lorenzo Benini, et al.; Report EUR 26842 EN". The weighting factors are based on "European Commission, 2014, Environmental Footprint Pilot Guidance document, - Guidance for the implementation of the EU Product Environmental Footprint (PEF) during the Environmental Footprint (EF) pilot phase, v. 4.0, May 2014" (all impact categories shall receive the same weight in the baseline approach)." (Pré Consultants, 2018).

To evaluate other relevant potential impacts, water use, and energy consumption were also assessed. To assess potential impacts on water use, the AWARE method was, as EC-JRC currently recommends. To evaluate total energy consumption the assessment was performed using the modelled information of energy sources for the system processes and their supply chain, using ecoinvent datasets for Low Heating Values, according to the Cumulative Energy Demand (LHV) method (Table 5).

Table 5 – Other impacts assessed

Impact	Unit	Description	Reference
Water consumption (WU)	m^3	AWARE is to be used as a water use midpoint indicator representing the relative Available WAter REmaining (AWARE) per area in a watershed after the demand of humans and aquatic ecosystems has been met. It assesses the potential of water deprivation, to either humans or ecosystems, building on the assumption that the less water remaining available per area, the more likely another user will be deprived.	AWARE 2016
Energy consumption (CEDt)	MJ	The Cumulative Energy Demand (LHV) method was created by PRé Consultants team based on data published by ecoinvent for raw materials available in the SimaPro database. The method calculates Lower Heating Values (LHV) of fuels used in each process.	Frischknecht, R. et al,. 2007. Weidema B, et al 2013

2.6 Carbon dioxide uptake and biogenic GHG emissions

Biogenic emissions and CO_{2eq} removals due carbon content in the reference flow are also considered. Forest-based products have a certain amount of carbon content due to carbon sequestration enabled by trees' photosynthesis process, which absorbs carbon dioxide from the atmosphere. Cork products have the capacity to retain carbon until their end-of-life for over 100 years, assuming the products get landfilled or recycled after their primary use (Demertzi et al. al 2015 b). In landfill, only a small part (around 2%) of the biogenic carbon is released into the atmosphere within 100 years, as the rest remains permanently stored in the landfill facility (Demertzi et al. al 2015 b). Only in the case of incineration, the biogenic carbon contained in the cork products is considered to be released back into the atmosphere, after the usage of the cork products (Demertzi et al. al 2015 b e Demertzi et al. 2018).

Accounting for carbon flows in forest-based products can be an especially complex task (Tellnes et al., 2017). The period during which the carbon is stored, which delays the emission of carbon dioxide, can vary a lot depending on the type of use given to the different types of cork products and by-products, in the different stages considered (Dias et al., 2014b). In the studied system different types of recycling can occur, so a simplified approach for accounting the carbon flows is needed.

In this study, all cork raw materials that enter the system were considered to have a similar amount of carbon stored. The calculation of CO_2 uptake is based on the atomic weights of carbon (12) and carbon dioxide (44), as well as the carbon fraction (dry basis) of 55% and a moisture fraction of 6% (Dias et al., 2014b).

Given the purpose of the assessment, emissions from biomass energy production are considered neutral, due to the assumption that the CO_2 that is being released in the incineration process (biogenic CO_2) was captured in the previous product stage 1 - forest management and cork harvesting (uptake), as so, it is no more than a short term delayed emission, resulting in a net neutral balance of CO_2 emissions (Demertzi et al., 2016; Rives et al., 2013).

Considering all these components and activity data, the carbon footprints of Underlays 5156 VB and Nature 8210 are assessed according to the following equation:

$$\frac{Total\ kg\ CO2eq}{1\ m^2\ underlay} = \frac{kg\ CO2eq\ GHG\ emissions}{1\ m^2\ underlay} + \frac{kg\ CO2eq\ Biogenic\ emissions}{1\ m^2\ underlay} - \frac{kg\ CO2eq\ removals\ (stored\ carbon)}{1\ m^2\ underlay}$$

2.7 Accounting the use of materials from recycling

Colored and white EVA used in Underlay 5156 VB and cork scraps used in Underlay Nature 8210 have been previously discarded by their first owner or product system, as these materials were not fit to be used in the primary product manufacturing at their source. As so, by using these materials, Amorim Cork Composites, and new product systems, become the secondary user and need to account for the use of recycled material (as a flow from technosphere).

The exact boundary settings between the first and the next product systems are defined by the willingness to pay for the recycled material. This implies that from the moment the user of a secondary material pays for the material, this (secondary) product system will also be responsible for the environmental burden from that point on. This principle is referred to as the Polluter Pays (PP) allocation method (EPD International, 2018).

As so, due to the inflow of recycled material to the production system, the transportation of these materials from their source to Amorim Cork Composites is included in this system. It can be assumed that the materials get repurposed once they enter the grinding process in this secondary system.

3. Life cycle inventory analysis

3.1 Data collection procedure and validation

With regards to data sources, data related to the production of Underlays 5156 VB and Nature 8210 was collected through the use of questionnaires carried out by Amorim Cork Composites (local data), while general production processes associated to raw materials production (chemical products, packaging materials), energy, transport and waste management were obtained from ecoinvent 3.5 database (Werner, et al., 2016). Amorim Cork Composites was responsible for the collection of raw data, using internal monitoring tools and estimates, when needed, on a one-year basis, adjusting the value to the functional unit of the study. Transport data (distance) for packaging materials, chemical products and waste generated in industrial activities considered the origin of the main suppliers or distributors for each product considered. Transport modes were provided by Amorim Cork Composites data, were the transport of raw materials were mostly done by truck as it is the most frequent type of transportation used, with some exceptions regarding materials sourced in other continents. Tonnage adopted varied according to distance of transport and type of material. Information regarding this issue was provided by Amorim Cork Composites.

Due to the amount and diversity of data collected in the inventory of relevant processes, data validation procedures were applied to verify raw data quality. These procedures focused at first in the mass balance for the product system. This procedure led to adjustments in the amounts of inputs and outputs being considered in each stage, to be in accordance with the total amount of cork raw material inputs and cork-based products and by-products as detailed in section 2. After final revisions, no significant deviations on mass balance between cork inputs and outputs were observed.

Finally, due to the relevance of carbon dioxide flows, when accounting for a mass allocation basis, the carbon content of the final product was checked through molar relationship to verify the carbon accounting procedures done in each stage (see section 2.6). Other procedures for validating data estimations included interviews with personnel responsible for data collection and data treatment, review of raw data collection procedures, review of calculation steps performed and review of data entry in the modelling software.

In this assessment, all datasets used were provided by ecoinvent v3.5 database, compiled in 2018. The ecoinvent v3.5 database contains LCI data from various sectors such as energy production, transport, building materials, production of chemicals, metal production and fruit and vegetables. The entire database consists of over 10,000 interlinked datasets, each of which describes a life cycle inventory on a process level. All published datasets are subject to an independent external review. The system model 'allocation, at point of substitution’ contains two methodological choices: 1) it uses the average supply of products, as described in market activity datasets and 2) it uses partitioning (allocation) to convert multi-product datasets to single-product datasets. The flows are allocated relative to their 'true value', which is the economic revenue corrected for some market imperfections and fluctuations.

3.2 Life cycle inventory

Inventory data was collected, for year 2020, according to the procedure described in section 3.1. Inputs and outputs considered, as well as the respective transport data are presented from Table 6 to Table 14, for 1 m^2 of Underlay 5156 VB, and from Table 15 to Table 22, for 1m^2 of Underlay Nature 8210. Adjustments to units of collected data were performed to align data with ecoinvent 3.5 datasets.

Underlay 5156 VB - Cork and EVA flows data:

Table 6 – Cork and EVA flows data adjusted to Underlay 5156 VB's FU

Input/output	Flow type	Flow	unit	Value per FU
Cork granulate production (ACF)				
Input	Raw material	Raw cork	kg	1,77E-01
Output	Product	Cork granulate (ACF)	kg	9,64E-02
	By-product	Cork dust	kg	7,63E-02
White EVA Grinding				
Input	Raw material	White EVA	kg	2,74E-01
Output	Product	White EVA MD	kg	2,60E-01
Colored EVA Grinding				
Input	Raw material	Colored EVA	kg	2,74E-01
Output	Product	Colored EVA MD	kg	2,60E-01
Agglomeration				
Input	Raw material	Cork granulate (ACF)	kg	9,64E-02
	Raw material	White EVA MD	kg	2,60E-01
	Raw material	Colored EVA MD	kg	2,60E-01
Output	Product	Agglomerated cork layers	kg	6,91E-01
Transformation and packaging				
Input	Raw material	Agglomerated cork layers	kg	6,91E-01
	Raw material	Plastic film PE	kg	4,10E-02
Output	Product	Underlay 5156 VB (packed)	kg	7,60E-01

Underlay 5156 VB - Industrial processes data:

Table 7 - Stage 2 – Cork granulate production (ACF)

Flow type	Flow	unit	Value per FU
Input			
Energy	Electricity	kWh	4,68E-02
Output			
Air emissions	PTS	kg	1,44E-08
	VOC's	kg	3,07E-09
Waste	Industrial waste to landfill	kg	4,40E-03

Table 8 - Stage 3 – Grinding EVA (White)

Flow type	Flow	unit	Value per FU
Input			
Energy	Electricity	kWh	5,20E-02
Output			
Air emissions	PTS	kg	6,81E-05
	VOC's	kg	1,60E-04
Waste	Recyclable waste	kg	1,37E-02

Table 9 - Stage 4 – Grinding EVA (Colored)

Flow type	Flow	unit	Value per FU
Input			
Energy	Electricity	kWh	5,20E-02
Output			
Air emissions	PTS	kg	6,81E-05
	VOC's	kg	1,60E-04
Waste	Recyclable waste	kg	1,37E-02

Table 10 - Stage 5 – Agglomeration

Flow type	Flow	unit	Value per FU
Input			
Chemical products	Polyurethane (PU) binder	kg	9,65E-02
Energy	Electricity	kWh	8,12E-02
	Biomass	GJ	9,70E-04
Output			
Waste	Recyclable waste	kg	1,91E-02

Table 11 - Stage 6 – Transformation and packaging

Flow type	Flow	unit	Value per FU
Input			
Chemical products	Polyurethane (PU) binder	kg	1,78E-02
	Cleaning Agent	Kg	6,55E-04
	Glue cleaning agent	kg	6,55E-05
Energy	Electricity	kWh	3,31E-03
Packaging materials	Polypropylene, granulate	kg	2,85E-03
	Kraft paper	kg	1,20E-03
	EUR-flat pallet	kg	2,59E-02
	Cardboard	kg	1,88E-02
	Packaging Film	kg	9,80E-04
	Glue tape	kg	8,91E-05
Output			
Air emissions	PTS	kg	2,62E-06
	VOC's	kg	2,62E-06
Waste	Industrial waste to landfill	kg	3,75E-02
	Recyclable waste	kg	2,49E-03

Underlay 5156 VB - Transport data:

Transport of raw material

Table 12 - Transportation of raw material data

Flow	Flow type	Origin	Destination	Unit	Distance
Raw cork	Raw material	ACF-Lourosa	Amorim Cork Composites (Mozelos)	km	253
White EVA	Raw material	Vietnam	Amorim Cork Composites (Mozelos)	km	16660
Colored EVA	Raw material	France	Amorim Cork Composites (Mozelos)	km	1600
Colored EVA	Raw material	Spain	Amorim Cork Composites (Mozelos)	km	900
Cork granulate (ACF)	Raw material	ACF-Lourosa	Amorim Cork Composites (Mozelos)	km	6
PE film layer	Raw material	Supplier (Portugal)	Amorim Cork Composites (Mozelos)	km	107

Table 13 - Transportation of raw material per type of transport used

Flow type	Transport	unit	Value per FU
Raw cork	Transport, freight, lorry 7.5-16 metric ton, euro4	tkm	4,48E-02
White EVA	Transport, freight, lorry 3,5-7.5 metric ton, euro4	tkm	1,64E-02
White EVA	Transport, freight, sea, transoceanic ship	tkm	4,54E+00
Colored EVA	Transport, freight, lorry 3,5-7.5 metric ton, euro4	tkm	6,84E-01
Cork granulate (ACF)	Transport, freight, lorry 3,5-7.5 metric ton, euro4	tkm	5,79E-04
PE film layer	Transport, freight, lorry 3,5-7.5 metric ton, euro4	tkm	4,39E-03

Transport of chemical products, packaging materials and waste

Table 14 - Transport of chemical products, packaging materials and waste data and type of transport

Flow type	Transport	unit	Value per FU
Stage 2 – Cork granulate production (ACF)			
Waste	Transport, freight, lorry 16-32 metric ton, euro4	tkm	1,10E-04
Stage 3 – Grinding EVA (White)			
Waste	Transport, freight, lorry 16-32 metric ton, euro4	tkm	1,61E-03
Stage 4 – Grinding EVA (Colored)			
Waste	Transport, freight, lorry 16-32 metric ton, euro4	tkm	1,61E-03
Stage 5 – Agglomeration			
Chemical products	Transport, freight, lorry 16-32 metric ton, euro4	tkm	1,18E-02
Waste	Transport, freight, lorry 16-32 metric ton, euro4	tkm	2,26E-03
Stage 6 – Transformation and packaging			
Chemical products	Transport, freight, lorry 16-32 metric ton, euro4	tkm	3,71E-02
Chemical products	Transport, freight, lorry 3,5-7.5 metric ton, euro4	tkm	1,64E-03
Packaging materials	Transport, freight, lorry 16-32 metric ton, euro4	tkm	5,64E-05
Packaging materials	Transport, freight, lorry 3,5-7.5 metric ton, euro4	tkm	3,53E-03
Waste	Transport, freight, lorry 16-32 metric ton, euro4	tkm	4,96E-04

Underlay Nature 8210 - Cork flows data:

Table 15 - Cork flows data adjusted to Underlay Nature 8210's FU

Input/output	Flow type	Flow	unit	Value per FU
Stage 2 - Cork granulate production (ACF)				
Input	Raw material	Raw cork	kg	3,24E-01
Output	Product	Cork granulate (ACF)	kg	1,76E-01
	By-product	Cork dust	kg	1,39E-01
Stage 3 - Grinding Cork (Re-granulated cork production)				
Input	Raw material	Cork scraps	kg	2,94E-01
Output	Product	Re-granulated cork	kg	2,64E-01
	By-product	Reused cork waste?	kg	2,89E-02
Stage 4 - Agglomeration				
Input	Raw material	Re-granulated cork	kg	2,64E-01
	Raw material	Cork granulate (ACF)	kg	1,76E-01
Output	Product	Agglomerated cork layers	kg	5,15E-01
Stage 5 - Transformation and packaging				
Input	Raw material	Agglomerated cork layers	kg	5,15E-01
Output	Product	Underlay Nature 8210 (packed)	kg	5,20E-01
	By-product	Cork Trim	kg	1,47E-02

Underlay Nature 8210 - Industrial processes data:

Table 16 - Stage 2 – Cork granulate production (ACF)

Flow type	Flow	Unit	Value per FU
Input			
Energy	Electricity	kWh	8,56E-02
Input			
Air emissions	Particulates	kg	2,63E-08
	VOC, volatile organic compounds	kg	5,61E-09
Waste	Industrial waste to landfill	kg	8,05E-03

Table 17 - Stage 3 – Grinding Cork (Re-granulated cork production)

Flow type	Flow	Unit	Value per FU
Input			
Auxiliary materials	Compressed air	kWh	5,04E-04
Energy	Electricity	kWh	8,40E-03
Output			
Air emissions	Carbon monoxide	kg	3,78E-03
	Particulates	kg	6,64E-03
	Nitrogen dioxide	kg	7,42E-03
	VOC, volatile organic compounds	kg	4,20E-03
Waste	Industrial waste to landfill	kg	4,44E-04

Table 18 - Stage 4 – Agglomeration

Flow type	Flow	Unit	Value per FU
Input			
Chemical products	Polyurethane (PU) binder	kg	6,18E-02
Water	Water	L	1,29E-02
Energy	Electricity	kWh	1,93E-01
	Biomass	GJ	1,04E-03

Table 19 - Stage 5 – Transformation and packaging

Flow type	Flow	Unit	Value per FU
Input			
Energy	Electricity	kWh	2,55E-03
Packaging materials	Polypropylene, granulate	kg	1,70E-03
	Kraft paper	kg	1,30E-03
	EUR-flat pallet	kg	1,43E-02
	Packaging film	kg	2,00E-03
	Cardboard	kg	1,00E-04
Input			
Air emissions	Particulates	kg	1,84E-04
Waste	Recyclable waste	kg	1,00E-04

Underlay Nature 8210 - Transport data:

Transport of raw material

Table 20 - Transportation of raw material data

Flow	Flow type	Origin	Destination	Unit	Distance
Raw cork	Raw material	Amorim Florestal	Amorim Cork Flooring	km	253
Cork scrap	Raw material	Amorim Cork	Amorim Cork Composites	km	2
Cork granulate (ACF)	Raw material	ACF-Lourosa	Amorim Cork Composites	km	6

Table 21 - Transportation of raw material per type of transport used

Flow	Flow type	Type of transport	Unit	Value per FU
Raw cork	Raw material	Transport, freight, lorry 7.5-16 metric ton, euro4	tkm	8,19E-02
Cork scrap	Raw material	Transport, freight, lorry 16-32 metric ton, euro4	tkm	5,22E-04
Cork granulate (ACF)	Raw material	Transport, freight, lorry 3,5-7.5 metric ton, euro4	tkm	1,06E-03

Transport of chemical products, packaging materials and waste

Table 22 - Transport of chemical products, packaging materials and waste data and type of transport

Flow type	Transport	unit	Value per FU
Stage 2 – Cork granulate production (ACF)			
Waste	Transport, freight, lorry 16-32 metric ton, euro4	tkm	2,01E-04
Stage 3 – Grinding Cork (Re-granulated cork production)			
Waste	Transport, freight, lorry 16-32 metric ton, euro4	tkm	5,51E-06
Stage 4 – Agglomeration			
Chemical products	Transport, freight, lorry 16-32 metric ton, euro4	tkm	5,27E-03
Stage 5 – Transformation and packaging			
Packaging materials	Transport, freight, lorry 16-32 metric ton, euro4	tkm	6,40E-04
Packaging materials	Transport, freight, lorry 3,5-7.5 metric ton, euro4	tkm	1,44E-03
Waste	Transport, freight, lorry 16-32 metric ton, euro4	tkm	1,24E-06

4. Results

The studied system was modelled providing information for environmental impacts per stage considered. This section presents an overall view of the impacts for the following categories, as described in section 2.5:

- Climate Change (CC)
- Ozone Depletion (OD)
- Human Toxicity: Cancer Effects (HTC)
- Human Toxicity: Non-Cancer Effects (HTCN)
- Photochemical Ozone Formation (POF)
- Acidification (A)
- Terrestrial Eutrophication (TEu)
- Freshwater Eutrophication (FEu)
- Marine Eutrophication (ME)
- Freshwater Ecotoxicity (FEc)
- Mineral and Fossil Resource Depletion (MFRD)
- Water use (WU)
- Cumulative Energy Demand - Total (CEDt)

The results section is subdivided in:

- General results - where the impacts of the main studied system are analyzed under the mass allocation approach, providing an overall view of the relative impacts per stage considered in each environmental impact category.

- A more detailed analysis is performed for the climate change impacts as well as for cumulative energy consumption impacts.

4.1 General results

4.1.1 Environmental impacts per stage

The life cycle assessments of Underlay 5156 VB and Underlay Nature 8210 are shown in Table 23 and Table 24. It was observed that the stages which carry the highest environmental loads depend on the category being assessed.

Table 23 - Overall results of the analysis and results per stage of Underlay 5156 VB

Impact category	Unit*	Stored carbon (cork)	Stored carbon (packaging)	Forest management	Grinding White EVA MD	Grinding Colored EVA MD	Cork granulatep roduction (ACF)	Agglomeration	Transformation and Packaging	Total Cradle-to-gate
CC	kg CO_2 eq	-1,66E-01	-7,10E-02	1,33E-03	6,82E-02	1,82E-01	9,54E-03	3,96E-01	2,23E-01	6,44E-01
OD	kg CFC-11 eq			2,59E-10	1,01E-08	3,06E-08	1,14E-09	8,96E-09	6,86E-09	5,79E-08
HNTC	CTUh			3,79E-11	8,68E-09	4,84E-08	2,37E-09	4,54E-08	2,86E-08	1,34E-07
HTC	CTUh			3,85E-11	2,27E-09	8,45E-09	4,28E-10	2,98E-08	1,22E-08	5,32E-08
POF	kg NMVOC eq			4,82E-05	8,66E-04	8,79E-04	4,22E-05	1,29E-03	8,50E-04	3,97E-03
A	molc H+ eq			1,13E-05	1,43E-03	9,21E-04	6,71E-05	1,94E-03	1,00E-03	5,37E-03
TEu	molc N eq			4,94E-05	3,14E-03	3,00E-03	1,54E-04	3,84E-03	2,17E-03	1,24E-02
FEu	kg P eq			7,94E-08	1,18E-05	2,30E-05	2,43E-06	7,38E-05	3,00E-05	1,41E-04
ME	kg N eq			5,03E-06	2,83E-04	2,75E-04	1,42E-05	4,75E-04	2,38E-04	1,29E-03
FEc	CTUe			2,73E-03	2,40E-01	1,20E+00	6,81E-02	1,96E+00	9,81E-01	4,45E+00
MFRD	kg Sb eq			2,60E-08	1,32E-06	2,17E-05	5,28E-07	2,95E-06	5,27E-06	3,18E-05
WU	m^3			3,08E-04	1,06E-02	2,00E-02	3,04E-03	4,52E-01	1,30E-01	6,16E-01
CEDt	MJ			2,34E-02	1,06E+00	2,80E+00	1,69E-01	9,91E+00	6,45E+00	2,04E+01

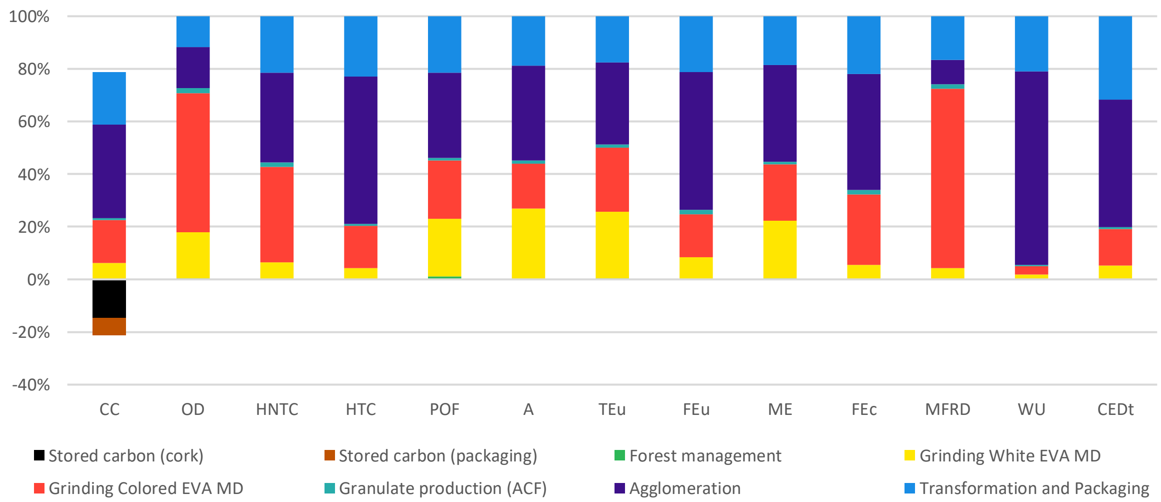


Figure 4 - Results per stage for selected impact categories for Underlay 5156 VB

Table 23 and Figure 4 show that forest management and granulate production (ACF) have a very low impact in the overall impacts considered. In contrast, Underlay 5156 VB agglomeration and grinding colored EVA stages show the highest level of potential impacts in the studied system. These stages include the main transformation and transport activities. The use of polyurethane binders and a polyethylene film layer in the agglomeration and transformation and packaging processes are the main contributor for the observed potential impacts. The impacts stemming from the transport of raw materials, namely the transport of colored EVA, are also especially relevant in the grinding white EVA and grinding colored EVA stages.

Table 24 - Overall results of the analysis and results per stage of Underlay Nature 8210

Impact category	Unit*	Stored carbon (cork)	Stored carbon (packaging)	Forest management	Cork granulate production (ACF)	Grinding Cork	Agglomeration	Transformation and packaging	Total Cradle-to-gate
CC	kg CO_2 eq	-3,30E-01	-3,40E-02	2,44E-03	1,74E-02	1,53E-03	2,77E-01	2,10E-02	-4,52E-02
OD	kg CFC-11 eq			4,74E-10	2,09E-09	7,90E-11	6,69E-09	9,44E-10	1,03E-08
HNTC	CTUh			6,92E-11	4,34E-09	3,93E-10	3,50E-08	4,27E-09	4,41E-08
HTC	CTUh			7,04E-11	7,83E-10	8,24E-11	2,03E-08	1,03E-09	2,23E-08
POF	kg NMVOC eq			8,81E-05	7,72E-05	1,16E-03	9,11E-04	8,14E-05	2,32E-03
A	molc H+ eq			2,06E-05	1,23E-04	2,74E-04	1,46E-03	8,82E-05	1,97E-03
TEu	molc N eq			9,03E-05	2,81E-04	4,17E-03	2,78E-03	2,11E-04	7,53E-03
FEu	kg P eq			1,45E-07	4,43E-06	6,68E-07	5,78E-05	3,63E-06	6,66E-05
ME	kg N eq			9,20E-06	2,60E-05	2,09E-06	3,35E-04	1,97E-05	3,92E-04
FEc	CTUe			4,99E-03	1,25E-01	1,33E-02	1,46E+00	9,07E-02	1,69E+00
MFRD	kg Sb eq			4,75E-08	9,65E-07	2,11E-08	2,13E-06	7,08E-07	3,87E-06
WU	m^3			5,62E-04	5,56E-03	8,97E-04	3,04E-01	8,67E-03	3,20E-01
CEDt	MJ			4,27E-02	3,09E-01	3,12E-02	7,25E+00	8,05E-01	8,43E+00

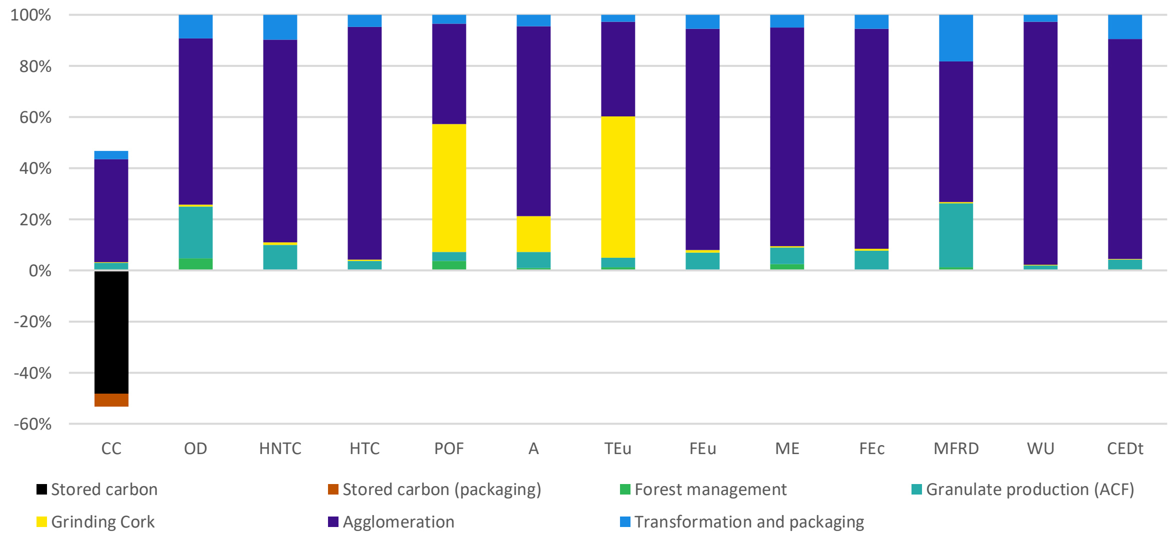


Figure 5 - Results per stage for selected impact categories for Underlay Nature 8210

Table 24 and Figure 5 show that forest management, granulate production (ACF), grinding cork and transformation and packaging stages have a very low impact in the overall impacts considered. In contrast, Underlay Nature 81210 agglomeration stage shows the highest level of potential impacts in the studied system. This stage includes the main production activities, such as agglomeration of the main underlay components. The use of polyurethane binders for the agglomeration process is the main contributor for the observed potential impacts. The impacts stemming from energy consumption, namely electricity, are also especially relevant in the grinding stages.

Carbon footprint

Table 23 and Figure 6 show the carbon footprint results for Underlay 5156 VB production. As observed, the carbon stored in the product represents -0,17 $kgCO_{2eq}$ per $1m^2$ of Underlay 5156 VB, from cork composition, and -0,07 $kgCO_{2eq}$ per $1m^2$ of Underlay 5156 VB, from the packaging materials, with the overall impacts of the transformation stages representing a total sum of 0,88 $kgCO_{2eq}$ per $1m^2$ of Underlay 5156 VB. As a result, the carbon footprint has a total value of +0,64 $kgCO_{2eq}$ per $1m^2$ of Underlay 5156 VB packed under a cradle to gate approach. As so, considering a cradle-to-gate approach, the stored carbon per $1m^2$ of Underlay 5156 VB is lower than potential climate impacts of the assessed industrial stages.

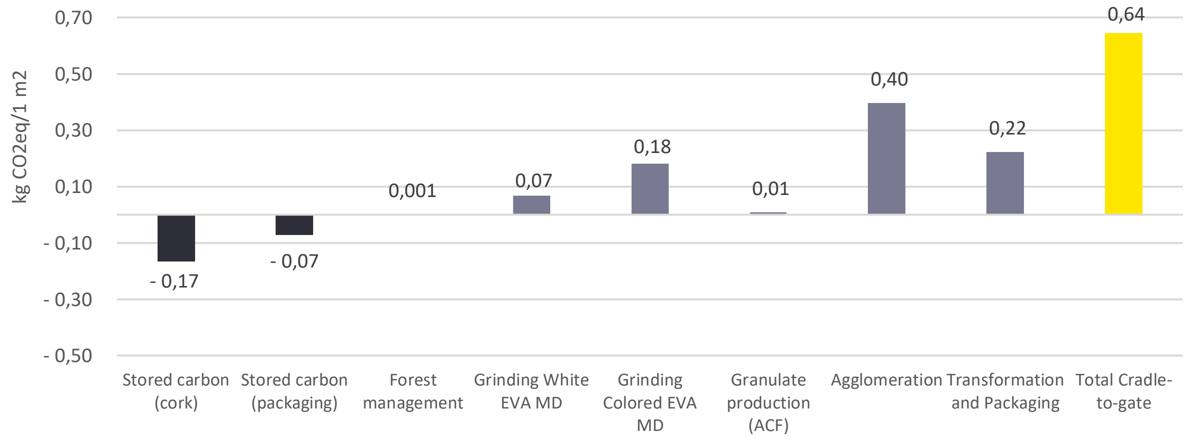


Figure 6 - Carbon footprint of Underlay 5156 VB per stage

Table 24 and Figure 7 shows the carbon footprint results for Underlay Nature 8210 production. As observed, the carbon stored in the product represents -0,33 $kgCO_{2eq}$ per $1m^2$ of Underlay Nature 8210, from cork composition, and -0,03 $kgCO_{2eq}$ per $1m^2$ of Underlay Nature 8210, from the packaging materials, with the overall impacts of the transformation stages representing a total sum of 0,32 $kgCO_{2eq}$ per $1m^2$ of Underlay Nature 8210. As a result, the carbon footprint has a total value of -0,05 $kgCO_{2eq}$ per $1m^2$ of Underlay Nature 8210 packed under a cradle to gate approach. As so, considering a cradle-to-gate approach, the stored carbon per $1m^2$ of Underlay Nature 8210 is higher than potential climate impacts of the assessed industrial stages.

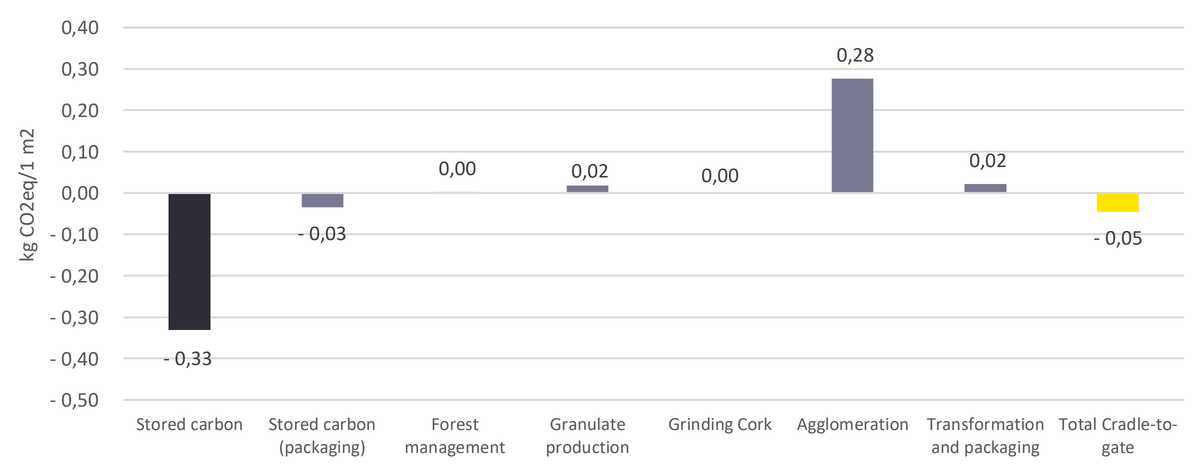


Figure 7 - Carbon footprint of Underlay Nature 8210 per stage

Results by emission source

The results per flow provide a detailed analysis of the GHG emissions of each emission source for the carbon footprint analysis. This analysis assists in detecting and quantifying impact hotspots for Underlays 5156 VB and Nature 8210's manufacturing processess, contributing to the objective of providing data to Amorim Cork Composites to understand and manage the potential environmental impacts of its products.

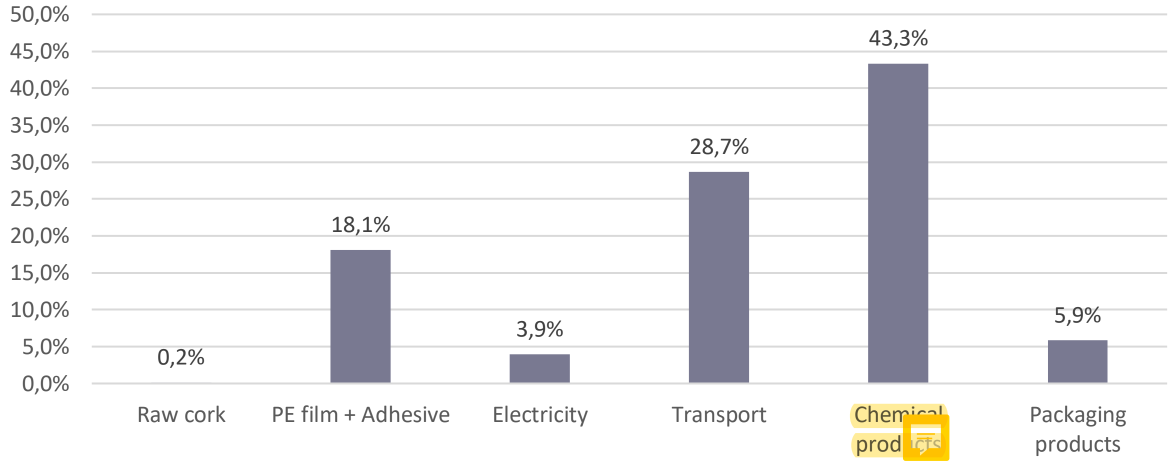


Figure 8 – Key emission sources of Underlay 5156 VB per emission source

As illustrated by Figure 8, the most relevant flows for the generation of GHG emissions in Underlay 5156 VB's life cycle system are the use of chemical products, mainly polyurethane binders, the transport of raw materials, mainly the transport of colored EVA, and the use of polyethylene film and polyurethane glue, in the transformation and packaging stages. Together, these three flows account for more than 90% of the impact.

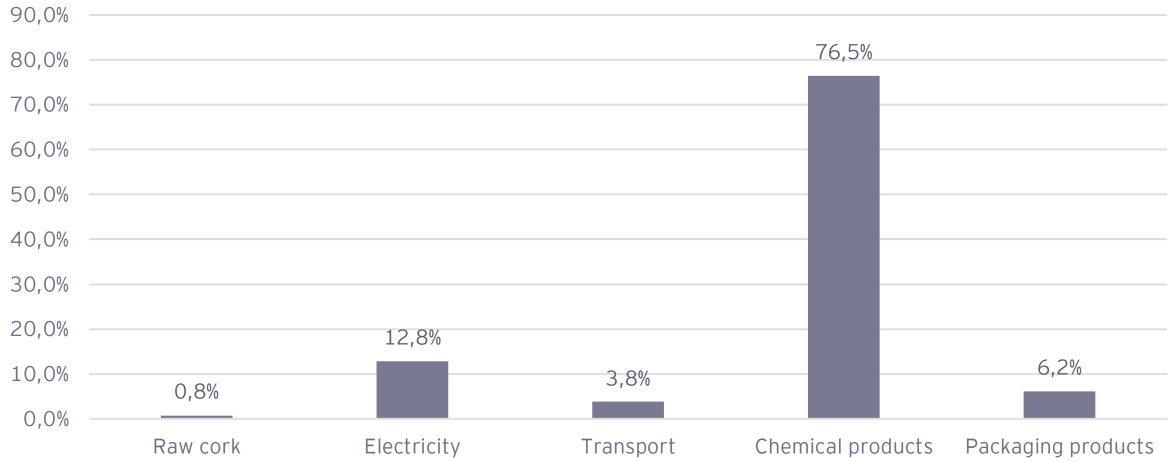


Figure 9 - Key emission sources of Underlay Nature 8210 per emission source

As illustrated by Figure 9, the most relevant emission source for the generation of GHG emissions in Underlay Nature 8210's life cycle system is the use of chemical products, mainly polyurethane binders, comprising 77% of the impact. Consumption of electricity also has some relevance to the overall carbon footprint result, representing 13% of the total GHG emissions.

4.1.2 Cumulative Energy Consumption per stage and Source of Energy

Table 25 - Energy consumption of Underlay 5156 VB per stage and energy source

Source	Total	Forest management	Grinding White EVA MD	Grinding Colored EVA MD	Cork granulate production (ACF)	Agglomeration	Transformation and Packaging	Unit
Non-renewable, fossil	15,9	0,0	0,9	2,6	0,1	7,3	4,9	MJ
Non-renewable, nuclear	1,8	0,0	0,0	0,1	0,0	1,1	0,6	MJ
Non-renewable, biomass	0,0	0,0	0,0	0,0	0,0	0,0	0,0	MJ
Renewable, biomass	2,3	0,0	0,0	0,0	0,0	1,3	0,9	MJ
Renewable, wind, solar, geothe	0,1	0,0	0,0	0,0	0,0	0,0	0,0	MJ
Renewable, water	0,3	0,0	0,0	0,1	0,0	0,1	0,1	MJ
Renewable, Total	2,7	0,0	0,1	0,1	0,0	1,5	1,0	MJ
Non-renewable, Total	17,7	0,0	1,0	2,7	0,1	8,4	5,5	MJ
Total CED (MJ)	20,4	0,0	1,1	2,8	0,2	9,9	6,5	MJ

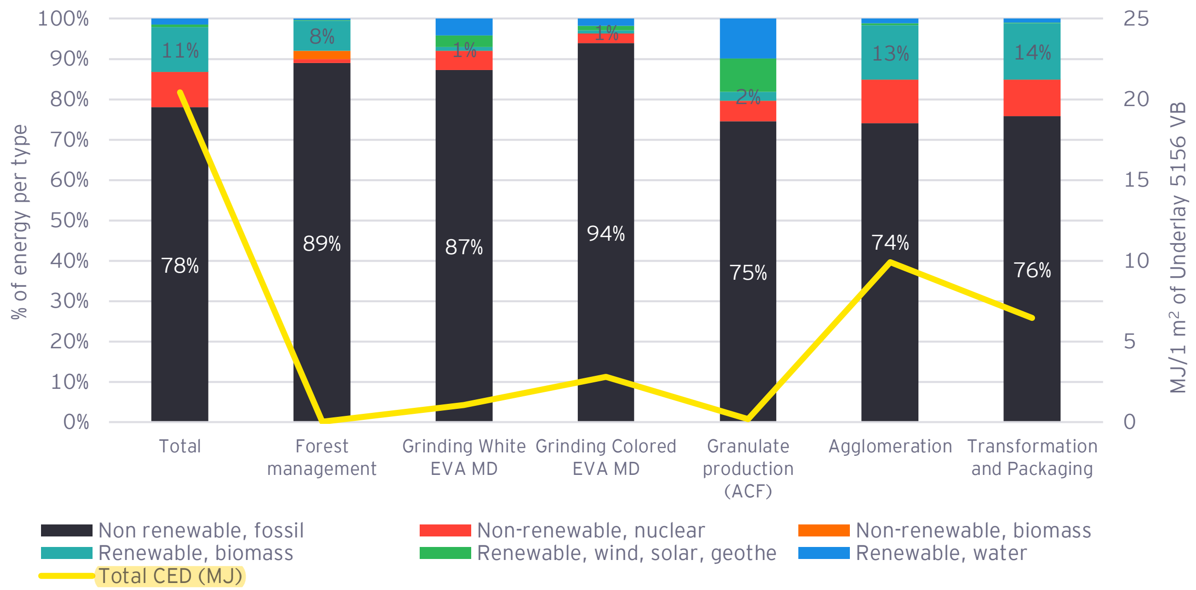


Figure 10 - Distribution of energy consumption of Underlay 5156 VB per stage and energy source

As observed in Table 25 and Figure 10, non-renewable energy is the most relevant source in overall cradle-to-gate scope with 87% of total cumulative energy consumption. Nonetheless, non-renewable sources of energy dominate cumulative energy consumption in all six processes considered. In two most energy-intensive processes, agglomeration and transformation and packing, 85% of the energy impacts are attributed to non-renewable sources, mostly due to the use of materials with high cumulative energy intensity, such as polyurethane binders, in both processes, and polyethylene film layer, in the transformation and packing stage.

Table 26 – Energy consumption of Underlay Nature 8210 per stage and energy source

Source	Total	Forest management	Cork granulate production (ACF)	Grinding Cork	Agglomeration	Transformation and Packaging	Unit
Non-renewable, fossil	5,6	0,0	0,2	0,0	5,0	0,4	MJ
Non-renewable, nuclear	0,8	0,0	0,0	0,0	0,7	0,0	MJ
Non-renewable, biomass	0,0	0,0	0,0	0,0	0,0	0,0	MJ
Renewable, biomass	1,7	0,0	0,0	0,0	1,3	0,4	MJ
Renewable, wind, solar, geothe	0,1	0,0	0,0	0,0	0,1	0,0	MJ
Renewable, water	0,2	0,0	0,0	0,0	0,2	0,0	MJ
Renewable, Total	2,0	0,0	0,1	0,0	1,6	0,4	MJ
Non-renewable, Total	6,4	0,0	0,2	0,0	5,7	0,4	MJ
Total CED (MJ)	8,4	0,0	0,3	0,0	7,2	0,8	MJ

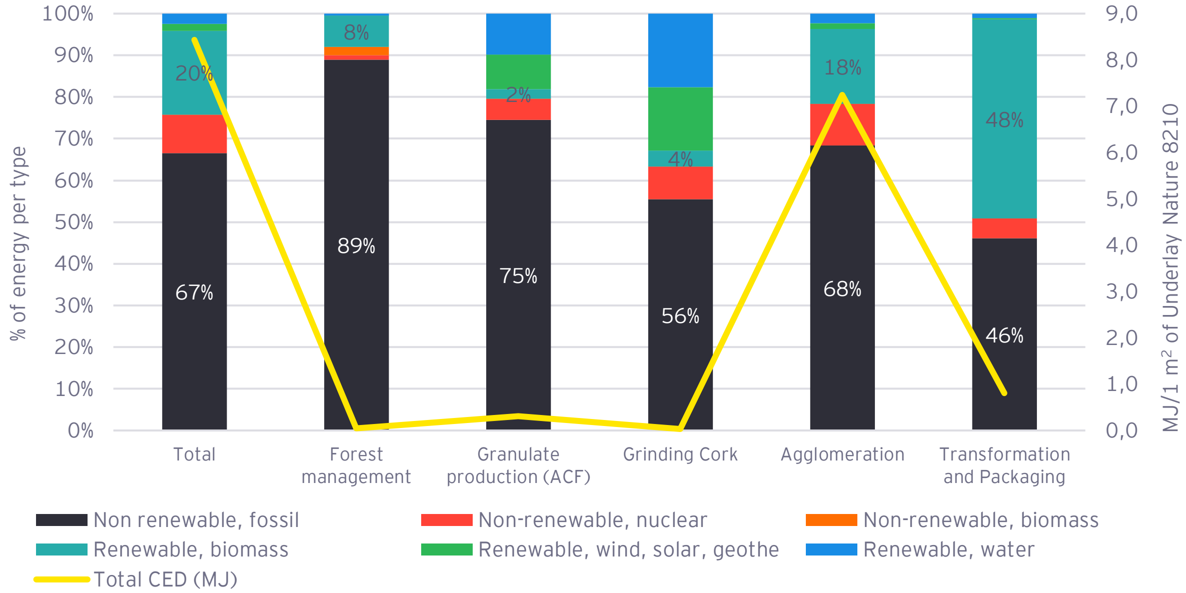


Figure 11 - Distribution of energy consumption of Underlay Nature 8210 per stage and energy source

As observed in Table 26 and Figure 11, non-renewable energy is the most relevant source in overall cradle-to-gate scope with 76% of total cumulative energy consumption. Nonetheless, non-renewable sources of energy dominate cumulative energy consumption in all five processes considered. In the most energy-intensive process, agglomeration, 78% of the energy impacts are attributed to non-renewable sources, mostly due to the use of materials with high cumulative energy intensity, such as the polyurethane binders, used in the agglomeration stage.

5. Scenario analysis for carbon sequestration of the cork oak forest

In past studies, the assumption that carbon sequestration of the cork oak forest can indirectly be attributed to cork products was simulated, as the cork transformation industry contribute to the exploitation and maintenance of the cork oak forest. This link is explored by a means of a scenario analysis of how much carbon retention by forest can be linked to an amount of cork produced PwC/Ecobilan 2008; Rives et al., 2013, EY, 2019a,b).

Since 2018, the Product Environmental Category Rules (PEFCR) for still and sparkling wine, published by the European Commission (EC), states that carbon stored by cork oak trees could be included in environmental footprints as additional environmental information, if carbon storage goes beyond 100 years, which is the case for cork. The PEFCR are applicable to wine companies that aim to conduct a Product Environmental Footprint (PEF) to a functional unit of "0,75 liters wine".

In this scenario analysis, the GHG emissions of the studied cradle-to-gate system are compared to the carbon uptake by the cork oak forest, considering the cork weight in the functional unit. The resulted carbon balance is here presented as additional environmental information, as should not be confused with the carbon footprint analysis, where GHG emissions and biogenic stored carbon by cork are addressed. Carbon stored in the product was excluded for this scenario to avoid double counting. Allocation of CO_2 uptake to the cork extracted from the cork oak stands follows the same premises of allocating environmental impacts in Dias et al. (2014a). Two perspectives were considered:

1. **Weight-based perspective:** All CO_2 uptake by the cork oak forest is allocated to extracted cork as cork production is the main economic activity of cork oak forest;

2. **Mass perspective:** CO_2 uptake by the cork oak forest is allocated to extracted cork considering the physical system of the cork oak stand (tree + cork), where, during the tree life cycle, cork mass represents about 31% of dry basis weight when compared to wood.

The analyzed scenarios consider carbon sequestration in well-managed cork oak forests, with a high tree coverage and good soil and climate conditions, with an average CO_2 uptake of 11 t CO_2/ha[5], reaching a maximum of 14,7 t CO_2/ha. Translating[6] these values in function of cork extraction, there is a CO_2 uptake of 55 t CO_2/t of cork extracted, reaching up to 73 t CO_2/t of cork extracted.

Taking into account both allocation perspectives, for Underlay 5156 VB:

- When considering the **weight-based perspective** of allocation procedure (1), a forest uptake of -4,8 kg CO_2/1 m^2, up to -6,4 kg CO_2/1 m^2, is attributed to the product and a carbon balance[7] of -4,0 kg CO_2/1 m^2, up to – 5,6 kg CO_2/1 m^2.

- When considering the **mass perspective** (2), there is a lower forest uptake attributed to the product of -1,5 kg CO_2/1 m^2, up to -2,0 kg CO_2/1 m^2, and a carbon balance of -0,7 kg CO_2/1 m^2, up to – 1,2 kg CO_2/1 m^2, as a lower fraction of CO_2 uptake is allocated to the extracted cork.

[5] Figures considered in the "The value of cork oak montado ecosystem services" (EY, 2019c). Average ecosystem CO_2 uptake (11 t CO_2/ha) considers wet and dry years in well managed forests, with a maximum of 14,7 t CO_2/ha registered in optimal climatic conditions (Costa-e-Silva et al., 2015).

[6] Conversion of forest ecosystem uptake per tonne of extracted cork considers the total cork oak occupation area in Portugal (719 937 ha) (ICNF, 2019) and an average value of cork production (145 000 t cork) based on a nine-year series (2003-2011) (APCOR, 2011).

[7] Considering 0,8 kg CO_{2eq}/1 m^2 of Underlay 5156 VB emitted during the production of Underlay 5156 VB.

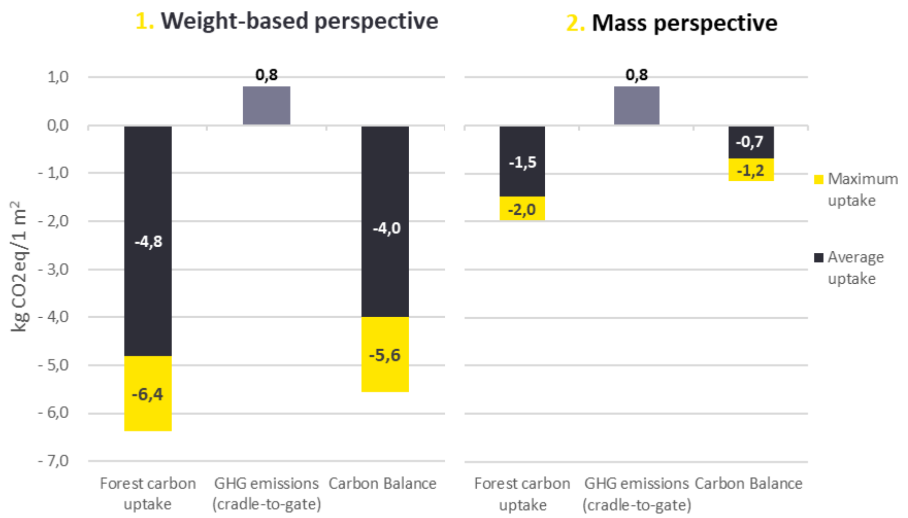


Figure 12 - Forest carbon uptake and carbon balance with product GHG emissions for Underlay 5156 VB

Taking into account both allocation perspectives, for Underlay Nature 8210:

- When considering the **weight-based perspective** of allocation procedure (1), a forest uptake of -9,6 kg CO_2/1 m^2, up to -12,7 kg CO_2/1 m^2, is attributed to the product and a carbon balance[8] of -9,3 kg kg CO_2/1 m^2, up to –12,4 kg kg CO_2/1 m^2.
- When considering the **mass perspective** (2), there is a lower forest uptake attributed to the product of -3,0 kg CO_2/1 m^2, up to -3,9 kg kg CO_2/1 m^2, and a carbon balance of -2,7 kg CO_2/1 m^2, up to – 3,7 kg CO_2/1 m^2, as a lower fraction of CO_2 uptake is allocated to the extracted cork.

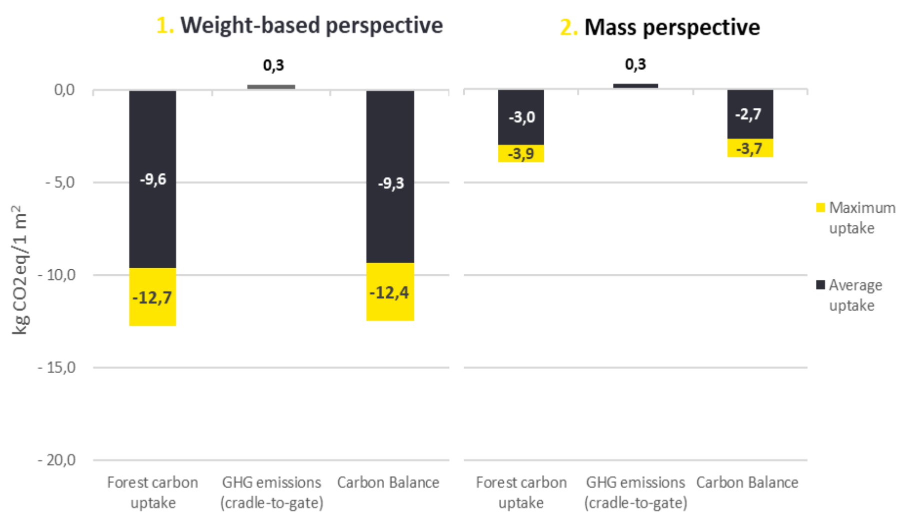


Figure 13 - Forest carbon uptake and carbon balance with product GHG emissions for Underlay Nature 8210

These results (Figure 12 and 13) illustrate the differentiating factor between cork and other forest-based products. As the cork oak tree retains carbon for over 100 years, regardless of cork harvesting (Bugalho et al., 2011), cork exploitation supports the maintenance of the ecosystem, thus having a positive contribution to global climate regulation. As stated above, it is important to note that this result should solely be considered as an additional environmental information to the carbon footprint presented in this study.

[8] Considering 0,3 kg CO_{2eq}/1 m^2 of Underlay Nature 8210 emitted during the production of Underlay Nature 8210.

6. Conclusions

In this assessment the different stages of Underlay 5156 VB and Underlay Nature 8210 production systems were studied. Main results (Tables 23 and Figure 4) show that overall the highest environmental impacts of Underlay 5156 VB VB are associated with the processes where the use of chemical products is higher and where the long distance transport of raw materials from suppliers take place, as a result, the impact of grinding colored EVA and agglomeration stages across all LCA impact categories is significant.

Main results (Table 24 and Figure 5) show that overall the highest environmental impacts are associated with the processes where the use of chemical products and energy consumption is higher, as a result, the impact of Underlay Nature 8210 agglomeration process all LCA impact categories is significant. To lower the impact from these activities, more efficient and less environmental harmful options should be studied when selecting materials to be included in the process. Renewable energy generation and energy efficiency measures can also be studied and implemented. These actions could substantially improve overall performance of the studied system.

Through the analysis of each stage in detail, for both products, it was possible to observe the relative contribution of each type of flow in each stage. By using natural raw materials, such as cork and recycled materials such as EVA and cork waste, that would otherwise be disposed, Amorim Cork Composites is able to lower the potential environmental impacts stemming from its product, opposed to a scenario where these main inputs would be sourced in the transformation industry, as they are the sole main components of the final product. Hence, here this recycled materials enter the system with no environmental burdens other than its transport to the industrial facilities. By putting the concepts of bio-based products and circular economy into practice, a reduction of expected potential impacts in the final product is observed.

For Underlay 5156 VB VB, total emissions account for an overall climate change impact of 0,9 kg CO_{2eq} per 1 m^2. Considering the carbon stored in the cork and packaging materials used to produce Underlay 5156 VB VB (0,2 $kgCO_2$/ 1 m^2), the carbon footprint of the product is +0,6 $kgCO_{2eq}$ per 1 m^2, under a cradle-to-gate approach. For Underlay Nature 8210, total emissions account for an overall climate change impact of 0,32 kg CO_{2e}q per 1 m^2. Considering the carbon stored in the cork and packaging materials used to produce Underlay Nature 8210 (0,36 $kgCO_2$/ 1 m2), the carbon footprint of the product is -0,05 kgCO2eq per 1 m^2, under a cradle-to-gate approach.

Considering a scenario analysis in Underlay 5156 VB VB, where the carbon sequestration of the cork oak forest can indirectly be attributed to cork products, based on well-managed cork oak forests, a forest carbon uptake up to -6,4 kg CO_2 per 1 m2 can be observed. Considering both the forest carbon uptake and the GHG emissions of maximum weight Underlay 5156 VB VB production (0,8 $kgCO_2$/ 1 m2), there is a carbon balance up to -5,6 kg CO_{2eq} per 1 m^2. In Underlay Nature 8210, a forest carbon uptake up to -12,7 kg CO_2 per 1 m^2 can be observed. Considering both the forest carbon uptake and the GHG emissions of maximum weight Underlay Nature 8210 production (0,3 $kgCO_2$/ 1 m^2), there is a carbon balance up to -12,4 kg CO_{2eq} per 1 m^2. This balance illustrates the differentiating factor between cork and other products.

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Appendix A

The information contained in this appendix is confidential and property of EY. The total or partial reproduction of this appendix is limited to its use for evaluation as part of this document. Copies, whether total or partial, may not be provided to entities other than Amorim Cork Composites, without previous authorization from EY.

This appendix contains preliminary results, not verified by any third party. Benchmark analysis is based on publicly available data for standard market activities datasets, therefore the comparability is limited to the scope of each assessment. This exercise does not comply with ISO 14044 requirements for product comparison and should not be shared with any third party other than EY and Amorim Cork Composites.

Benchmark analysis

In this appendix, a comparison of Underlays 5156 VB and Nature 8210 environmental performance is made with two materials : polyurethane foam[9] and low density polyethylene[10]. This comparison uses standard market activities datasets, for each material, assuming the same product area and thickness (volume) as the products assessed. The materials density was provided by Amorim Cork Composites.

The assessed impacts are based on ecoinvent version 3.5 database (2018) and uses the impact categories were selected: Climate Change (CC), Ozone Depletion (OD), Human Toxicity: Cancer Effects (HTC), Human Toxicity: Non-Cancer Effects (HTCN), Photochemical Ozone Formation (POF), Acidification (A), Terrestrial Eutrophication (TEu), Freshwater Eutrophication (FEu), Marine Eutrophication (ME), Freshwater Ecotoxicity (FEc), and Mineral and Fossil Resource Depletion (MFRD).

Product comparison highlights

Underlay 5156 VB

- Has **up to 13 times** less environmental impacts than average polyurethane foam materials in typical impact categories and **up to to 7 times** less environmental impacts than average polyethylene materials in typical impact categories.
- Generates **over 11 times less** GHG emissions than average polyurethane foam materials and **almost 5 times less** GHG emissions than average low density polyethylene materials.
- Requires **almost 13 times less** water resources than average polyurethane foam materials and **2 times less** water resources than average low density polyethylene materials.
- Generates **over 3 times less** resource depletion than average polyurethane foam materials and **almost 2 times more** than average low density polyethylene materials.
- Consumes **over 8 times less** energy than average polyurethane foam materials, using **over 3 times more** renewable energy in the energy mix, and **over 6 times less** than average low density polyethylene materials, using **over 7 times more** renewable energy in the energy mix.

The Underlay 5156 VB was compared with two other products, the polyurethane foam and the polyethylene foam reticulated (low density), for each impact category considered. The following results consider the weight of **1 m^2 of product with 1,8 mm thickness**.

[9] The dataset used for polyurethane foam was "Polyurethane, flexible foam {RER}| market for polyurethane, flexible foam | APOS, U", ecoinvent v3.5 database.

[10] The dataset used for polyethylene materials was Polyethylene, low density, granulate {GLO}| market for | APOS, U", from ecoinvent v3.5 database.

Underlay Nature 8210

- Has **3 to 36 times less** environmental impacts than average polyurethane foam materials in typical impact categories and **up to 23 times less** environmental impacts than average polyethylene foam materials in typical impact categories.

- Generates **over 36 times less** GHG emissions than average polyurethane foam materials and **over 15 times less** GHG emissions than average polyethylene foam materials.

- Requires **almost 28 times less** water resources than average polyurethane foam materials and **over 4 times less** water resources than average polyethylene foam materials.

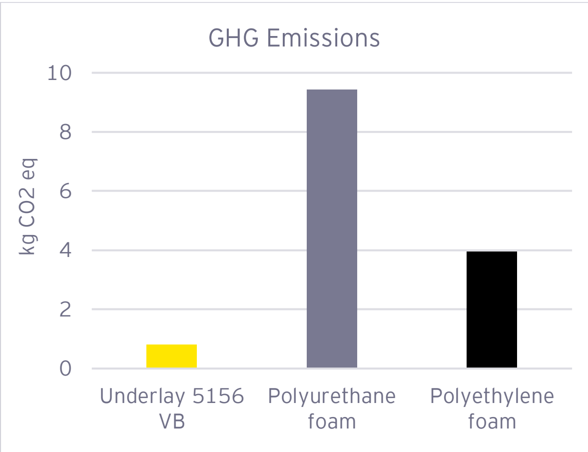
- Generates **over 32 times less** resource depletion than average polyurethane foam materials and **over 4 times less** than average polyethylene foam materials.

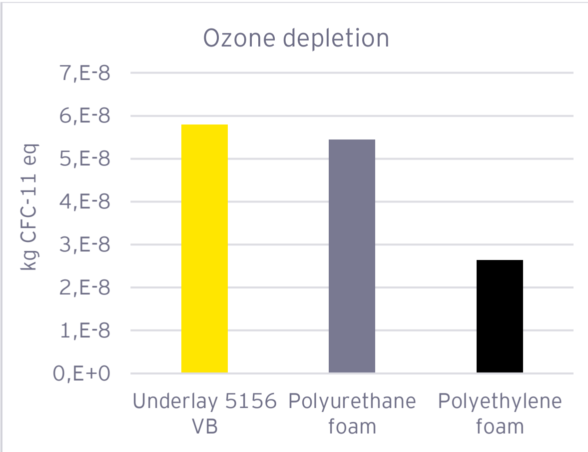
- Consumes **over 23 times less** energy than average polyurethane foam materials, using **6 times more** renewable energy in the energy mix, and **almost 18 times less energy** than average polyethylene foam materials, using **13 times more** renewable energy in the energy mix.

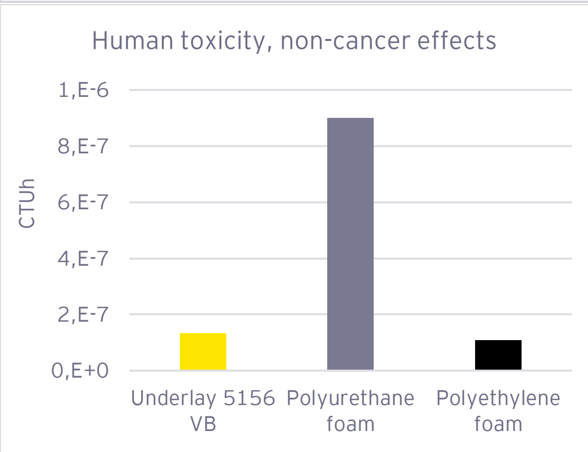
The Underlay Nature 8210 was compared with two other products, the polyurethane foam and the polyethylene foam reticulated (low density), for each impact category considered. The following results consider the weight of **1 m² of product with 2 mm thickness.**

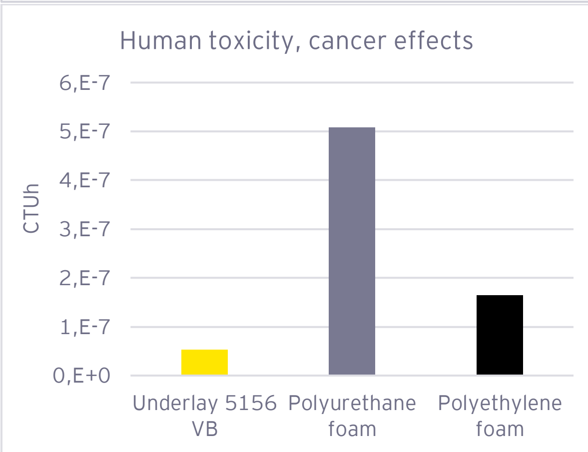
Product comparison results for each impact category

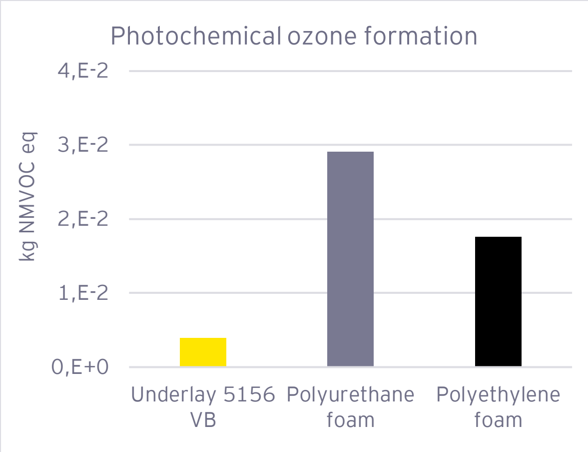
Underlay 5156 VB

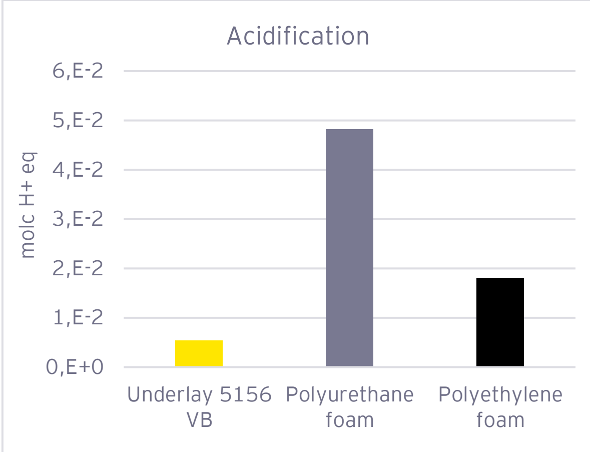


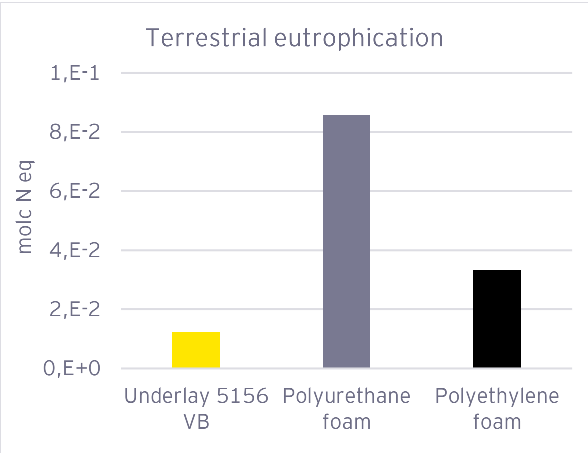


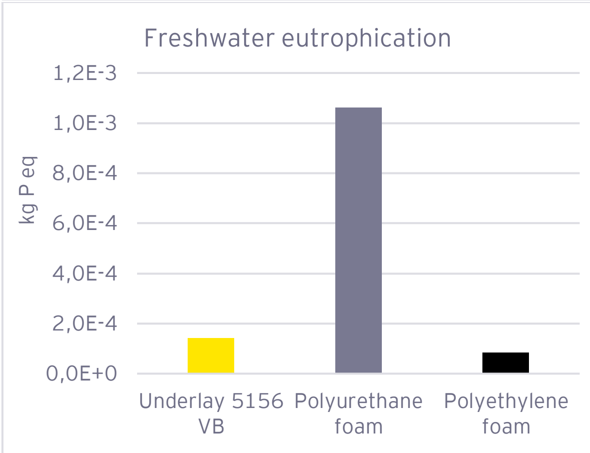


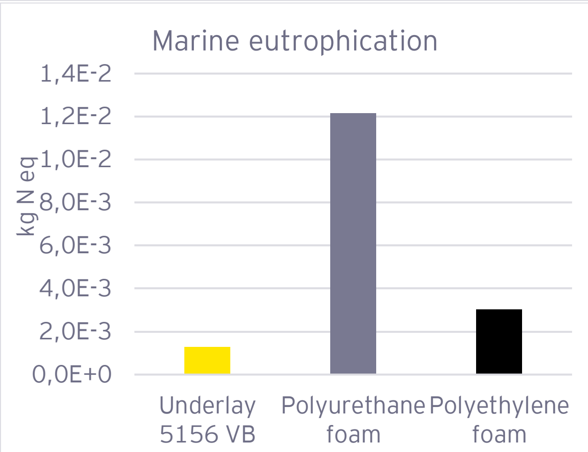


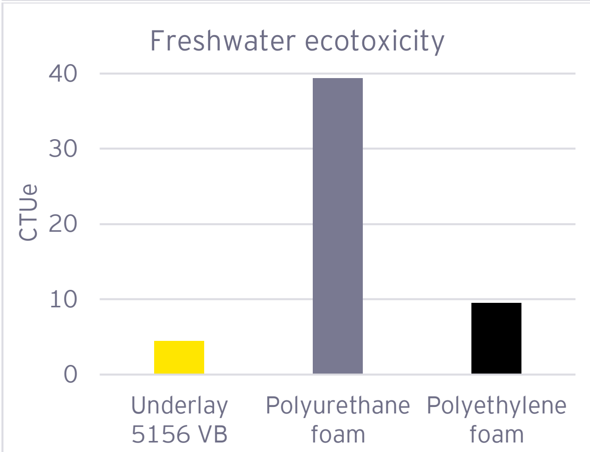

Photochemical ozone formation
kg NMVOC eq
4,E-2
3,E-2
2,E-2
1,E-2
0,E+0
Underlay 5156 VB
Polyurethane foam
Polyethylene foam

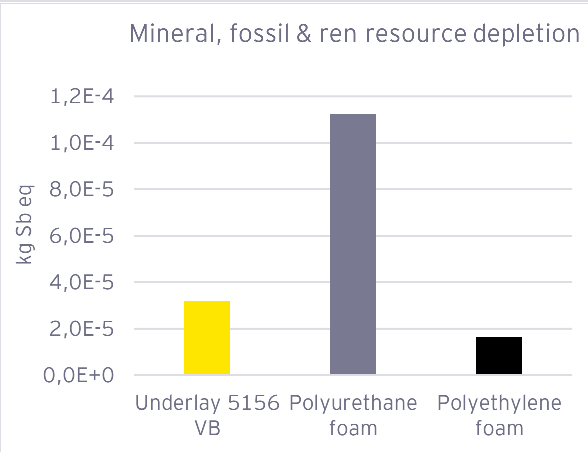

Acidification
molc H+ eq
6,E-2
5,E-2
4,E-2
3,E-2
2,E-2
1,E-2
0,E+0
Underlay 5156 VB
Polyurethane foam
Polyethylene foam

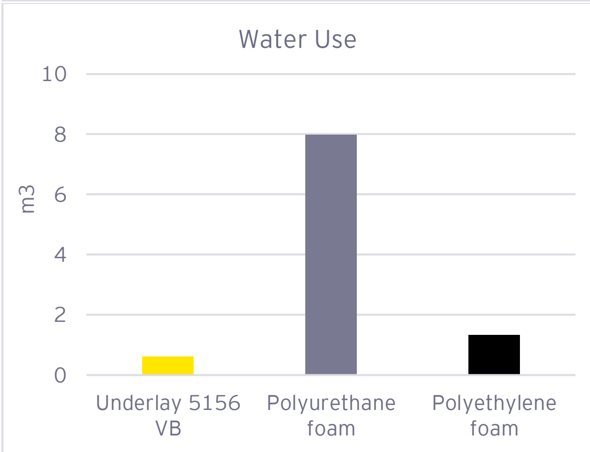

Terrestrial eutrophication
molc N eq
1,E-1
8,E-2
6,E-2
4,E-2
2,E-2
0,E+0
Underlay 5156 VB
Polyurethane foam
Polyethylene foam

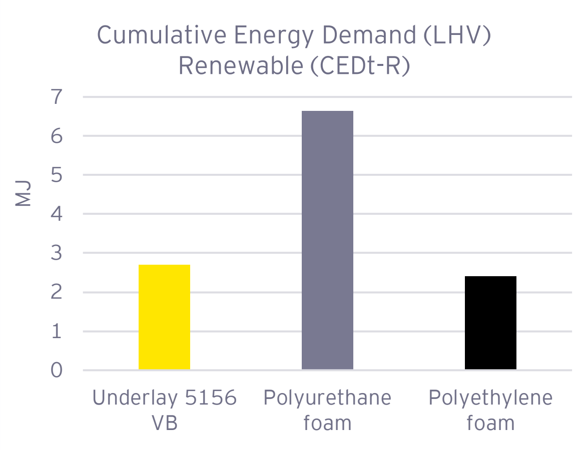

Freshwater eutrophication
kg P eq
1,2E-3
1,0E-3
8,0E-4
6,0E-4
4,0E-4
2,0E-4
0,0E+0
Underlay 5156 VB
Polyurethane foam
Polyethylene foam

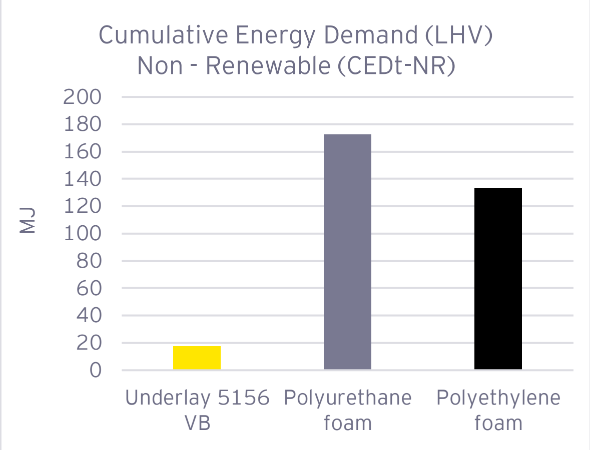

Marine eutrophication
kg N eq
1,4E-2
1,2E-2
1,0E-2
8,0E-3
6,0E-3
4,0E-3
2,0E-3
0,0E+0
Underlay 5156 VB
Polyurethane foam
Polyethylene foam

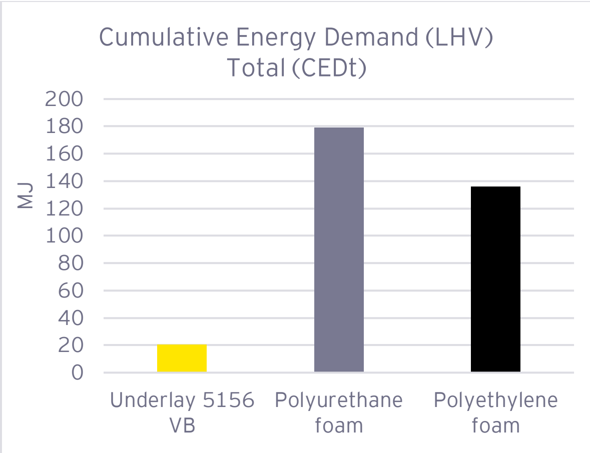

Freshwater ecotoxicity
CTUe
40
30
20
10
0
Underlay 5156 VB
Polyurethane foam
Polyethylene foam


Mineral, fossil & ren resource depletion
kg Sb eq
1,2E-4
1,0E-4
8,0E-5
6,0E-5
4,0E-5
2,0E-5
0,0E+0
Underlay 5156 VB
Polyurethane foam
Polyethylene foam

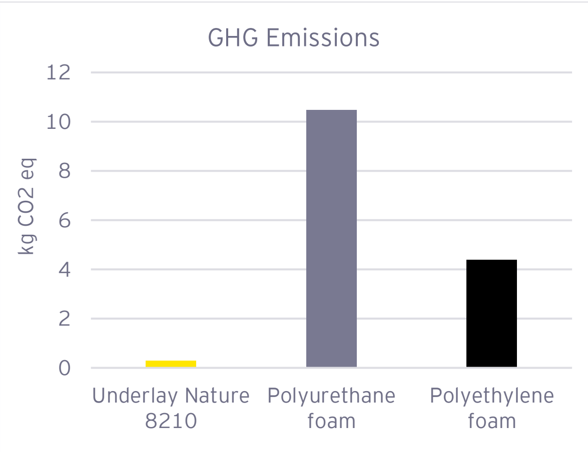

Water Use
m3
10
8
6
4
2
0
Underlay 5156 VB
Polyurethane foam
Polyethylene foam

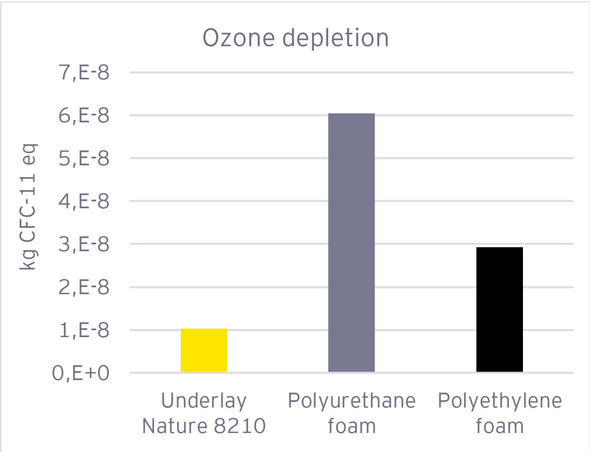


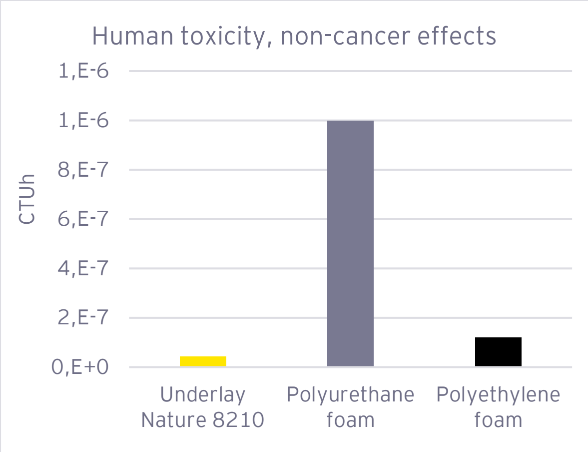


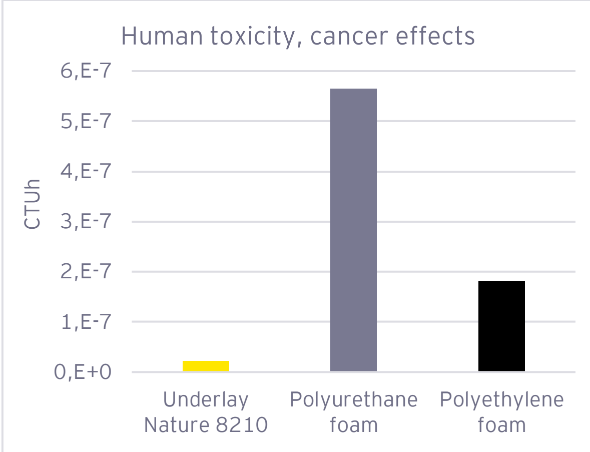


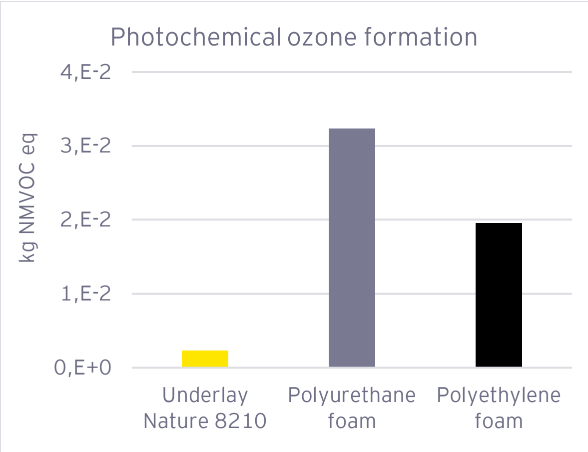
Underlay Nature 8210

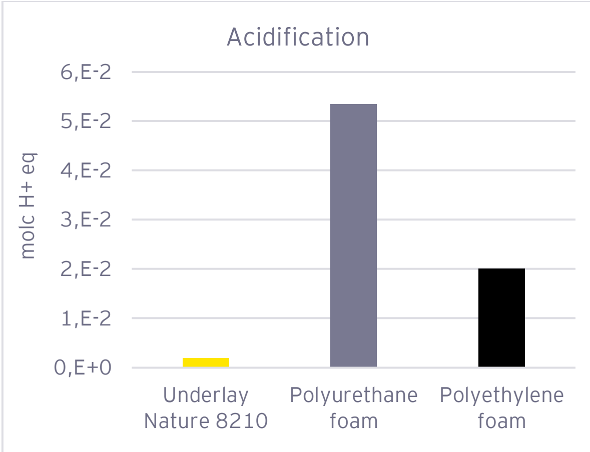


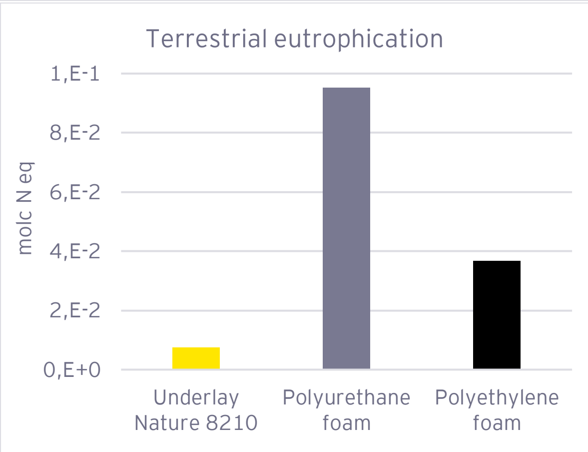


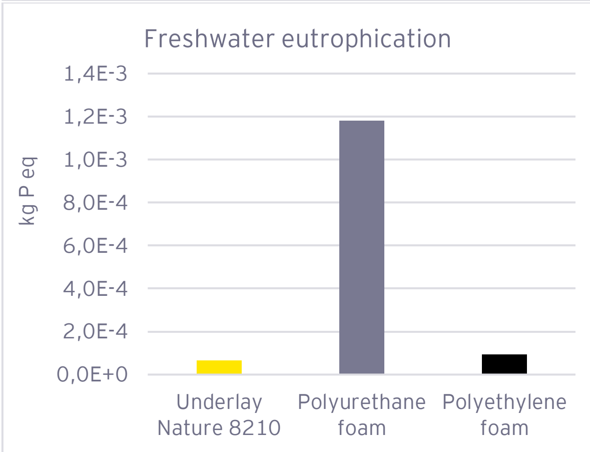

Human toxicity, non-cancer effects
CTUh
1,E-6
1,E-6
8,E-7
6,E-7
4,E-7
2,E-7
0,E+0
Underlay Nature 8210
Polyurethane foam
Polyethylene foam

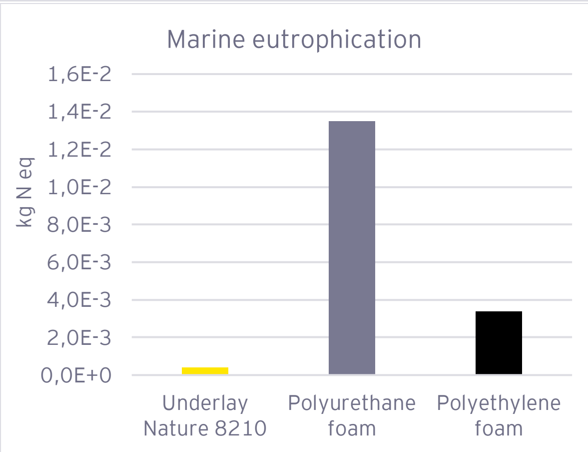

Human toxicity, cancer effects
CTUh
6,E-7
5,E-7
4,E-7
3,E-7
2,E-7
1,E-7
0,E+0
Underlay Nature 8210
Polyurethane foam
Polyethylene foam

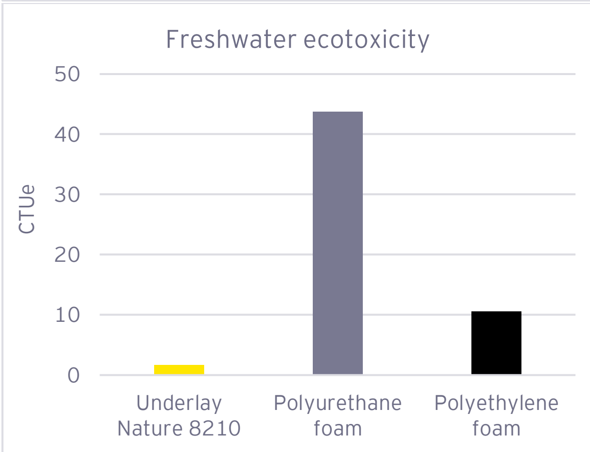

Photochemical ozone formation
kg NMVOC eq
4,E-2
3,E-2
2,E-2
1,E-2
0,E+0
Underlay Nature 8210
Polyurethane foam
Polyethylene foam

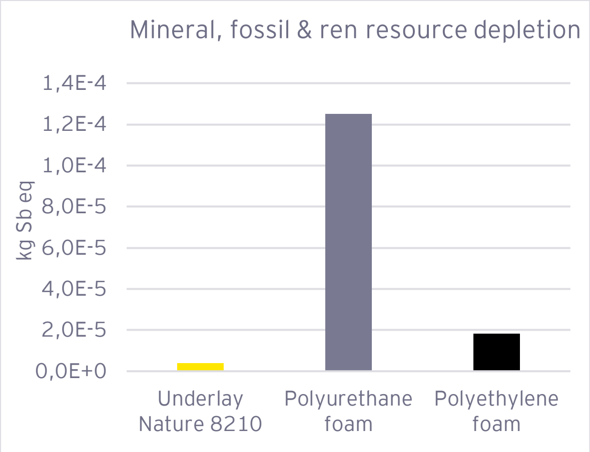

Acidification
molc H+ eq
6,E-2
5,E-2
4,E-2
3,E-2
2,E-2
1,E-2
0,E+0
Underlay Nature 8210
Polyurethane foam
Polyethylene foam

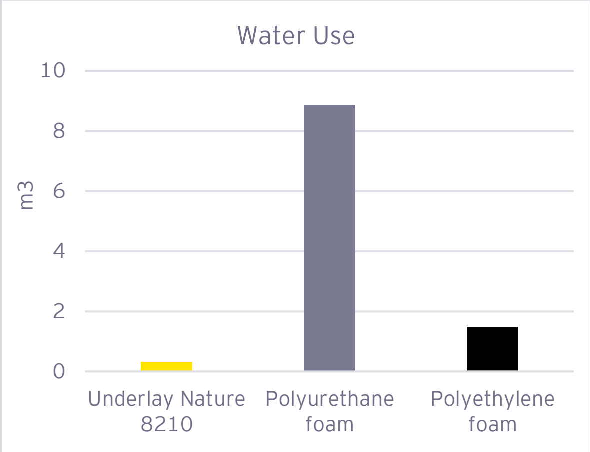

Terrestrial eutrophication
molc N eq
1,E-1
8,E-2
6,E-2
4,E-2
2,E-2
0,E+0
Underlay Nature 8210
Polyurethane foam
Polyethylene foam

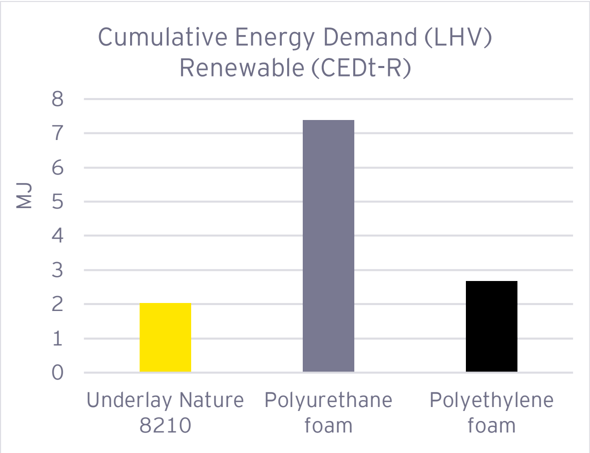

Freshwater eutrophication
kg P eq
1,4E-3
1,2E-3
1,0E-3
8,0E-4
6,0E-4
4,0E-4
2,0E-4
0,0E+0
Underlay Nature 8210
Polyurethane foam
Polyethylene foam

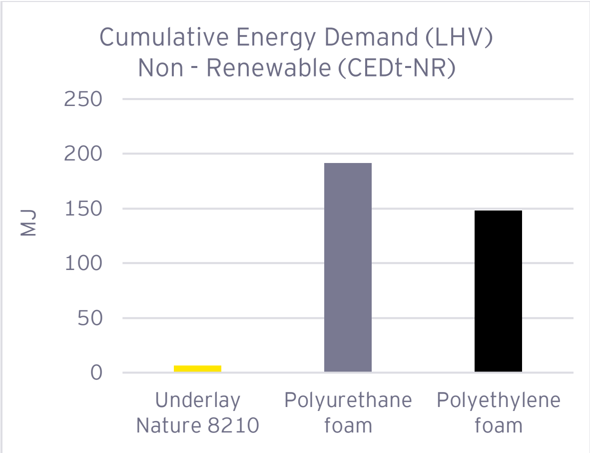

Marine eutrophication
kg N eq
1,6E-2
1,4E-2
1,2E-2
1,0E-2
8,0E-3
6,0E-3
4,0E-3
2,0E-3
0,0E+0
Underlay Nature 8210
Polyurethane foam
Polyethylene foam

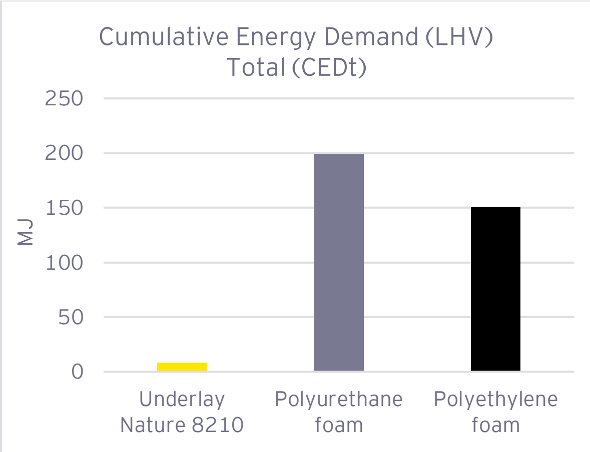

Freshwater ecotoxicity
CTUe
50
40
30
20
10
0
Underlay Nature 8210
Polyurethane foam
Polyethylene foam


Mineral, fossil & ren resource depletion
kg Sb eq
1,4E-4
1,2E-4
1,0E-4
8,0E-5
6,0E-5
4,0E-5
2,0E-5
0,0E+0
Underlay Nature 8210
Polyurethane foam
Polyethylene foam


Water Use
m3
10
8
6
4
2
0
Underlay Nature 8210
Polyurethane foam
Polyethylene foam


Cumulative Energy Demand (LHV) Renewable (CEDt-R)
MJ
8
7
6
5
4
3
2
1
0
Underlay Nature 8210
Polyurethane foam
Polyethylene foam


Cumulative Energy Demand (LHV) Non - Renewable (CEDt-NR)
MJ
250
200
150
100
50
0
Underlay Nature 8210
Polyurethane foam
Polyethylene foam


Cumulative Energy Demand (LHV) Total (CEDt)
MJ
250
200
150
100
50
0
Underlay Nature 8210
Polyurethane foam
Polyethylene foam

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