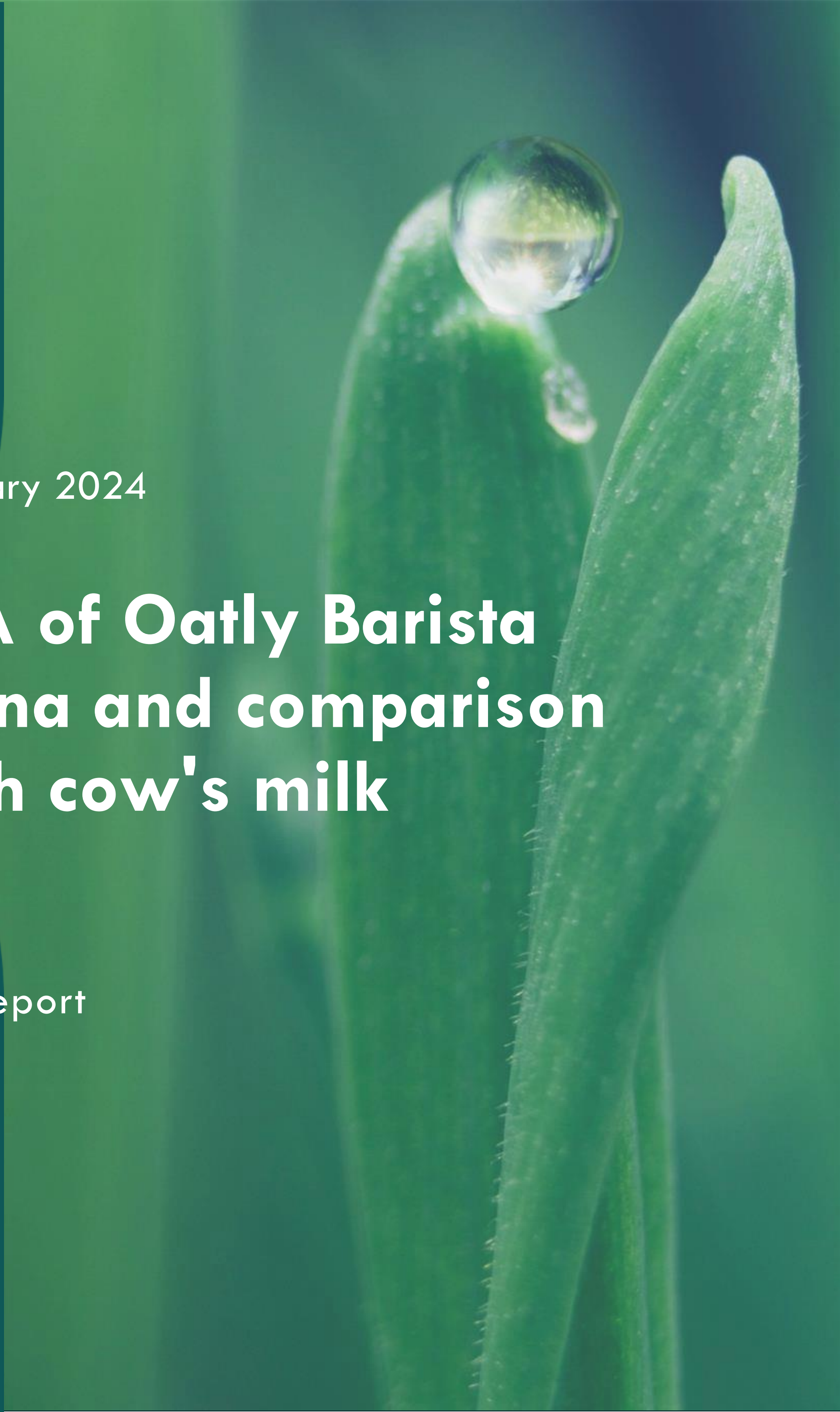

February 2024

LCA of Oatly Barista China and comparison with cow's milk

LCA report

Blonk CONSULTANTS

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Abbreviations

CFF	Circular Footprint Formula
CN	China
CO_2-eq	Carbon dioxide-equivalents
DC	Distribution centre
E2E	End-to-End (factory type)
EF	Environmental Footprint (method developed by the European Commission)
EoL	End of Life
Eq	Equivalent
HTST	High Temperature Short-Time
ISO	International Organisation for Standardization
kWh	Kilowatt hour
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MJ	Megajoules
NDU	Nutrient Density Unit
NL	The Netherlands
PEFCR	Product Environmental Footprint Category Rules
SG	Singapore
UHT	Ultra High Temperature
US	United States

Executive Summary

Introduction

A Life Cycle Assessment (LCA) has been performed to compare the environmental performance of Oatly Barista (an oat-based drink), to cow's milk in China[1]. In addition, the study has analysed the drivers and opportunities linked to the environmental impact of Oatly Barista as produced in Singapore and China[2] and sold in China. This study builds on the foundations of the previous LCA study for Oatly, "LCA of Oatly Barista and comparison with cow's milk", investigating Oatly Barista produced and sold in multiple countries (te Pas & Westbroek, 2022).

The functional unit considered for this study is 1 liter of Oatly Barista / cow's milk at the point of sale in China, including packaging manufacturing and packaging end of life. For cow's milk, a mix of milk with different fat contents was considered, focusing on long-life (UHT) milk since it is the most sold type of milk in the country (ultra-high temperature, UHT; Tang et al., 2022).

The foreground data for Oatly Barista is based on company-specific data from Oatly with regards to the production of the oat drink and refers to production from Oatly's End-to-End (E2E) factory (entire process operated by Oatly) located in Ma'anshan (China), and an Oatly/partner hybrid configuration, where part of the process is operated by a co-manufacturer[3], located in Singapore. Additionally, it was investigated how the current configuration compares to the previous situation, in which Oatly Barista was imported from The Netherlands (Vlissingen factory).

Based on recommendations from an expert familiar with the Chinese dairy sector[4] in October 2023, milk production for packaged milk was modelled with the US milk production model as developed in the previous Barista study, but with adjustments to reflect Chinese yields (Dong & Wei, 2021), most common Chinese manure management (100% solid storage), and feed sources adjusted to China production where available.

The study was performed and critically reviewed according to ISO 14040/14044 and ISO/TS 14071:2014 standards for comparative assertions that may be disclosed to the public and is in line with LCA guidelines including the European Product Environmental Footprint Category Rules (PEFCR). Even though this is primarily a European standard, the general principles described in these PEFCRs are often valuable input for LCAs in other countries and are therefore applied whenever relevant.

The analysis was done for 10 key impact categories from the ReCiPe 2016 impact assessment method, which were considered the most relevant environmental impact categories for food products, based on similar impact categories mentioned in the available PEFCRs for food and beverage products (Technical Secretariat of the PEF pilot on pasta, 2018; Technical Secretariat of the PEF pilot on Wine, n.d.; The Brewers of Europe, 2015; The European Dairy Association, 2018).[5] The study was conducted between May 2023 and February 2024.

Comparison of Oatly Barista with cow's milk

Based on this LCA, all Oatly Barista products in scope have a lower impact than cow's milk for climate change (68% lower), fine particulate matter formation (81% to 86% lower), terrestrial acidification (89% to 91% lower), freshwater eutrophication (53% to 60% lower), marine eutrophication (61% to 89% lower), mineral resource scarcity (48% to 50% lower), fossil resource scarcity (33% to 46% lower) and water consumption (30% to 78% lower).

[1] Whenever "China" is mentioned in this report, we intend to address mainland China.
[2] As of 2023, these two factories produce 100% of the 1 L ambient Oatly Barista product sold in China.
[3] End-to-End (E2E) Factory: The entire production chain happens within Oatly's own factory. From grains to the finished product. The data collected for this study refers to this configuration for the Ma'anshan location for the period September 2022 to September 2023. Hybrid Oatly/partner configuration: a contract manufacturer (co-manufacturer) factory receives Oatly Oatbase via pipeline, then the co-manufacturer formulates the Finished Product, fills and packs the products for Oatly. At the time of this study this is the case for the Singapore factory, which receives Oatbase from Oatly's Oatbase factory in Singapore (data from 2022).
[4] Jelle Zijlstra, Dairy Economist, Wageningen Livestock Research, Wageningen University & Research.
[5] Note that ecotoxicity is excluded in the most relevant impact categories and in calculating the single score of these PEFCRs as the methodology was under development. Nevertheless, this impact category is not investigated in detail in this report as ecotoxicity impact is very much dependent on the type of active ingredient used in e.g. pesticides and is hence most relevant and representative if based on primary data instead of background datasets for cultivation.

For land use impact (both characterized as well as uncharacterized), Oatly Barista from the Ma'anshan factory (being supplied with oats from Sweden, Finland, Estonia, and Australia) has a lower impact than cow's milk (respectively -17% and -26%). Oatly Barista from Singapore (being supplied with oats from Australia) has a higher impact (+26%) than cow's milk in the characterized results (which assesses land surface considering the relative species loss due to local land use), however due to the use of global biodiversity factors which are not regionalised, the geographic representation and validity of this method can be debated. The second method employed (uncharacterized) land occupation category shows comparable impact for Oatly Barista from Singapore and Chinese cow's milk (+8%). The difference in land use and land occupation of Oatly Barista from the two locations, is primarily caused by differences in yield, which is partially caused by differences in fertilizer application. Table 1 presents the differences in detail.

TABLE 1 RELATIVE DIFFERENCES OF OATLY BARISTA COMPARED TO COW'S MILK AT POINT OF SALE IN CHINA. FOR EXAMPLE, -68% INDICATES THAT OATLY BARISTA HAS A 68% LOWER IMPACT COMPARED TO COW'S MILK. THE DIFFERENCES HAVE BEEN COLOR-CODED AS FOLLOWS: GREEN – MORE THAN 10% DIFFERENCE FAVORING OATLY BARISTA; RED – MORE THAN 10% DIFFERENCE FAVORING COW'S MILK; YELLOW - THE DIFFERENCE IS 10% OR LOWER INDICATING SIMILAR PERFORMANCE FOR THE COMPARED PRODUCTS

Factory	Climate change	Fine particulate matter	Terrestrial acidifi-cation	Freshwater eutrophi-cation	Marine eutrophi-cation	Land use	Land occu-pation	Mineral resource scarcity	Fossil resource scarcity	Water consum-ption
	kg CO_2 eq	*kg PM2.5 eq*	*kg SO_2 eq*	*kg P eq*	*kg N eq*	*m^2a crop eq*	*m^2a*	*kg Cu eq*	*kg oil eq*	*m^3*
Ma'anshan (CN)	-68%	-86%	-91%	-60%	-61%	-17%	-26%	-50%	-46%	-78%
Singapore (SIN)	-68%	-81%	-89%	-53%	-89%	26%	8%	-48%	-33%	-30%

When analysing the various life cycle stages (Figure 1; see Chapter 4 for detailed graphs), the production of raw cow's milk (i.e. the animal production system itself) is the predominant driver of impact for cow's milk for nearly all environmental impact categories (linked to processes such as enteric fermentation, manure management, and feed cultivation). The impacts of Oatly Barista are distributed between oat cultivation, factory processing, distribution, and packaging, and are analysed in detail in the next section of the Executive Summary (Drivers and Opportunities for Oatly Barista).

The influence of assumptions and modelling choices (such as the system boundaries, life cycle impact assessment (LCIA) method and cow's milk modelling) were assessed in the sensitivity analyses to evaluate the robustness of the results. Next to the sensitivity analysis, an uncertainty analysis has been performed to determine the range in outcomes when considering uncertainties regarding data quality. All scenarios assessed in the sensitivity analysis uphold the conclusions above. Using a different impact assessment method, the globally oriented IMPACT WORLD+ method, resulted in comparable conclusions as with the ReCiPe method for the impact categories in scope, except for the land and water impact categories.

The climate change impact of cow's milk estimated in this study is higher than other studies found in the literature (Wang et al., 2018; Wang et al., 2019; Ledgard et al., 2019; Zhao et al., 2018) but of similar order of magnitude as the most recent and most extensive study (including 181 data sources, compared to maximally 36 in the other studies) (Dong & Wei, 2021).

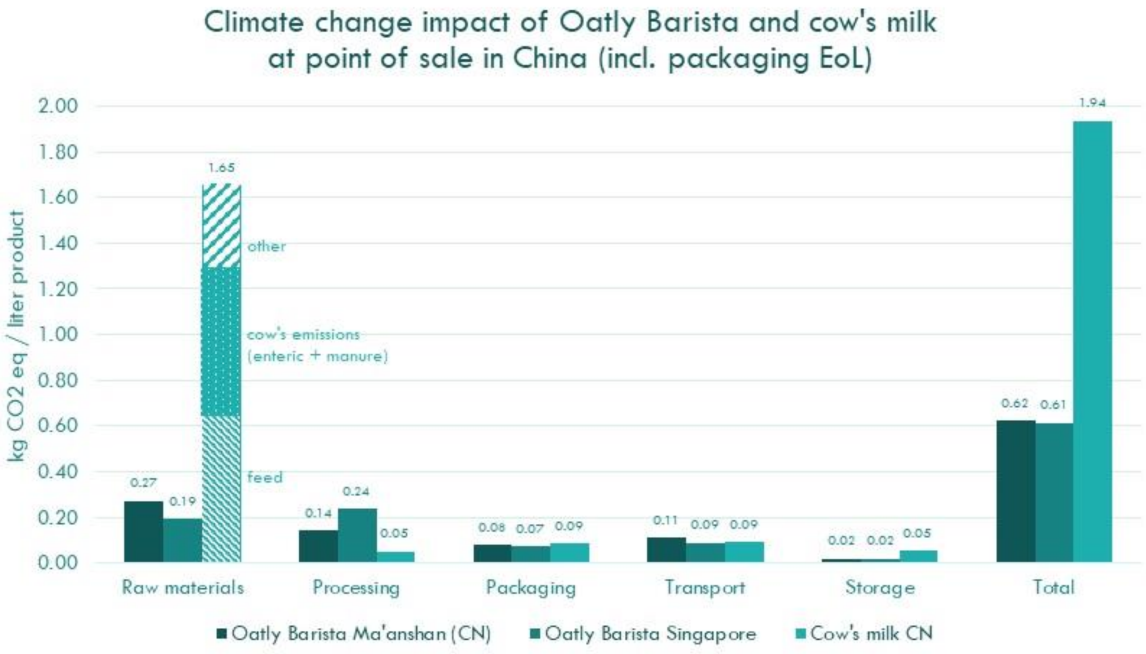

FIGURE 1: CLIMATE CHANGE IMPACT OF OATLY BARISTA AND COW'S MILK AT POINT OF SALE INCLUDING END-OF-LIFE (EOL) OF PACKAGING.

Drivers and Opportunities for Oatly Barista

Analysing the impact of Oatly Barista across all impact categories in scope, the following main drivers and opportunities have been identified for each stage of the supply chain (for more details see Chapters 4 & 5). The total impact of both variants is similar, but there are large differences in the contribution of the individual life cycle stages. The raw material stage is relatively high in Ma'anshan in comparison to Singapore, but this is compensated amongst others by a lower impact in the processing stage.

- **Ingredients (raw materials):** For both production locations of Oatly Barista(Ma'anshan and Singapore), the oat cultivation stage is among the highest contributing factors to the climate change, fine particulate matter, terrestrial acidification, freshwater eutrophication, marine eutrophication, land use, and mineral resource scarcity impact categories. Collecting data at cultivation level, could help Oatly to gain a better understanding of the main opportunities to reduce impacts at this stage, such as through more efficient fertilizer application and water use, intercropping and other measures to reduce inputs or increase yields. This could be valuable not only for oat cultivation, but also for rapeseed, which is the second biggest contributor to these impact categories. Oatly might also consider the trade-offs between the different oat cultivation sources. For example, the oats from Australian origin show relative low yields (partially caused by lower fertilizer application than other countries[6]), high land use and water impacts, but the short distance leads to relative low impact (in several impact categories) of transport in comparison to the European oats.
- **Factory (processing):** Energy consumption at the factory is the main contributing factor to the fossil resource scarcity impact in both production locations due to the use of fossil-based fuels for thermal energy).On the other hand, the use of renewable electricity (100% in Ma'anshan End-to-End factory and 100% for the Oatbase production in Singapore) leads to a higher impact on mineral resource scarcity due to the metals used to produce solar panels and wind turbines. The processing stage is also a large contributor with respect to water consumption.
- **Transportation:** the climate change impact of the distribution of Oatly Barista in China differs for the two production locations; for Oatly Barista from Ma'anshan, the hotspot is in the transport from distribution center to the retail locations, while for Oatly Barista from Singapore, the transport from the

[6] The specific reason for this difference is unknown. The data on fertilizer application in the background database (Agri-footprint) comes from FAO statistics and the Feedprint study (Vellinga et al., 2013), without further explanation on the agriculture practises.

Singapore factory to the distribution center in China has a higher impact. In addition to the long transport distance from Singapore (5261 km), the fact that a part of the year (62%) refrigerated ships and trucks were used, also contributes to the distribution impact. Since December 2022, this refrigerated transport has stopped, which means the impact will be lower when assessing only 2023 and beyond. Import from the Netherlands, as was occurring until 2022, generates a 4% higher climate change impact than the products produced in Ma'anshan and Singapore. Shifting to a more local approach (using 100% Australian oats, all processed in the Ma'anshan factory) could reduce the total impact with 15% in comparison to import from the Netherlands.

- **Packaging:** Packaging is the third or fourth most contributing life cycle stage in most impact indicators. The corrugated board box has the highest impact in the packaging climate change impact, as being the material with the highest weight in the total pack. The second highest impact is caused by the smallest amount of material: aluminum. The third contributing material, even though its weight is also low (8%) compared to the total weight, is BioPE.
- **Consumer (use phase):** The impact at the consumer stage (refrigeration, food waste, heating) was investigated in in the sensitivity analysis and showed that the primary driver of the use phase is linked to heating the product and to food waste. Due to lack of consumer data, food waste percentages were based on defaults and were considered the same for both cow's milk and Oatly Barista.

Conclusions

The results show that overall:

- The top impact drivers for Oatly Barista are oat cultivation, factory processing, distribution, and packaging. However, their contribution varies depending on the environmental impact category and case.
- Oatly Barista has a lower impact than cow's milk for the two main production facilities for the Chinese market included in this study (Ma'anshan and Singapore) for climate change, fine particular matter, terrestrial acidification, and freshwater, marine eutrophication, mineral resource scarcity, fossil resource scarcity and water consumption.
- For land use impact (both characterized as well as uncharacterized), only Oatly Barista from the Ma'anshan factory has a lower impact than cow's milk. Oatly Barista from Singapore has a higher impact than cow's milk in the characterized results, but a similar impact in the (uncharacterized) land occupation category.
- For cow's milk, the main driver of all impact categories is the raw material (i.e feed, emissions from cow and other activities in the raw milk production). Despite the lack of primary data, the results are of the same order of magnitude as the most extensive and most recent study available, and can be considered of sufficient quality for the goal of this study. The uncertainty analyses confirm the robustness of the results.

执行摘要

引言

一项在中国[7]进行的生命周期评价(LCA)比较了 Oatly Barista (一种燕麦奶) 与牛奶的环境影响表现。此外，该研究还分析了在新加坡和中国[8]生产并在中国销售的 Oatly Barista 对环境影响的驱动因素及其中蕴藏的机会。本研究是建立在之前对 Oatly 的生命周期评价研究《Oatly Barista 的生命周期评价与牛奶的比较》的基础之上，并对在多个国家生产和销售的 Oatly Barista 进行了调查 (te Pas & Westbroek, 2022)。

本研究采用的功能单位是在中国销售的 1 升装 Oatly Barista 或 1 升装牛奶，包括包装制造和包装寿命终结两个阶段。对于牛奶，本研究探讨了混合不同脂肪含量的牛奶，尤其是长效超高温灭菌乳(UHT milk)，因为它是该国最畅销的牛奶类型 (超高温, UHT; Tanget al., 2022)。

Oatly Barista 的前景数据是基于 Oatly 公司关于燕麦奶生产的特定数据，并参考了 Oatly 位于马鞍山(中国)的端到端(E2E)工厂生产流程(整个过程由 Oatly 操作)，以及 Oatly-合作伙伴的混合配置，其中部分过程由位于新加坡的合作制造商[9]操作。此外，研究人员还调查了目前的配置与之前情况(从位于荷兰 Vlissingen 的工厂进口 Oatly Barista) 的对比。

根据一位熟悉中国乳制品行业的专家[10]在 2023 年 10 月提出的建议，包装牛奶的生产过程采用了先前 Barista 研究中开发的美国牛奶生产模型，但后来进行了相应调整以反映中国的产量 (Dong & Wei, 2021)、最常见的中国粪肥管理措施(100%固态储存)，及在可行情况下根据中国生产情况调整的饲料来源。

本研究是根据 ISO 14040/14044 和 ISO/TS 14071:2014 标准进行的。这些标准符合包括欧洲产品环境足迹类别规则(PEFCR)的生命周期评价指南并可能会对大众公开。尽管这是一项适用于欧洲的标准，但这些规则中描述的一般原则往往来自其他国家生命周期评价的研究精髓，因此在情况相似时可以予以应用。

根据现有食品和饮料产品环境足迹类别规则中提到的相似影响类别，本研究对 ReCiPe 2016 影响评估方法中规定的 10 个关键影响类别进行了分析，这些类别被认为是与食品产品最相关的环境影响类别(面食产品环境足迹试点技术秘书处, 2018; 葡萄酒产品环境足迹试点技术秘书处; 欧洲酿酒商, 2015; 欧洲乳制品协会, 2018)。[11]本研究于 2023 年 5 月至 2024 年 2 月进行。

Oatly Barista 与牛奶的比较

本研究范围内所有的 Oatly Barista 产品对气候变化的影响值都低于牛奶 (低 68%)。其中细颗粒物形成度低 81%-86%、陆地酸化度低 89%-91%、淡水富营养化度低 53%-60%、海洋富营养化度低 61%-89%、矿产资源稀缺度低 48%-50%、化石资源稀缺度低 33%-46%，以及水资源消耗度低 30%-78%。

对于土地使用的影响 (包括特征化和非特征化的影响)，马鞍山厂的 Oatly Barista (由瑞典、芬兰、爱沙尼亚和澳大利亚供应燕麦) 的影响低于牛奶 (分别为-17%和-26%)。产自新加坡厂的 Oatly Barista (由澳大利亚供应燕麦) 在特征结果 (此类结果评估了考虑到当地土地利用导致物种多样性损失的陆地表面)中比牛奶具有更高的影响(+26%)，然而，由于本研究使用了未进行地区化的全球生物多样性系数，该方法的地理代表性和有效性可能存在争议。本研究采用的第二种方法(非特征化方法)，即土地占用影响类别表明，产自新加坡的 Oatly Barista 和产自中国的牛奶对土地使用的影响相当(+8%)。两个地点 Oatly Barista 的土地利用和土地占用影响类别的差异主要是由于产量的差异，而产量的差异部分是由肥料施用的差异造成的。表 1 详细列出了这些差异。

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[7] 此报告中提到的“中国”是指中国大陆。
[8] 截至 2023 年，这两家工厂负责生产所有在中国销售的 1 升装常温 Oatly Barista 产品。
[9] 端到端(E2E)工厂：从谷物到成品，整个生产链在 Oatly 自己的工厂内完成。本研究收集的数据来自马鞍山厂在 2022 年 9 月至 2023 年 9 月期间的这种操作配置。Oatly-合作伙伴配置：一个联合制造商工厂接收 Oatly 的 Oatbase，然后为 Oatly 配制成品，灌装及包装产品。在本研究进行期间，位于新加坡的工厂采取的就是此类做法——该工厂从新加坡 Oatly 的 Oatbase 工厂接收 Oatbase (数据来自 2022 年)。
[10] Jelle Zijlstra，瓦赫宁根大学畜牧研究所乳业经济学家。
[11] 请注意，在最相关的影响类别和计算这些产品环境足迹类别规则的单一分数时，生态毒性被排除在外，因为针对它的计算方法仍在开发中。然而，由于生态毒性影响类别很大程度上取决于杀虫剂中活性成分的类型，所以，基于原始数据而不是基于栽培的背景数据集计算的生态毒性影响类别才是最相关和最具代表性的。因此，本报告没有详细调查这一影响类别。

表 1：在中国销售点 OATLY BARISTA 与牛奶的相对差异。例如，-68%表示 OATLY BARISTA 对环境的影响比牛奶低 68%。不同颜色的差异如下：绿色-超过 10%的差异倒向 OATLY BARISTA；红色-超过 10%的差异倒向牛奶；黄色-差异为 10%或更低，表明所比较产品的表现相似。

工厂	气候变化	细颗粒物	陆地酸化度	淡水富营养化度	海洋富营养化度	土地使用度	土地占有度	矿物资源稀缺度	化石资源稀缺度	水资源消耗度
	kg CO_2 eq	*kg PM2.5 eq*	*kg SO_2 eq*	*kg P eq*	*kg N eq*	*m^2a crop eq*	*m^2a*	*kg Cu eq*	*kg oil eq*	*m^3*
马鞍山(中国)	-68%	-86%	-91%	-60%	-61%	-17%	-26%	-50%	-46%	-78%
新加坡(新加坡)	-68%	-81%	-89%	-53%	-89%	26%	8%	-48%	-33%	-30%

在分析各个生命周期阶段时(图 1；参见第 4 章的详细图表)，原牛奶的生产过程(即动物生产系统本身) 是几乎所有影响类别(与肠道发酵、粪肥管理和饲料作物栽培等过程有关) 对牛奶环境影响的主要驱动因素。Oatly Barista 的环境影响分布在燕麦种植、工厂加工、分销和包装阶段中，这部分内容将在执行摘要的下一章(Oatly Barista 的驱动因素和机会)进行详细介绍。

为评估结果的稳健性，本研究在敏感性分析中评估了假设和建模选择所致的影响(如系统边界、生命周期影响评价(LCIA)方法和牛奶建模)。在敏感性分析以外，本研究还进行了不确定性分析，以确定对数据质量把握不足时研究结果的所在区间。敏感性分析中评估的所有情景均支持上述结论。在采取了一种不同的影响评估方法，即面向全球的 impact WORLD+方法之后的结论表明，除了土地和水资源影响类别外，研究范围内的影响类别得出的结论与 ReCiPe 方法相当。

本研究估算的牛奶对气候变化的影响高于其他文献中的发现 (Wang et al., 2018; Wang et al., 2019; Ledgard et el., 2019; Zhao et al., 2018)，但与最近且最详尽的一项研究 (包括 181 个数据源，而其他研究最多有 36 个)结果在数量级上相似 (Dong & Wei, 2021)。

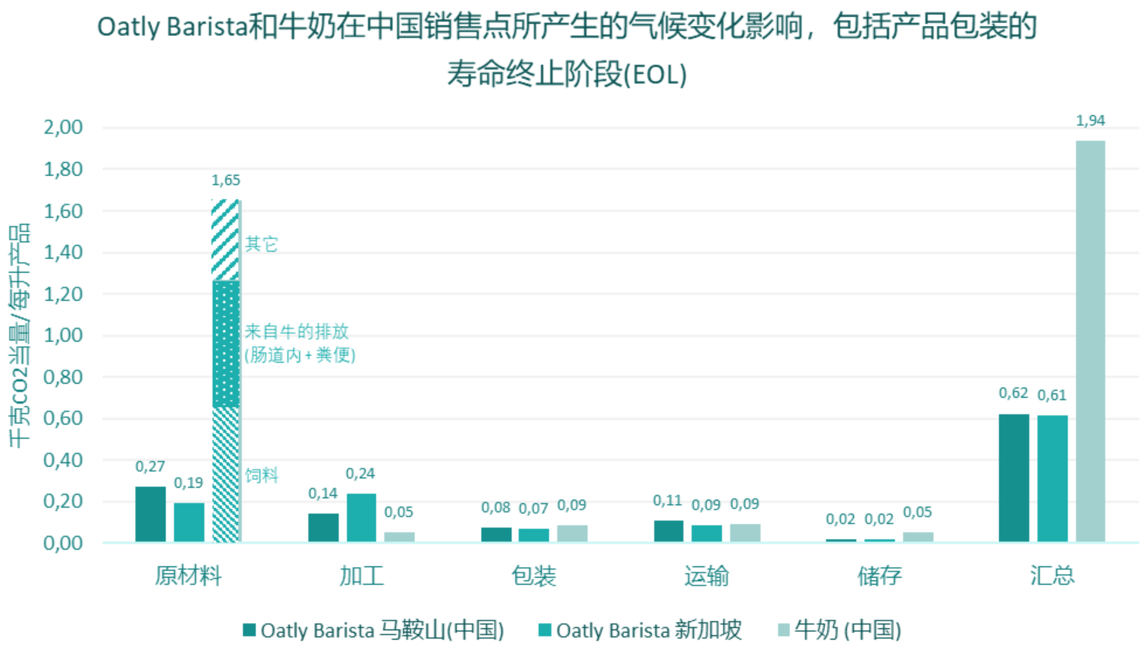


图 1：气候变化影响类别对 OATLY BARISTA 和牛奶在销售点的影响，包括产品包装的寿命终止阶段(EOL)

Oatly Barista 环境影响的驱动因素及机会

通过对 Oatly Barista 在研究范围内的环境影响进行分析，本研究确定了供应链每个阶段环境影响的主要驱动因素和机会(详情请参见第 4 章和第 5 章)。两处产地流程所得的影响总值是相似的，但在各个生命周期阶段的贡献上有很大差异。与新加坡厂相比，马鞍山厂在原材料生产阶段产生的环境影响较高，但加工阶段的影响较低，从而弥补了这一点。

- **原料**：对于 Oatly Barista 的两个产地(马鞍山和新加坡)，燕麦种植阶段是气候变化、细颗粒物、陆地酸化、淡水富营养化、海洋富营养化、土地利用和矿产资源稀缺这些类别里对环境影响总值贡献最大的阶段之一。在种植层面收集数据可以帮助 Oatly 更好地了解在这一阶段降低环境影响的机会，例如采取更高效的施肥用水方式、间作以及其他减少投入或提高产量的措施。这不仅对燕麦种植有帮助，对油菜种植也有参考价值，考虑到油菜是这些影响类别的第二大贡献者。Oatly 可能还会在不同燕麦产地之间权衡。例如，澳大利亚原产燕麦的产量相对较低 (其中一个原因是其肥料用量低于其他国家[12])，对土地和水资源的影响较大；但与欧洲原产的燕麦相比，因其距离(新加坡或中国)较近，因而其运输影响相对较小 (在几个影响类别中)。

- **工厂(加工)**：由于使用化石燃料作为热能，工厂的能源消耗是造成两个产地中化石资源稀缺度影响的主要因素。另一方面，由于生产太阳能电池板和风力涡轮机所用的金属，使用可再生电力(马鞍山端到端工厂以及新加坡 Oatbase 的生产全部使用可再生电力)会对矿产资源稀缺度造成更大的影响。加工阶段也是水资源消耗的一个重要贡献因素。

- **交通**：Oatly Barista 在中国的分销产生的气候影响在两种方案中有所不同；对于产自马鞍山厂的 Oatly Barista 来说，环境影响的热点是从配送中心到零售地点的运输；而对于产自新加坡厂的 Oatly Barista，从新加坡厂到中国配送中心的运输过程则具有更高的环境影响。除了从新加坡运输的长距离外(5261 千米)，一年中有部分时间(62%)使用冷藏船和冷藏卡车配送也对运输过程中的环境影响有贡献。这种冷藏运输自 2022 年 12 月以来已经中止，意味着仅评估 2023 年及以后的环境影响时，影响值将会降低。直到 2022 年，从荷兰进口的产品对气候变化的影响比在马鞍山和新加坡生产的产品高 4%。转向一个更本地化的方式(如全部使用澳大利亚原产的燕麦，并在马鞍山厂加工)与从荷兰进口相比，可以减少 15%的总环境影响值。

- **包装**：在大多数环境影响指标中，产品包装阶段是具有第三或第四大贡献的生命周期阶段。瓦楞纸箱在包装对气候变化的影响中贡献最大，它是总包装中重量最高的材料。第二高的环境影响是由含量最少的材料——铝引起的。第三大贡献材料是 BioPE，尽管其重量与包装总重量相比很低(8%)。

- **消费者(使用)阶段**：本研究在敏感性分析中调查了消费者阶段(制冷、食物浪费、加热)产生的环境影响，结果表明使用阶段环境影响的主要驱动因素与加热产品和食物浪费有关。由于缺乏消费者数据，食物浪费百分比是基于默认值的，牛奶和 Oatly 咖啡都被认为是相同的。

结论

研究结果表明：

- 对 Oatly Barista 环境影响最大的驱动因素是燕麦种植、工厂加工、分销和包装。但它们的贡献值因环境影响类别和具体情况而异。
- 对于本研究涵盖的中国市场的两个主要生产设施(马鞍山和新加坡)，Oatly Barista 在气候变化、细颗粒物、陆地酸化度、淡水及海洋富营养化度、矿产资源稀缺度、化石资源稀缺度和水资源消耗度类别上的环境影响要低于牛奶。
- 对于土地使用的影响(包括特征化和非特征化方法所得的结果)，只有马鞍山厂生产的 Oatly Barista 的环境影响低于牛奶。产自新加坡的 Oatly Barista 在特征化结果上的影响比牛奶高，但在(非特征化)土地占用类别上的影响相似。

对于牛奶，所有影响类别的主要驱动因素是原材料(即饲料、奶牛自身的排放、原牛奶生产中的其他活动)。虽然缺乏原始数据，但本研究的结果与现有最近最广泛的研究具有相同的数量级，可以认为足以实现本研究的目标。而不确定性分析则证实了结果的稳健性。

[12] 造成这种差异的具体原因尚不清楚。背景数据库(Agri-footprint)中的肥料施用数据来自粮农组织的统计数据和 Feedprint 研究(Vellinga et al.， 2013)，没有对现实中的农业实操方法进行进一步解释。

1. Goal & Scope

1.1 Introduction

For over 25 years, Oatly has focused on developing expertise in oats processing which has led to the creation of a broad portfolio of oat-based products. Oatly's ambition is to play a major role in driving a food system shift[13]. To investigate the environmental sustainability of certain of its products throughout their supply chain, Oatly has commissioned the execution of a life cycle assessment (LCA) in which a selection of Oatly's strategic products, more specifically Oatly Barista, is assessed and in addition compared to cow's milk, both specifically for production and distribution in China[14]. This study builds on the foundations of the previous LCA study for Oatly, investigating Oatly Barista in multiple countries (te Pas & Westbroek, 2022). This study uses the LCA methodology outlined below to calculate and compare the environmental impacts of the products in scope.

LCA is a standard method that allows the quantitative analysis of the environmental impacts of a product or system throughout all the stages of its life cycle. LCAs provide a holistic approach, allowing the observation of how individual life cycle stages contribute to the overall environmental impact of the product in scope, and how substances or emissions contribute to different impact categories. This can result in the identification of opportunities for direct and indirect management actions that may lead to a reduction of environmental impacts throughout the life cycle.

This LCA is conducted according to the iterative, multi-step methodology proposed in ISO 14040 and 14044 LCA methodological standards (ISO, 2006a; ISO, 2006b) Click or tap here to enter text., including a critical review by a panel of independent experts, as prescribed by ISO 14044. In addition, the LCA follows the guidance established by the European Commission in the Product Environmental Footprint (PEF) project (Zampori, 2019) and product specific Product Environmental Footprint Category Rules (PEFCR) when dealing with specific products such as the PEFCR for Dairy Products and the PEFCR on feed for food producing animals ((European Commission, 2018b).

The LCA is conducted according to the following steps, as defined by the abovementioned ISO standards.

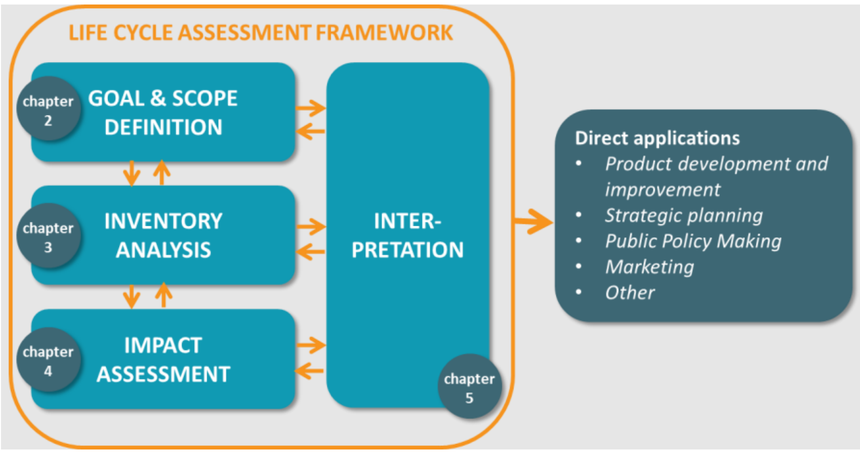


FIGURE 2: METHODOLOGICAL PHASES IN LCA BASED ON ISO 14040

- **Goal & scope definition:** This phase defines the goal of the study and provides a description of the product system in terms of system boundary and functional unit.
- **Life cycle inventory (LCI):** results in a list with the consumption of resources and the quantities of waste flows and emissions caused by or otherwise attributable to a product's life cycle.
- **Life cycle impact assessment (LCIA):** provides indicators and the basis for analysing the potential contributions of the resource extractions and emissions in an inventory to a number of potential impacts.

[13] https://www.oatly.com/sustainability/drive-a-food-system-shift
[14] Whenever "China" is mentioned in this report, we intend to address mainland China.

- **Life Cycle Interpretation**: in this phase the results of the analysis and all choices and assumptions made during the analysis are evaluated in terms of soundness and robustness. After this, overall conclusions are drawn.

This report follows the steps as defined above: it describes the goal and scope of the study, the data and methodology used to model the products (i.e. the LCI), after which it provides the results and interpretation for the main analyses and for a number of sensitivity analyses.

1.2 Goal

The goal of the study is to assess the environmental impacts of Oatly Barista distributed in China and in addition compare them to cow's milk produced and distributed in China. Oatly Barista sold in China is produced both in China (Ma'anshan) and Singapore under two different article numbers. As of 2023, these two factories are producing 100% of the 1 L ambient Oatly Barista product sold in China. Prior to the commissioning of the Oatly's Singapore and Ma'anshan factories, the product was produced in the Netherlands (Vlissingen). This scenario was also assessed for estimating the differences with the new configuration, however in depth analysis is limited to climate change.

An attributional life cycle assessment was performed to evaluate the environmental impact of these products. Following the ISO 14040/14044 and ISO/TS 14071:2014 standards (ISO, 2014), the comparative assertion has been validated by an independent external review panel of four experts.

The intended application of the study is twofold. Its aim is primarily to create internal awareness of Oatly's environmental hotspots throughout the production chains and sales markets in scope and identify areas of improvement. Secondly, the results of the comparative assertion with cow's milk may be communicated externally. This external communication might include business-to-business communication, as well as communication to a broader audience, including investors, policy advocates, customers, other industry partners, and consumers.

Oatly aims to accelerate the transformation of an animal-based diet into a plant-based diet. The study is done to show the environmental impacts of their plant-based products compared to animal-based products with similar functions. The study does not aim to compare Oatly to other plant-based products, because they are part of the same transition towards a more plant-based diet.

1.3 Scope

1.3.1 Products in scope and their functional units

The comparative assertion of the oat-based and cow's milk-based products requires that all products are compared based on the same function. Other requirements of a comparative study according to ISO 14044 include an assessment of data quality (including completeness and representativeness of the data used for both systems), equivalence of both systems, sensitivity analysis, uncertainty analysis (including evaluation of significance) and use of relevant and internationally accepted impact indicators. All these elements are tackled in this report.

The main function fulfilled by Oatly Barista and cow's milk is that they are added to food and beverage items to provide taste and texture. The study focuses on this functionality of Oatly Barista and cow's milk only, and not on the replacement of any specific macronutrient (e.g. protein or fibre). Nonetheless, due to the ongoing debate on the inclusion of nutritional aspects in food LCAs, a comparison of Oatly Barista and cow's milk on a nutritional basis was included in the sensitivity analysis in the previous Barista report, where it was concluded that the differences in climate change impact between Oatly Barista and cow's milk were bigger when using a functional unit based on nutritional value (NDU) compared to a functional unit based on volume. Because of this outcome, the analysis based on NDU was not repeated for the Chinese Barista, since nutritional properties are expected to be similar, and conclusions are not expected to change. However, it should be stressed that the full diet of a person needs to be considered when meeting dietary needs, and assessing single products might not be sufficient.
The function based on which the two systems are compared is defined as follows: the provision of cow's milk or oat-based drinks, provided in most occurring packaging 1L for Oatly Barista and 1 L for cow's milk, as done in the Barista study), both at point of sale in China.

The functional units associated with both systems are:

- Oat drink:
  - 1 liter of Oatly Barista Oat drink as produced and distributed in China, including packaging, at point of sale (chilled storage)
  - 1 liter of Oatly Barista Oat drink as produced in Singapore and distributed in China, including packaging, at point of sale (chilled storage)
- Cow's milk: 1 liter of long life (UHT) cow's milk at a mix of fat rates as produced and distributed in China, including packaging, at point of sale (chilled storage)

Table 2 lists the reference flows related to the Oatly products in scope, as well as for their cow's milk equivalents. The temporal scope of this assessment focused on using the most recent and complete data sets available. For Oatly Barista from Singapore, data for a full year (2022) was used. For the recently opened Ma'anshan factory, data from the period September 2022-September 2023 was used because from this period onwards, the factory was starting to deliver stable energy efficiency and other process information. For cow's milk, modelling was based on various sources because of lack of a single source. Major inputs were acquired for the year 2021 (e.g. milk per cow yield), while other inputs were acquired from older sources (see Appendix II for more details).

TABLE 2: REFERENCE FLOWS OF THE PRODUCTS IN SCOPE. ALL PRODUCTS ARE ANALYZED FOR SELLING IN CHINA UNDER CHILLED CONDITIONS.

Reference flow	Product name (in this study)	Local name	Produced in	Distributed in	Temporal scope
1 liter	Oatly Barista Ma'anshan (CN)	咖啡大师燕麦饮 Oat Drink Barista Edition	Ma'anshan, China	China	September 2022 to September 2023
1 liter	Oatly Barista Singapore (SG)		Singapore	China	2022
1 liter	Cow's milk, country average mix (CN)	Cow's milk	China	China	2021 and before; see Appendix II for more details

Oatly Barista is an oat-based drink that is fortified with calcium. Next to that, oil is added as a functional ingredient that provides structure and texture to the drink. "Barista" refers to the oat drink's functionality in coffee, for which Oatly Barista's foamability and stability are the leading properties. The nutritional value of Oatly Barista is shown in Table 3.

TABLE 3: NUTRITIONAL VALUE OF OATLY BARISTA AND COW'S MILK, AT POINT OF SALE IN CHINA, PER 100 ML.

Nutrient	Oatly Barista[15]	Cow's milk[16]
Energy	240 kJ/60 kcal	284 kJ/68 kcal
Fat	3.0 g	4.0 g
of which saturated	0.3 g	unknown
Carbohydrates	6.5 g	4.8 g
of which sugars	4.0 g (natural sugars from oats)	unknown
Fibre	0.8 g	unknown
Protein	1.0 g	3.2 g
Salt	0.1 g	0.062 g
Calcium	120 mg	100 mg

Oatly Barista is intended to replace any type of cow's milk. That is why the country-average mix of semi-skimmed and whole cow's milk is selected. Full fat milk is reported as the most occurring milk type, by 83%[17]. No data was found on the representation of the other milk types, therefore they were presumed to contribute equally in the remaining 17%. The different fat contents are compared separately in the sensitivity analysis, see 5.2.3.

The environmental impact of cow's milk is modelled using national data on milk production, so it represents average cow's milk produced in China. Only cows raised in conventional production systems (thus not organic or other types of farming systems) are taken into consideration, as this is the dominant production system in modern Chinese production systems, since they are expected to aim to resemble US systems[18]. Domestically produced milk accounts for the vast majority of milk consumed (average of 68% in the period 2014-2021), as shown by

[15] Based on data from Oatly: https://www.oatly.com/en-cn/stuff-we-make/oat-drink/oat-drink-barista-edition.
[16] Based on the product nutritional value from one of China's main milk brands (Mengniu UHT whole milk).
[17] Number derived from Euromonitor, global market research & industry analysis, for the year 2022.
[18] Based on recommendations from an expert familiar with the Chinese dairy sector: Jelle Zijlstra, Dairy Economist, Wageningen Livestock Research, Wageningen University & Research; October 2023.

national data (Tang et al., 2022), therefore no imported milk is taken into account in the calculation of the Chinese cow's milk.

Oatly Barista is heat treated. The most common cow's milk pasteurisation type in China is UHT (ultra-high temperature treatment) (Tang et al., 2022). This is also the most conservative approach, since the impact of chilled milk was found to have a slightly higher footprint than ambient milk in the previous Barista study.

The oat drink is packaged in a 1L beverage carton before being distributed in China. The only information about average packaging materials for Chinese milk that was found, was the remark that Tetra Pak is a major supplier (Tang et al., 2022). Therefore, the modelling of the packaging was kept equal to Oatly Barista's packaging in China, which is supplied by Tetra Pak.

1.3.2 System boundaries

The system boundaries for Oatly's Barista products as well as cow's milk are from **cradle-to-point of sale**, as shown in Figure 3 and Figure 4 respectively. To adequately reflect the complete impact of packaging, the End of Life (EoL) of the packaging is considered as well.

The system starts at oat cultivation, after which the oats are dehulled and dried at a mill. The dehulled and dried oats are transported to one of Oatly's production facilities, where they are transformed into "oat base", which is a mixture of oats, water, and enzymes. Fiber residues are the by-product of this process. In a subsequent processing step (either at the same or at a different location), the oat base is formulated into the final product with the addition of water, vitamins, minerals, and oil. After formulation, the product is heat-treated and packed, after which the product is distributed to retail stores (supermarkets) or on-premise food service locations.

It should be noted that the consumption life cycle stage is excluded (except for the packaging end of life), as it is assumed that this life cycle stage is identical for both systems. However, an estimation of the entire life cycle (cradle-to-grave) is included as sensitivity analysis (see section 5.2.2).

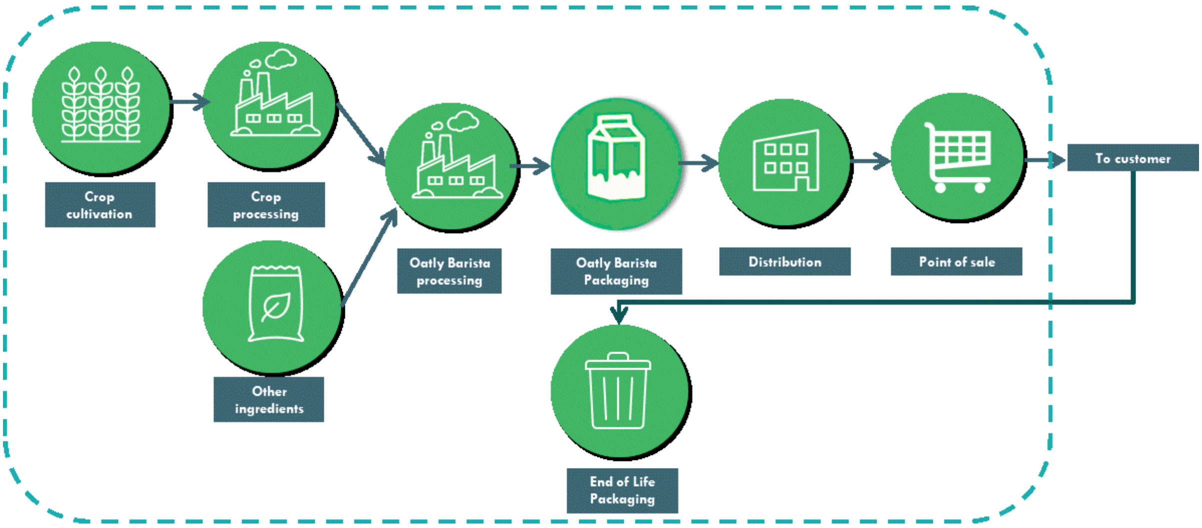


FIGURE 3: SYSTEM BOUNDARIES PACKAGED OATLY BARISTA CHINA. POINT OF SALE REFERS TO RETAIL AND FOOD SERVICE IN CHINA.

The dairy system follows the same system boundaries, starting at cultivation of feed, followed by feed processing, raw milk production, milk processing, packaging, and distribution to point of sale.

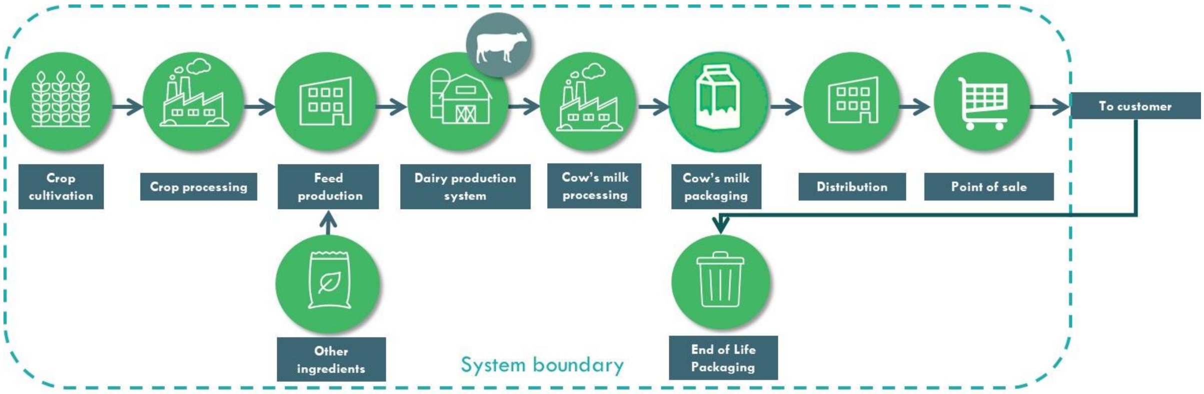


FIGURE 4: SYSTEM BOUNDARIES PACKAGED COW'S MILK IN CHINA. POINT OF SALE REFERS TO RETAIL AND FOOD SERVICE IN CHINA.

1.3.3 Critical review

A critical review is carried out according to ISO 14040/14044 and ISO/TS 14071:2014 standards (ISO, 2014), in order to assess whether this study is consistent with LCA principles and meets all criteria related to methodology, data, interpretation and reporting. Because of the comparative nature of this LCA, the review is conducted by a panel.

A review panel of four independent and qualified reviewers has been compiled, reflecting a balanced combination of qualifications (LCA, dairy, nutrition) and backgrounds (academic, research institute, non-governmental organisation).

- Jasmina Burek (chair): Assistant Professor at University of Massachusetts Lowell (based in the US)
- Joanna Trewern: Food Systems and Sustainable Diets expert (based in the UK)
- Jens Lansche: LCA expert (based in Switzerland)
- Hayo van der Werf: LCA expert (based in France)

This review panel is the same panel who has reviewed the previous studies for Oatly (Pas & Westbroek, 2022;Pas, 2023; Keijzer et al., 2023), and therefore the goal & scope have not been reviewed in a separate step, as was done in the first Oatly study. The panel has reviewed the full report in two review rounds, to ensure that the interpretation of the results is appropriate and reflects the limitations and uncertainties identified. In addition, the panel safeguarded that the results have been presented in a transparent and consistent manner.

The critical review statement and review report can be found in Appendix V.

2. Calculation method

2.1 Methodological standards & approach

Relevant methodological standards and calculation guidelines used for this study are:

- The ISO LCA standards (ISO 14040/14044), which are the leading international LCA standards that describe the overarching principles and framework for LCA, as well as specific requirements and guidelines.
- The latest version of the Product Environmental Footprint Category Rules (PEFCR) from the European Commission (Zampori & Pant, 2019) builds upon these ISO standards, and provides more in-depth guidance on methodological choices, such as how to model specific life cycle stages. It was created as a harmonized approach that ensures consistency and comparability of LCA studies.
- Cow's milk is modelled using Blonk's Animal Production System Footprint (APS Footprint), a tool for computing lifecycle environmental impacts of animal production systems, according to well-defined LCA-standards and guidelines regarding methodology and data (Blonk Consultants, 2020a, 2020b). The methodological framework regarding allocation, functional units, boundary definitions and emission modelling is based on the following published and recognized international guidelines (European Commission, 2018b; European Environment Agency, 2016; IPCC, 2006) :
    - Product Environmental Footprint Category Rules for Dairy Products (European Commission, 2018b) is the leading guideline. This document was developed by the European Commission to standardize the LCA framework for dairy products, in the context of the PEFCR project and is a further concretization of the FAO LEAP guidelines for large ruminants (FAO LEAP, 2016) and the IDF guidelines (IDF, 2010) for calculating GHG emissions.
    - Chapter 3.B of EMEP/EEA air pollutant emission inventory guidebook (European Environment Agency, 2016). This document was published by the European Environment Agency to help government bodies to measure air pollution. It proposes calculation methods for nitrogen volatilization, Non-Methane Volatile Organic Compounds (NMVOC) emissions and Particulate Matters (PM) emissions.
    - Chapter 10 of IPCC (2006b) on emissions from livestock and manure management (IPCC, 2006). The Intergovernmental Panel on Climate Change (IPCC) developed calculation methods and standards to estimate the climate change impact for various industry sectors. This chapter focuses on enteric methane production in animal farms and methane and nitrous oxide emissions from manure management.[19]

2.2 Environmental impact assessment method

The environmental impact of the systems under study is evaluated over the following impact categories from ReCiPe 2016 v 1.01 (Huijbregts et al., 2016). In addition to the Barista report and in line with the Oatly No Sugars report (Pas, 2023), land occupation (uncharacterized) was added to this collection in order to exclude the uncertainties involved with geographic representation and validity of the characterized land use method, due to the use of global biodiversity factors which are not regionalised.

TABLE 4: OVERVIEW OF THE ENVIRONMENTAL IMPACT CATEGORIES AND RELATED INDICATORS FROM RECIPE 2016 (HUIJBREGTS ET AL., 2016).

Midpoint impact category	Characterization Factor	Unit
Climate change	Global warming potential (GWP)	kg CO_2-eq to air
Fine particulate matter formation	Particulate matter formation potential (PMFP)	kg PM2.5-eq to air

[19] The APS tool does not yet include emission factors from the latest IPCC guidelines (it will in a future update). It is estimated that updated emission factors might result in a 1-10% change in methane emissions from manure management and enteric fermentation (the new guidelines provide some minor changes in factors and some more detailed options, e.g., subcategories of certain manure management systems based on different storage times). Variability in emissions from these two sources are covered in the uncertainty analysis.

Midpoint impact category	Characterization Factor	Unit
Terrestrial acidification	Terrestrial acidification potential (TAP)	kg SO_2-eq to air
Freshwater eutrophication	Freshwater eutrophication potential (FEP)	kg P-eq to freshwater
Marine eutrophication	Marine eutrophication potential (MEP)	Kg N-eq to marine water
Mineral resource scarcity	Surplus ore potential (SOP)	kg Cu-eq
Fossil resource scarcity	Fossil fuel potential (FFP)	kg Oil-eq
Water consumption	Water consumption potential (WCP)	m^3 water-eq consumed
Land use	Agricultural land occupation potential (LOP)	m^2 x yr annual crop land eq.
Land occupation	None	m^2 x yr

For the climate change impact category, the GWPs were updated using the most recent ones from the IPCC AR6 2021 (IPCC, 2021). Greenhouse gas emissions caused by land use change (LUC) and peat oxidation are included in the climate change impact category, but are also reported separately in line with the PEFCR guidelines. LUC emissions are calculated according to the PAS 2050:2011 method (BSI, 2011), as defined by the PEFCR. Whenever climate change impacts are shown individually, they reflect the results including LUC and peat oxidation.

The impact categories listed above were selected as they are considered the most relevant environmental impact categories for food products, based on similar impact categories mentioned in the available PEFCRs for food and beverage products (Technical Secretariat of the PEF pilot on pasta, 2018; Technical Secretariat of the PEF pilot on Wine, n.d.; The Brewers of Europe, 2015; The European Dairy Association, 2018).[20]

Even though the interpretation focusses on the abovementioned ten impact categories, the full results are provided for all 18 ReCiPe midpoint impact categories, as well as its 3 endpoint impact categories (Appendix IV). It should be noted that the conversion and aggregation of midpoint indicators into endpoint indicators is accompanied by multiple assumptions which adds uncertainty to the resulting endpoint indicators[21]. However, they do give a generic and easy-to-understand indication of the impact of both production systems on human health, ecosystems, and resources.

More details on impact assessment and the above impact categories can be found in Appendix I.

2.3 Allocation PEFCR

When a process in the life cycle has more than one function related to it, it is necessary to allocate all inputs and outputs associated with the process to each of the relevant functions (such as co-products). According to ISO 14044, wherever possible, allocation should be avoided through subdividing a process into sub-processes, or through system expansion. If this is not possible, allocation should be based on underlying physical relationships of the different products or functions like mass, or alternatively, on other relationships, such as their economic value. For example, in the PEFCR on feed for food producing animals (European Commission, 2018a), it had been decided to apply economic allocation at the cultivation stage. The same approach applies to allocation at crop processing. The by-products at the mill and oat drink processing stage (oat middling and fiber residue) are largely used as animal feed and/or as feedstock in energy production through anaerobic digestion. Due to the very low economic value of both co-products, it has been decided to allocate all impact to the main product at both stages (conservative approach).

Following the PEFCR on Dairy Products (European Commission, 2018b), biophysical allocation is applied at the dairy farm (meaning a division of impacts between the masses of raw milk and liveweight of animals) and dry matter allocation at dairy processing (skimmed milk and cream). A sensitivity analysis was carried out in the first Barista study to compare both products using economic allocation only, for consistency of the allocation method

[20] Note that ecotoxicity is excluded in the most relevant impact categories and in calculating the single score of these PEFCRs as the methodology was under development. Nevertheless, this impact category is not investigated in detail in this report as ecotoxicity impact is very much dependent on the type of active ingredient used in e.g. pesticides and is hence most relevant and representative if based on primary data instead of background datasets for cultivation.
[21] However, the uncertainty of endpoint factors has not yet been broadly implemented, and therefore cannot be assessed.

(see Table 5 and Table 6), but this did not lead to change in conclusions; when using the economic allocation method, the impact of cow's milk would become higher and hence the difference between the oat drink and the cow's milk would become even larger. The tables below indicate at which production steps co-products are generated, and what allocation choices are made.

TABLE 5: IMPACT ALLOCATION FOR OAT DRINK PRODUCTION

Production step	Co-products	Allocation type	Remark
Oat cultivation	Raw oats and oat straw	Economic	Allocation based on Agri-footprint (86% to oats, 14% to oats straw)
Oat mill	Dehulled, dried oats and oat middlings	Economic	100% allocation to dried oats
Oat drink processing	Oat base and fiber residue	Economic	100% allocation to oat base

TABLE 6: IMPACT ALLOCATION FOR COW'S MILK PRODUCTION

Production step	Co-products	Allocation type	Remark
Crop cultivation for feed	Main crop and crop residue (e.g. straw)	Economic	Allocation based on Agri-footprint (86%-97% to main crop, remainder to crop residue)
Crop processing	Grain and hulls	Economic	Allocation based on Agri-footprint
Animal farm	Cow's milk and meat	Biophysical allocation	A sensitivity analysis on cow's milk allocation was included in Barista report; it was concluded that this allocation decision leads to lower impact of cow's milk, and is thus a conservative approach
Milk processing	(Semi-)skimmed cow's milk and cream	Mass allocation based on dry matter (82% to milk, 18% to cream)	

2.4 Data sources and data quality

The majority of the data for Oatly Barista as produced in Singapore and China and sold in China was delivered by Oatly specifically for this study. The part of the data which is not specific for Oatly Barista sold in China (e.g. energy consumption of distribution centers) is based on the previous LCAs performed for Oatly Barista (Pas & Westbroek, 2022) and Oatly Original US (Keijzer et al., 2023) in order to keep results stable and comparable. Summarizing, per life cycle stage, the products have been modelled as follows:

Oatly:

- **Ingredient sourcing**: data provided by Oatly (primary data)
- **Oat milling**: in 5 different mills (primary data, data gaps filled with data from similar mills)
- **Oatbase manufacturing**: data on recipe and utilities at Ma'anshan and Singapore factories (primary data)
- **Oatly Barista manufacturing**: data on recipe and utilities from Ma'anshan and Singapore factories (primary data)
- **Packaging materials and sourcing**: specific information on weights and materials (primary data)
- **Distribution**: specific transport distances and modes (primary data)
- **Storage & losses at retail**: amounts based on US Barista data (Pas & Westbroek, 2022), by lack of literature data for China (secondary data), but modelled with Chinese datasets
- **Use**: based on losses & energy consumption for US Barista (Pas & Westbroek, 2022), by lack of literature data for China (secondary data), but modelled with Chinese datasets
- **EoL**: modeled by use of the Circular Footprint Formula (CFF), based on literature data (secondary data)

Cow's milk:

- **Cow's milk production**: based on US cow's milk production as modeled in the previous Barista report (Pas & Westbroek, 2022) but modelled with Chinese datasets and with specific adjustments for the Chinese situation based on literature and expert recommendations (secondary data).

A more detailed overview of the foreground system data and sources used per system is presented in the Life Cycle Inventory (Chapter 3). The primary data (mass, water & energy balance, inputs and auxiliary materials, transport modes & distances, and packaging data) was delivered by Oatly for the complete year 2022 for Singapore and for September 2022 till September 2023 for the Ma'anshan production location[22]. The primary and secondary data is linked to LCI datasets (background data) derived from the following databases:

- Cultivation data: Agri-footprint 6.3 (economic)
- Energy: ecoinvent 3.8 (cut-off) (also used in Agri-footprint processes)
- Auxiliary materials: ecoinvent 3.8 (cut-off)
- Transport: Agri-footprint 6.3 is used, as it provides more transport options (e.g. different load factors and empty return), compared to ecoinvent transport processes.

2.4.1 Data quality rating

Data quality of both systems (Oatly Barista and cow's milk) is assessed based on the PEFCR's data quality criteria, which include the following four requirements:

- Technological-Representativeness
- Geographical-Representativeness
- Time-Representativeness
- Precision/uncertainty

These data quality criteria are assessed according to the simplified data quality ranking as presented in Table 7 below and are applied to rate key data points in this report.

TABLE 7: DATA QUALITY RANKING

Data quality indicator (SD^2)	Characteristics of data
Poor (>1.4)	• Default data, not necessarily specific for the system in scope (e.g. transport of products from retail to consumer) • Data with high uncertainty/variability
Fair (1.30-1.39)	• Literature data, specific to the system in scope • Less accurate estimates (e.g. transport distance of oat fields to mills)
Good (1.20-1.29)	• Recent data specific to the system in scope, based on qualified estimates or good reviewed literature sources. • Primary data, that is based on qualified estimates, not reviewed (e.g. transport distance in between two locations)
Very good-Excellent (1.00-1.19)	• Recent data (<6 years), primary company data based on measurements, reviewed

The benchmarks for each rating are based on SimaPro's pedigree uncertainty calculator. This calculator computes the combined uncertainty value based on the rating for each of five criteria (the four listed above and additionally considering completeness, see Table 8 below. The pedigree uncertainty calculator is used to define the SD^2 (square of the geometric standard deviation) for each data point in SimaPro, which is used for the uncertainty analyses. A basic uncertainty factor of 1.1 is applied (somewhat higher than recommended basic of 1.05). For critical parameters in the animal production system model, such as methane emissions and feed composition, relatively high uncertainty factors are applied, as further explained in the sensitivity analysis.

The pedigree matrix functionality combines the uncertainty factors into an overall uncertainty factor (SD^2) with the following formula (Goedkoop et al., 2013):

[22] Since the Ma'anshan factory was recently opened, it started to deliver stable energy efficiency and other process information from September 2022 onwards. For that reason, not the calendar year but the year data from September 2022 till September 2023 was used.

$$SD^2 = \sum_{n=1}^{6} = SD_n^2$$

Where SD^2 is the total uncertainty expressed as square of the geometric standard deviation, SD_1 is the basic uncertainty factor and SD_2 to SD_6 the additional uncertainty factors based on the criteria.

TABLE 8: DETAILED DATA QUALITY RANKING, BASED ON SIMAPR''S PEDIGREE UNCERTAINTY CALCULATOR

	Excellent	Very good	Good	Fair	Poor
Precision	Verified based on measurements	Non-verified measurements/verified assumptions	non-verified data based on qualified estimate	qualified estimate	non-qualified estimate
Temporal	<3 years	<6 years	<10 years	<15 years	>15 years
Geographical	From area under study	Larger area in which area under study is included	Area with similar production conditions	Area with slightly similar production conditions	Unknown/ distinctly different area
Technological	Data from processes under study	Data from processes under study, but different enterprise	Data from processes under study, but different technology	Data on related processes	Data on related processes from different technology
Completeness	Representative data from all relevant sites	Representative data from >50% relevant sites	Representative data from only some sites	Representative data from only one site	Representative-ness unknown

2.4.2 Data consistency and completeness

Consistency check

Assumptions, methods, and models in the completion of this LCA are as much as possible in line with the goal and scope formulated. In principle, the majority of the data has been kept equal to the Barista study, in order to ensure consistency and comparability, except for the specific data for Oatly Barista. To showcase important aspects to be considered regarding the consistency in this report, the data of both systems has been checked based on the following criteria:

TABLE 9: CONSISTENCY CHECK

Criterion	Oatly Barista	Cow's milk
Data quality:	Data quality is very good. Most recent available and verified (by Ernst and Young, with limited assurance[23]) scope 1 and scope 2 primary data, which is used for Oatly's other sustainability reporting activities, is used. Only for some data points estimates are used (such as for storage at DC and retail). No primary data was collected for the oat cultivation stage, but this is derived from Agri-footprint, which ensures consistency with the cultivation of feed ingredients (for the cow's milk).	Data quality is good. Since the aim of the study is to compare Oatly's Barista to average cow's milk in China, national data is used to model the cow's milk where possible (e.g. fat content, heat treatment). For the data points where national data was lacking (e.g. feed intake, productivity, processing energy), the US dairy model as developed in the previous Barista study was adapted for Chinese conditions, based on recommendations from an expert familiar with the Chinese dairy sector[24] in October 2023. The LCA results are cross-checked with other studies about Chinese milk production (see section 2.7).
Geographical representativeness:	The data used refers to Oatly's end-to-end production at Ma'anshan (China), and production in Singapore which represents the full production in 2022 for this specific product. For storage at DC and retail defaults were used based on US information.	Data represents country-average data for packed milk, so adequately represents the average milk as sold and consumed in China. For storage at DC and retail defaults were used based on US information, as was done similarly for Oatly Barista in China.
Temporal representativeness:	The Oatly supply chain and processing data for Oatly from Singapore was derived from the complete year 2022 and for Oatly Barista from Ma'anshan for September 2022 to	Most essential data points, milk output and quantity of feed consumed, are based on recent reports for the US situation, such as national inventory report, NIR (United States Environmental Protection Agency, 2021a). Other

[23] See more info on the Auditor's Limited Assurance Report at Oatly's 2022 sustainability report (https://a.storyblok.com/f/107921/x/11daa2b42e/oatly-sustainability-report-2022.pdf)
[24] Jelle Zijlstra, Dairy Economist, Wageningen Livestock Research, Wageningen University & Research.

Criterion	Oatly Barista	Cow's milk
	September 2023.	data points, which are not reported in the NIR, such as rations or resource use, are based on other literature sources, as explained in Appendix II. The most recent sources were used, however, in some cases data originates from 2010. For definition of the Chinese milk market, very recent Chinese data have been used (Tang et al., 2022). Specific data on milk per cow yields has been derived from a recent scientific meta-study, including 181 farms in the period 2019-2020 (Dong & Wei, 2021).
Allocation rules:	Consistent application of economic allocation throughout all life cycle stages.	Economic allocation is applied throughout all life cycle stages in general, except for the application of biophysical allocation at the farm level and dry matter allocation at the milk processing level, which is in line with the Dairy PEFCR. This provides the most conservative choice when comparing cow's milk to oat drink, as confirmed by the sensitivity analysis in the previous Barista report.
System boundaries:	All life cycle stages are considered from cradle to point of sale, including cultivation, milling, processing, distribution, and sale at retail/foodservice (including transport in between these stages). Packaging end of life is included too.	In line with Oatly Barista system boundaries, all life cycle stages are considered from cradle to retail, including cultivation, feed processing, animal production, dairy processing, distribution, and retail (including transport in between these stages). Packaging end of life is included too.
Impact assessment methodology:	All impact categories of the ReCiPe 2016 impact assessment methodology are applied.	All impact categories of the ReCiPe 2016 impact assessment methodology are applied.

Completeness check

Table 10 provides an overview of the data that is included and excluded for each of the life cycle stages for the two systems. Whenever data is excluded, a justification if provided. Capital goods (such as buildings, machines, other basic infrastructure) are excluded in line with the latest PEFCR guidelines.

TABLE 10: COMPLETENESS CHECK

	Complete?	Included	Excluded
Oatly Barista			
Oat cultivation	Yes	• Cultivation data is derived from Agri-footprint • All necessary data and emissions as indicated by the PEFCR, including peat emissions and land use change	n/a
Oat milling	Yes	• All material, water and energy inputs • Co-products and waste streams are considered	• Capital goods
Rapeseed cultivation	Yes	• Cultivation data is derived from Agri-footprint for rapeseed 100% produced in China[25] • All necessary data and emissions as indicated by the PEFCR, including peat emissions and land use change	n/a
Rapeseed processing	Yes	• Processing data is derived from Agri-footprint for US, with adaptations made for water, crude rapeseed source (China) and electricity mix • Co-products and waste streams are considered	• Capital goods
Transport	Yes	• Mode and load of transport, transport distances	• Capital goods
Processing step 1: oat base production	Yes	• All material and energy inputs • All water consumption (in recipe and for cleaning) • Waste streams (fiber residues) are considered	• Capital goods
Processing step 2: finished oat product	Yes	• All material and energy inputs • All water consumption (in recipe and for cleaning) • Waste streams (5% losses i.e. loss in production) are considered	• Capital goods
Packaging	Yes	• Packaging raw materials type and mass • Energy for assembling packaging materials • Transport of packaging materials • Recycled content of packaging materials • End-of-life of packaging materials	• Capital goods
Distribution	Yes	• Energy and water consumption, based on PEFCR	• Capital goods

[25] This is representative for the Mongolian rapeseed as used in Oatly Barista from Ma'anshan, but a proxy for the Malaysian rapeseed used in Oatly Barista from Singapore, by lack of better data.

	Complete?	Included	Excluded
Point of sale	Yes	• Energy and water consumption, based on PEFCR • Losses in distribution	• Capital goods
Cow's milk			
Feed cultivation	Yes	• Cultivation data derived from Agri-footprint • All necessary data and emissions as indicated by the PEFCR, including peat emissions and land use change	n/a
Feed processing	Yes	• All material (feed crops and other ingredients) and energy inputs for compound feed processing and silage production	• Capital goods
Transport	Yes	• Mode and load of transport, transport distances	• Capital goods
Dairy farm	Yes	• Feed ration per animal type • Housing system (energy, material and water inputs) • Manure management emissions • Emissions from enteric fermentation	• Capital goods
Milk processing	Yes	• Energy and material inputs for milk processing • Dry matter content/price for allocation	• Capital goods
Packaging	Yes	• Packaging raw materials type and mass, based on PEFCR dairy • Energy for assembling packaging materials • Transport of packaging material • Recycled content of packaging material • End-of-life of packaging materials	• Capital goods
Distribution	Yes	• Energy and water consumption, based on PEFCR	• Capital goods
Point of sale	Yes	• Energy and water consumption, based on PEFCR • Losses from farm to retail, based on PEFCR	• Capital goods

2.5 General assumptions and limitations

- The comparative assertions are made between products, of which data is based on different sources. The impact of Oatly Barista products is calculated using mainly primary data, whereas the impact of cow's milk is calculated using secondary data, based on different sources. To overcome this, multiple sensitivity analyses are carried out, which are discussed in chapter 2.7.2, as well as in the previous Barista report (e.g. ambient vs. chilled milk). It should be noted that for the cow's milk, the most suitable way to model country-average conditions of milk production is by means of national statistics and data, but these were not available for most datapoints. Following recommendations from a scientific expert who is familiar with the Chinese dairy sector[24] in October 2023, the cow's milk modelling was based on data for US cow's milk (with some adjustments), because modern Chinese dairies have been designed to emulate US systems, although they have not been able to achieve similar efficiencies. This means that, although key data points were not specified for the Chinese situation (e.g. feed intake), the modelling was specified to the Chinese situation wherever possible (e.g. yields, manure management system and feed datasets) and based on a trustworthy source. Multiple sensitivity analysis, amongst others to compare the outcomes of this study with other studies, were executed to further investigate the robustness of the cow's milk's results. This is further explained in section 2.7.2.
- It is intended to compare the Oatly Barista and cow's milk based on their main functional application, which is to add taste and texture to food and beverages. Its main function is not to provide a certain quantity of nutrients, like protein or fibre. Therefore, no conclusions on the effect on nutrient intake are intended to be drawn from this study. However, as a sensitivity analysis, a functional unit that considers nutritional quality has been considered in the first Barista study. Since this analysis did not alter the main conclusions, this analysis is not repeated.

Assumptions and limitations related to the specific products in scope are elaborated in Chapter 3.

2.6 Cut-offs

Capital goods (such as machines and infrastructure used in dairy/Oatly factories) are not considered in modelling the foreground processes. As suggested by the latest PEFCR guidelines, capital goods can be excluded unless there is evidence from previous studies that they are relevant.

When it comes to animal feed for the dairy system, those ingredients are included that represent 90% of the total mass of feed ingredients and are extrapolated to represent 100% of the feed intake.

2.7 Sensitivity and uncertainty analyses

Several sensitivity and uncertainty analyses are performed to assess the robustness of the results, specifically the sensitivity to assumptions made and uncertainties present in input data and models.

2.7.1 Uncertainty analyses

Two types of uncertainty analyses are included:

1. A general uncertainty analysis, showing the range of uncertainty for each of the products in scope.
2. A paired Monte Carlo uncertainty analysis for two products (Oatly Barista and cow's milk), which helps to determine whether the differences between the two products are significant or not.

Both analyses are carried out in SimaPro. As in many cases uncertainty ranges of foreground data are not known, they are estimated with SimaPro's Pedigree Uncertainty Calculation (see also section 2.4.1). For certain parameters that are critical to the animal production system (such as emissions from enteric fermentation and manure management), relatively high uncertainty factors have been selected as described under sensitivity analysis below.

2.7.2 Sensitivity analyses

Below a differentiation is made between sensitivity analyses that apply to both Oatly Barista and cow's milk, and that apply to the two individual systems.

General sensitivity analyses

- A sensitivity analysis on the ReCiPe2016 LCIA method is performed to test the robustness of the results calculated with this method. Impact World+ is used as an alternative impact assessment method, because it is a muli-impact methodology which is globally applicable (by lack of specific Chinese or Asian methodology).
- A sensitivity analysis is executed to calculate the results using the 20-year timeframe for climate change (ReCiPe, Individualist) to account for the different residence time of greenhouse gases, next to the prevalent 100-year timeframe (ReCiPe, Hierarchist). GWPs are updated in line with the most recent IPCC report (IPCC, 2021).
- A sensitivity analysis is performed to consider the entire life cycle (cradle-to-grave) of both systems. The consumer (or use) phase, which is not included in the main analyses, is modelled as follows:
    - Transport from point of sale to consumer is derived from Burek et al. (2017) for the US.
    - It is assumed that both Oatly's Barista and cow's milk have the same share of losses during consumption[26]. Losses at consumption stage were presumed to be the same as in the previous Barista report.
    - It is assumed that both Oatly's Barista and cow's milk is stored in the fridge, assuming to be the same as in the previous Barista report.
    - As a conservative approach, it is assumed that both drinks are heated (even though it can also be added to drinks without heating), using 50% of the PEFCR default for energy needed to boil water as a proxy. This is because milk is not boiled but heated to 50-60 degrees Celsius (Borcherding et al., 2008; Kamath et al., 2008). Energy use for foaming is left out as this is assumed negligible compared to boiling and is not applied in all use cases.

Cow's milk

- The sensitivity of key parameters in dairy systems is assessed, which include emissions from manure management, enteric fermentation, and feed intake. This has been assessed through selection of high uncertainty factors (SD^2) for these parameters in the uncertainty analysis (see 2.4.1 for further explanation of uncertainty factors).

[26] All Oatly Oatdrink products can be preserved longer (months) while fresh milk best before date is much shorter. Therefore, Oatly Barista might probably have fewer losses at a consumer level and the gap between milk and Oatly Barista could be even higher. Given the absence of qualitative data, we assume losses to the same level as milk as a conservative approach.

    - Methane emissions from manure management and enteric fermentation were given an uncertainty factor 1.5 (somewhat higher than the uncertainty factor recommended for methane and N_2O for agriculture (1.2 and 1.4) in the (GHG Protocol, 2011).
    - Feed rations were also given a high uncertainty factor (1.5) because some assumptions were made on feed composition as explained in Appendix II.
    - For other data points the uncertainty factors are applied as described in section 2.4.1.
- Similar to the previous Barista study, a sensitivity analysis was executed to analyze the impact of the selection of "average fat content" instead of a single type of milk with a specific fat content.
- The processing of the milk was based on data from the US for consistency reasons, but this life cycle stage was observed to contribute less to overall impacts than processing in other countries (in the Barista study), a sensitivity analysis was executed to compare the results as with processing data from the other country for which UHT processing data was available (Germany).
- The results of the cow's milk impact assessment were compared with results from other studies, in order to get an impression of the variability in the results and validity of the conclusions.

The following sensitivity analyses were already evaluated in the Oatly Barista study and therefore not included here:

- Nutritional value has already been evaluated in the Barista report, where it was concluded that the differences in climate change impact between Oatly Barista and cow's milk were bigger when using a functional unit based on nutritional value (NDU) compared to a functional unit based on volume. For this reason, the sensitivity analysis for the Chinese Barista was not repeated, since nutritional properties are expected to be similar and conclusions are not expected to change.
- The type of dairy system (i.e. economic allocation) was already analyzed in the Barista report; since the modelled milk is the same, and economic allocation increased the impact of cow milk and thereby enforces the main conclusions, this sensitivity analysis was not repeated.
- A sensitivity analysis to investigate the impact of UHT in comparison to HTST milk was already done in the Barista report and it did not alter the conclusions; therefore this sensitivity analysis was not repeated.

3. Life Cycle Inventory (LCI)

This chapter describes the production chain of Oatly Barista and cow's milk in more detail, as well as the data used for the different stages of each production chain. The quality of these data is assessed using the quality indicators presented in section 2.4. A detailed life cycle inventory can be found in Appendix II and III.

3.1 Oatly Barista

3.1.1 Description of production process

In this work we assessed two Oatly factories, operating in China and Singapore at the time of the study[27]. The two factories together produced the major part of Oatly Barista supplied to the Chinese market in the period of study.

Production in Ma'anshan, China

Oat cultivation takes place in Sweden, Finland, Estonia, and Australia. The oats are dehulled and dried at 4 mills: Roeselaere (Belgium), Lahti (Finland), Vaasa (Finland) and Suqian (China). The processed oats are then transported to the Ma'anshan production facility in China. In Ma'anshan, oat base as well as the finished Oatly Barista is produced (end-to-end production). The primary packaging is supplied by a packaging production site in Beijng, the compound is supplied by a packaging production site in Belgium and the cap is supplied by a packaging production site in Europe (Italy or Germany). The secondary packaging is supplied by a packaging production site in Ma'anshan. The finished Oatly Barista is then transported ambient to several warehouses across China for distribution throughout China.

Production in Singapore

Oat cultivation takes place in Australia. The oats are dehulled and dried at a mill in Malaysia. The processed oats are then transported to the Oatly production facility in Singapore. In the Oatly production facility Singapore, oat base is produced, while the finished Oatly Barista is produced at a co-manufacturer located in the same building complex. The primary packaging is supplied by a packaging production site in Singapore, the compound is supplied by a packaging production site in Belgium and the cap is supplied by a packaging production site in Germany. The secondary packaging is supplied by a packaging production site in Malaysia. The finished Oatly Barista is then transported to several warehouses across China for distribution throughout China. The transport was modelled as refrigerated for a part of the assessed year (62%), since refrigerated transport stopped since December 2022.

3.1.2 Inventory of data used

Table 11 provides an overview of the data used to model the environmental footprint of Oatly Barista. Data with regard to the processing stage is verified by an external party. This concerns Scope 1 & 2 data which has been audited by Ernst and Young with limited assurance[23] (Oatly Group AB, 2022)(Oatly Group AB, 2022)(Oatly Group AB, 2022)(Oatly Group AB, 2022). Oatly has purchased renewable energy attribute certificates (EACs) for the Ma'anshan factory and the Oatly Singapore factory (oatbase production). A detailed life cycle inventory can be found in Appendix III (excluded from the online report due to confidential data).

TABLE 11: INVENTORY DATA LIFE CYCLE STAGES OATLY BARISTA

Life cycle stage	Description of data	Data quality
1a. Oat cultivation	Modelled using oat cultivation datasets from Agri-Footprint 6. Agri-footprint datasets consider cultivation-related inputs and resources (yield, water consumption, land occupation/ transformation, input of manure, fertilizers, lime, pesticides, start material, energy and transport of inputs), as well as emissions related to the use of these inputs and resources (nitrous oxide, ammonia, nitrate, nitric oxide, carbon dioxide, phosphorus, pesticide, heavy metals). Emissions from land use change and peat oxidation are included as well. For the	*Good*

[27] End-to-End (E2E) Factory: The entire production chain happens within Oatly's own factory. From grains to the finished product. A co-manufacturing Factory: a contract manufacturer factory receives Oatly oatbase on tankers. The co-manufacturer, formulates the Finished Product, fills, and packs the products for Oatly.

Life cycle stage	Description of data	Data quality
	production of Oatly Barista in China, oats originate from Sweden, Finland, Estonia and Australia. For the production of Oatly Barista in Singapore, oats originate from Australia.	
1b. Other ingredient production	The quantity of other ingredients used during processing or added to the final product are provided by Oatly. These include rapeseed oil, acidity regulator (dipotassium phosphate), calcium carbonate, calcium phosphates and iodised salt. Rapeseed oil (from inner Mongolia for the Ma'anshan production, and from Malaysian origin for the Singapore production) were modelled as an adaptation from US rapeseed from the Agri-footprint database, whereas the other ingredients were modelled using datasets from ecoinvent 3.8.	*Good*
2. Oats transport to mill	To account for transport from oat cultivation to mills, estimates are provided by Oatly (as location of farmers is not available). All trucks are modelled with a capacity >20t, a load factor of 80% and an empty return. All ships were modelled with a 60,000 deadweight tonnage (DWT), a load factor of 80% and default return in AFP.	*Fair*
3. Oats milling	Primary data was provided by Oatly on energy use (electricity and heat), and water consumption for all mills except Vaasa and Malaysia. The oat hulls are going to either animal feed or xylitol production. By lack of information on the xylitol production, a conservative approach is followed: the value of this stream is considered negligible, thus all impacts are allocated to the oats.	*Good*
4a. Transport of oats to factory	Distance based on locations of the mills and the Oatly factories. Transport was modelled using a combination of trucks and ships, taking into account mill to port, port to port and port to factory transport.	*Very good*
5. Processing – oat base	The input use (energy, heat, water) to generate oat base and finished product was provided by Oatly based on data from the production facilities in scope. Water use includes both water in the recipe (final product), and water used for processing (mainly cleaning). The quantity of water going to wastewater treatment is also recorded for both factories. For the Singapore factory, water being discharged was not recorded; this missing water flow was estimated based on Ma'anshan data.	*Very good*
6. processing – Oatly Barista	The input use (energy, heat, water) to generate oat base and finished product was provided by Oatly based on data from the production facilities in scope. Water use includes both water in the recipe (final product), and water used for processing (mainly cleaning). The quantity of water going to wastewater treatment is also recorded for both factories. For the Singapore factory, water being discharged was not recorded; this missing water flow was estimated based on Ma'anshan data. To account for losses during processing, an estimation was provided by Oatly of 5% losses during production. This concerns a maximum and is based on an interview with Oatly's factory controller (Veljanovski, 2022).	*Very good*
7a. packaging	Primary data on packaging composition is supplied by the packaging manufacturer. Next to the materials used (such as LDPE, aluminum, paperboard), energy was accounted for processing these materials based on ecoinvent datasets (sheet rolling for aluminum, injection molding for the HDPE cap etc.). Secondary packaging (corrugated board) is also included. In the CFF, for R1 European values have been used, since most of the packaging comes from Europe.	*Very good*
7b. Transport of packaging material	Upstream data for packaging (e.g. of raw materials) is already included in the ecoinvent datasets used. Transport (assuming a combination of diesel trucks and ships) was added from the packaging manufacturing facilities to Oatly's corresponding factories based on their locations.	*Very good*
8a. Distribution to DC	The transport from the factory to the distribution center is provided by Oatly. Oatly uses trucks with a capacity of 21.5-36 tons	*Good*

Life cycle stage	Description of data	Data quality
	(Månsson, 2022) (modelled as >20ton trucks with a load factor of 80%). The transport of Oatly Barista produced in Ma'anshan to the distribution center is 100% ambient transportation. The transport from the Singapore production location to the distribution center in China was refrigerated for a part of the assessed year (62%)[28]. Refrigerated transport was modelled based on ecoinvent datasets for refrigerated transport. Since ecoinvent only included a small refrigerated transport option (truck < 16 ton), transport for a >20 ton truck was modelled using the same assumptions as for the smaller trucks: 20% higher fuel use for the refrigeration machine, and the use and emission of 1.71E-5 kg R134/tkm.	
8b. Distribution to Retail	For China, Oatly has provided data on the transport distance from DC to retail by means of ambient diesel trucks.	*Fair*
9. Storage at DC and retail	For China, storage at DC and retail was modelled using data for the US situation from Burek et al. (2017).	*Fair-Poor*
10. Use (only for sensitivity analysis)	The use stage was modelled as follows: • Transport from retail to customer: 0.195 km/kg product (based on US data, Burek et al., 2017). • Electricity fridge: 0.0222 kWh/kg product (based on Dairy PEFCR default for UHT milk: 2 days storage for UHT milk, assuming 3 times product volume and electricity use of 1350kwh/m^3/y). • Heating: assuming 50% of boiling energy (=0.5*0.18kWh/L), as milk is not boiled but heated to 50-60 degrees Celsius (Borcherding et al., 2008; Kamath et al., 2008). • Losses at consumer: 20% (based on US data, Burek et al., 2017).	*Poor*
11. End of Life of Packaging	The EoL of the packaging material is calculated using the Circular Footprint Formula (CFF) from the PEFCR. Landfill, incineration and recycling rates were derived from a World Bank Group report (World Bank Group, 2019), where the category "other" (2%) was assumed to reflect recycling, by lack of specific recycling data[29]. For secondary packaging material (corrugated board) no CFF was applied, and dataset was selected that already includes recycled material.	*Fair*

3.1.3 Assumptions and limitations

- The impact at the mill is allocated 100% to the production of dehulled, dried oats (conservative assumption).
- At end-to-end factories[30], i.e. Ma'anshan, the energy and water were divided between the two processes based on the following logic: the energy and water consumption from all Oatly and partner factories that produce either only oatbase or only finished product (oatbase is delivered to the factory in this case) were analyzed and ranges for the two separate processes were extracted. By analyzing the available data, it has been possible to define the approximate energy/water consumption ranges for producing oatbase only and producing finished product only. As a consequence, the appropriate allocation shares between oatbase and finished product could be estimated for the factories where both outputs are produced.
- The water balance from the Singapore production line was not complete since wastewater to discharge was missing, and therefore the data were adapted to the same water consumption ratios as in

[28] Refrigerated transport has stopped since December 2022.
[29] Note that there are studies supposing the recycling rate is higher for LDPE & aluminium in packaging (up to 70% recovery), thanks to plastic pickers, but this could not be verified by official statistics. Therefore, we stuck to the World Bank Group data, which is thus a conservative approach.
[30] End-to-End (E2E) Factory: The entire production chain happens within Oatly's own factory. From grains to the finished product.

Ma'anshan, presuming a conservative approach where all water was send to wastewater treatment. These values were crosschecked with water ratios from the US factories, showing similar values.

- Information on the type and quantity of packaging material is provided by packaging producers. Energy consumption required to assemble the primary packaging is based on data from ecoinvent.
- The circular footprint formula (CFF) is only applied to the main packaging type, not to secondary packaging. For secondary packaging, a corrugated board dataset was used that already includes recycled material.
- Some transport distances concern (conservative) estimates, such as the transport of oat fields to the mills and from DCs to point of sale.
- Energy and water consumption at DCs and retail is based on literature for the US, by lack of primary Chinese data.

3.2 Cow's Milk

Secondary data is used to model the dairy production chain. The most important element of the footprint of cow's milk at point of sale is raw cow's milk from dairy farms (Blonk Consultants, 2020b).

Animal Production System Footprint (APS Footprint) is a tool for computing LCA impacts of animal production systems, according to well-defined LCA-standards and guidelines regarding methodology and data (Blonk Consultants, 2020a, 2020b). The methodological framework regarding allocation, functional units, boundary definitions and emission modelling is based on published and recognized international guidelines (European Commission, 2018b; European Environment Agency, 2016; IPCC, 2006).

Representative data for dairy production in China are not publicly available. An expert familiar with modern Chinese dairy production[24] who was consulted in October 2023, recommended modeling analogous to US cow's milk production with some adjustments. The reason for this, is because modern Chinese dairy suppliers (whose marketing focuses at packaged milk for retail) have been designed to replicate US production. Therefore, the US dairy model developed in the previous Barista study was used as the starting point for modelling Chinese dairy production. Milk yields, manure management, and feed origin were adapted as described below. A full account of the methodology and data sources that were used to model raw cow's milk is provided in Appendix II.

3.2.1 Inventory of data used

TABLE 12: INVENTORY DATA COW'S MILK

Life cycle stage	Description of data	Data quality

1. Raw milk	A brief overview of the data used to model raw milk is provided below. A detailed overview of all datapoints used, as well as the APS methodology, is provided in Appendix II. In general, the Chinese milk production was based on the model for US cow's milk in the previous Barista report, with some adaptations.
	
	The following data were collected to calculate the environmental footprint of cow's milk using the APS Footprint tool:
	• Milk output per cow and fat and protein content (China specific from Dong & Wei, 2021)
	• Herd characteristics
	• Feed ration and characteristics
	• Energy input
	• Water input
	• Bedding material
	
	Based on these parameters, the footprint is calculated per kg of milk output. The footprint consists of:
	• Emissions from manure management and enteric fermentation:
	  o Methane (CH_4) from enteric fermentation (calculated with IPCC Tier 2)
	  o CH_4 from manure (calculated with IPCC Tier 2)
	  o Direct dinitrogen monoxide (also called nitrous oxide) (N_2O) from manure (calculated with IPCC Tier 2)
		Fair-Poor

Life cycle stage	Description of data	Data quality
	○ Indirect N2O from leaching of manure (calculated with IPCC Tier 2) ○ Indirect N2O from volatilization of ammonia (NH3) and nitrogen oxides (nOx); (calculated with IPCC Tier 2) ○ Non-methane volatile organic compounds (NMVOC) from manure (calculated with EMEP/EEA Tier 2) ○ Particulate matter (PM2.5 and PM10) from manure (calculated with EMEP/EEA Tier 1) • Emissions from the cultivation and processing of feed crops (modelled with Agri-footprint 6.0 data). Agri-footprint datasets consider cultivation-related inputs and resources (yield, water consumption, land occupation/ transformation, input of manure, fertilizers, lime, pesticides, start material, energy and transport of inputs), as well as emissions related to the use of these inputs and resources (nitrous oxide, ammonia, nitrate, nitric oxide, carbon dioxide, phosphorus, pesticide, heavy metals). Emissions from land use change and peat oxidation are covered as well. Further processing of the crops into feed ingredients, as well as country-specific market mixes, are also included. • Emissions related to energy use and bedding material (modelled with ecoinvent energy data and Agri-footprint for bedding material).	
2. Transport of milk to factory	The transport distance is supposed to be the same as for the US, derived from literature: 425 km (Burek et al., 2017). Transport in a refrigerated truck of >20 tons with empty return.	*Fair-Poor*
3. Milk processing	Energy and water consumption was supposed to be the same as for the US, derived from (Burek et al., 2017). The dry matter content was supposed to be the same as for the US, derived from (Thoma, Popp, Nutter, et al., 2013a), leading to the following allocation factors: • Whole milk: 93% milk, 7% cream • Semi-skimmed milk:81.6% milk, 18.4% cream • Skimmed milk: 65.8% milk, 34.2% cream With regard to losses, the PEFCR default is applied encompassing losses from farm to retail (applied at retail level).	*Fair*
4. Milk packaging	The only information about average packaging materials for Chinese milk that was available, was the remark that Tetra Pak is a major supplier (Tang et al., 2022). Therefore, the modelling of the packaging was kept equal to Oatly Barista's packaging in China, which is supplied by Tetra Pak.	*Fair*
5. Distribution to DC and retail	By lack of primary data, distribution was presumed similar to distribution of US cow's milk.	*Fair*
6. Storage at DC and supermarkets	By lack of primary data, storage was presumed similar to storage of US cow's milk.	*Fair*
7. Use (only included in sensitivity analysis)	Use was presumed similar to use of Oatly Barista China	*Fair*
8. End of Life of packaging	The EoL of the packaging material is calculated using the Circular Footprint Formula (CFF) from the PEFCR. Landfill, incineration and recycling rates were derived from a World Bank Group report (World Bank Group, 2019), where the category "other" was assumed to reflect recycling, by lack of specific recycling data. For secondary packaging material (corrugated board) no CFF was applied, and dataset was selected that already includes recycled material.	*Fair*

3.2.2 Assumptions and limitations

- Milk is modelled based on a US model and supplemented with literature data and expert judgement. This approach was deemed sufficient for the goal of this study, since the Chinese system is similar to the US system (according to an international dairy expert[4], familiar with the Chinese production system) and some of the most important parameters (e.g. milk yields, manure management and feed origin) were adjusted with China-specific data. Processing energy, packaging composition and storage at DC & Retail is based on defaults from the Dairy PEFCR.
- For certain data points, estimates had to be made, such as for transport distances from dairy farm to factory, from factory to DC and from DC to retail. These were consistently based on national transport distances from Blonk's transport model.
- In some cases, assumptions had to be made in case data on feed ration composition was absent (e.g. for calves <1 year) or aggregated. These are described in Appendix II.
- The APS tool does not yet include updated emission factors for manure management and enteric fermentation from the latest IPCC guidelines (it will in a future update). It is estimated that updated emission factors might result in a 1-10% change (positive or negative) in methane emissions from manure management and enteric fermentation. Variability in emissions from these two sources are covered in the uncertainty analysis.

4. Life Cycle Impact Assessment (LCIA)

The Life Cycle Impact Assessment provides the main results for all products in scope, whereas the next chapter (Life Cycle Interpretation) provides a more detailed account of the stages and processes contributing the most to the impact, as well as how assumptions in data and modelling choices influence the outcomes (section 5.2). The uncertainty present in the data is analyzed in section 5.3.

Figure 5 shows the climate change impact results for Oatly Barista and cow's milk at point of sale in China (incl. packaging EoL). The results for all key impact categories are listed in Table 13, and for all other impact categories can be found in the Appendix IV.

For China, the two articles include Oatly Barista produced in the Ma'anshan factory and the Singapore factory. The percentages indicate how the environmental impact of Oatly Barista compares to cow's milk (e.g. -50% indicates a 50% lower footprint of Oatly Barista compared to cow's milk on a liter basis). Both variants available on the Chinese market, show both an approximate 68% lower carbon footprint than cow's milk on a liter basis.

Table 13 shows that, in China, both variants of Oatly Barista have a lower environmental impact than cow's milk when it comes to the environmental impact categories climate change, fine particulate matter formation, terrestrial acidification, freshwater eutrophication, marine eutrophication, mineral resource scarcity, fossil resource scarcity and water consumption. For land use impact (both characterized as well as uncharacterized), Oatly Barista from the Ma'anshan factory (being supplied with oats from Sweden, Finland, Estonia, and Australia) has a lower impact than cow's milk. Oatly Barista from Singapore (being supplied with oats from Australia) has a higher impact than cow's milk in the characterized results (which assesses land surface considering the relative species loss due to local land use), however due to the use of global biodiversity factors which are not regionalised, the geographic representation and validity of this method can be debated. The second method employed (uncharacterized) land occupation category shows a similar impact for Oatly Barista from Singapore in comparison to Chinese cow's milk.

Differences between the products are explained in more detail in the next chapter (life cycle interpretation).

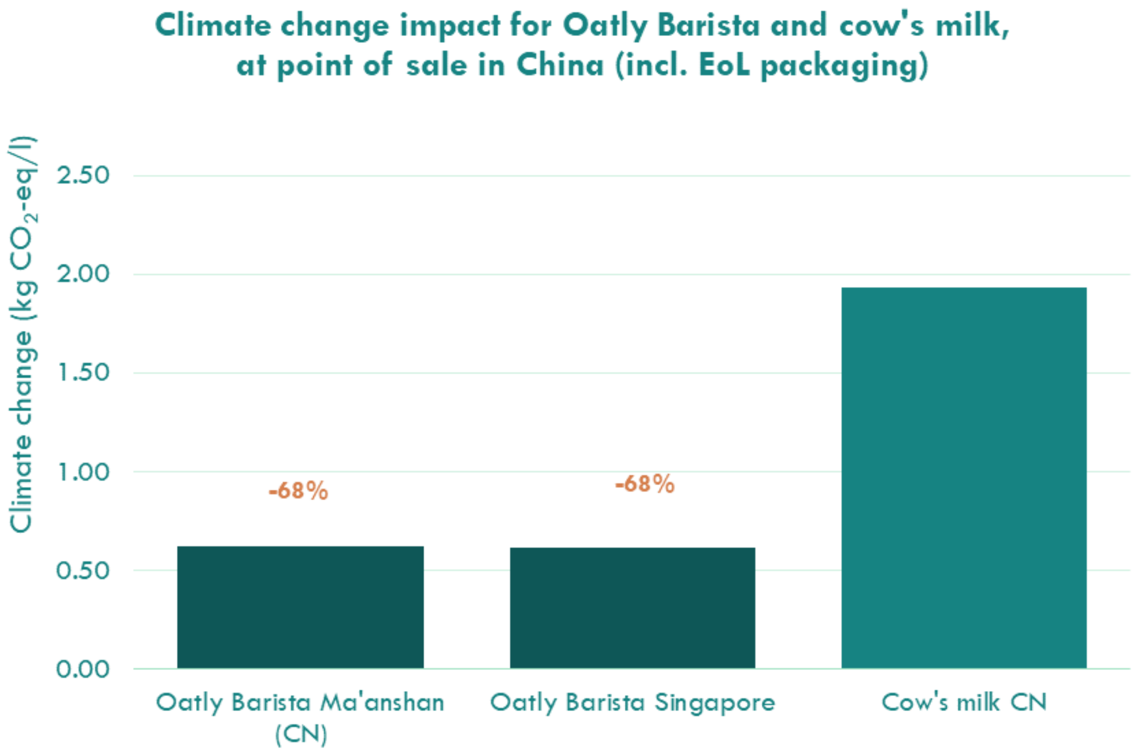


FIGURE 5: CLIMATE CHANGE IMPACT OF 1L OATLY BARISTA AND COW'S MILK AT POINT OF SALE INCLUDING END-OF-LIFE (EOL) OF PACKAGING.

TABLE 13: RESULTS FOR KEY IMPACT CATEGORIES FOR 1L OATLY BARISTA AND COW'S MILK AT POINT OF SALE INCLUDING END-OF-LIFE (EOL) OF PACKAGING. RELATIVE RESULTS ARE INDICATED WITH COLOR: FOR EXAMPLE, -68% INDICATES THAT OATLY BARISTA HAS A 68% LOWER IMPACT COMPARED TO COW'S MILK. THE COLOUR SCALE USES GREEN TONES TO SHOW WHERE OATLY BARISTA HAS A SIGNIFICANTLY (>10%) LOWER IMPACT THAN COW'S MILK, RED TONES WHERE COW'S MILK HAS A SIGNIFICANTLY (>10%) LOWER IMPACT THAN OATLY BARISTA, AND YELLOW TONES ARE APPLIED FOR NON-SIGNIFICANT DIFFERENCES (<10%)

Impact category	Unit	Oatly Barista Ma'anshan (CN) factory		Oatly Barista Singapore factory		Cow's milk (CN)
Climate change - incl LUC and peat ox	kg CO_2 eq	6.24E-01	-68%	6.18E-01	-68%	1.94E+00
Climate change - excl LUC and peat ox	kg CO_2 eq	4.84E-01	-73%	6.08E-01	-66%	1.81E+00
Climate change - only LUC	kg CO_2 eq	2.14E-02	-81%	9.35E-03	-92%	1.12E-01
Climate change - only peat ox	kg CO_2 eq	1.18E-01	924%	1.06E-03	-91%	1.15E-02
Fine particulate matter formation	kg PM2.5 eq	6.57E-04	-86%	8.72E-04	-81%	4.57E-03
Terrestrial acidification	kg SO_2 eq	1.85E-03	-91%	2.25E-03	-89%	2.00E-02
Freshwater eutrophication	kg P eq	2.63E-04	-60%	3.08E-04	-53%	6.60E-04
Marine eutrophication	kg N eq	4.84E-04	-61%	1.37E-04	-89%	1.24E-03
Land use	m^2a crop eq	9.00E-01	-17%	1.37E+00	26%	1.09E+00
Land occupation	m^2a	1.01E+00	-26%	1.48E+00	8%	1.37E+00
Mineral resource scarcity	kg Cu eq	1.39E-03	-50%	1.44E-03	-48%	2.78E-03
Fossil resource scarcity	kg oil eq	1.38E-01	-46%	1.71E-01	-33%	2.54E-01
Water consumption	m^3	7.07E-03	-78%	2.29E-02	-30%	3.27E-02

5. Life Cycle Interpretation

5.1 Contribution analysis

A contribution analysis allows to assess the influence of individual life cycle stages on the impact results. A contribution analysis is provided for all products in scope, after which more detail is provided for Oatly Barista and cow's milk separately. The contribution analyses focus on the climate change impact but are also provided for the other impact categories.

5.1.1 Comparison of Oatly Barista and cow's milk

Figure 6 shows the contribution analysis of the climate change impact category, and Figure 7 shows the same analysis for the other main impact categories.

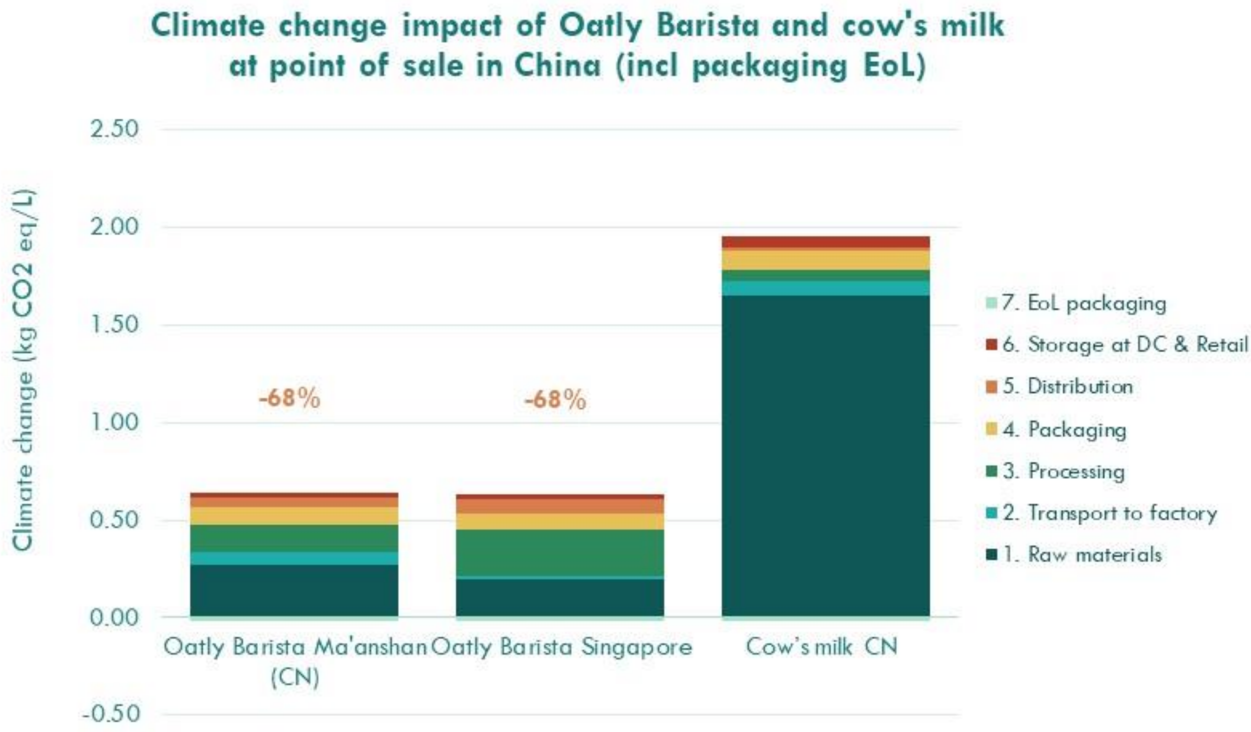


FIGURE 6: CLIMATE CHANGE IMPACT OF 1L OATLY BARISTA AND COW'S MILK AT POINT OF SALE INCLUDING END-OF-LIFE (EOL) OF PACKAGING

These graphs better explain the differences already observed in the previous chapter. A few key processes contributing to the different impact categories are highlighted here:

- **Climate change** is mainly linked to carbon dioxide and nitrous oxide emissions from the cultivation of oats (contributing 32% to the total climate change impact of Oatly Barista from Ma'anshan and 16% for the Singapore production) and methane emissions from the production of raw cow's milk. Additionally, climate change is linked to the combustion of fossil fuels during processing and transport of Oatly Barista (processing 23-39%, distribution 8-13%) and to a number of processes in the rapeseed oil production chain (contributing 9% to the climate change impact of Oatly Barista from Ma'anshan and 6% for Singapore). For cow's milk, these life cycle stages contribute to a lesser extent. It should be noted that for cow's milk processing US data were used, which are relatively low in comparison to cow's milk processing data for other countries, as seen in the previous Barista report. This is further investigated in a sensitivity analysis (see section 5.2.4).
- **Fine particulate matter formation** is mainly linked to ammonia emissions from manure (cow's milk), and to a lesser extent to combustion of fuels related to transport and packaging production for both cow's

milk and Oatly Barista, as well as the ammonia emissions from the application of fertilizers during cultivation (oats, rapeseed, and cow's feed crops).

- **Terrestrial acidification** is mainly linked to ammonia emissions from manure (cow's milk), and to a lesser extent to ammonia and nitrogen oxide emissions from the application of fertilizers during cultivation (oats, rapeseed, and cow's feed crops).
- **Freshwater eutrophication** is linked to phosphate emissions during cultivation of oats, rapeseed and cow's feed crops, but also to chemical oxygen demand (COD) from waste treatment of packaging more specifically, long-term leachate from landfill.
- **Marine eutrophication** is linked to nitrate from the application of fertilizers and manure during cultivation of oats, rapeseed, and cow's feed crops. Marine eutrophication impact is lower for Oatly produced in Singapore due to lower fertiliser application in oat production in Australia.
- **Land use** is mostly related to cultivation of crops (oats and feed crops). The land use of Oatly Barista from the Ma'anshan factory (being supplied with oats from Sweden, Finland, Estonia and Australia) has a lower impact than cow's milk. Oatly Barista from Singapore (being supplied with oats from Australia) has a higher impact than cow's milk. This is due to the supposed lower yield from Australian oats, as represented in the AFP database and derived from FAO statistics. Whether this is accurately the case for the farms supplying Oatly, is unknown since primary data from the farms is lacking. While the land use impact is caused mainly by oat cultivation (66-79%), the second contributor in this category is rapeseed cultivation (16-26%).
- **Land occupation** (which entails total, uncharacterized land surface used) shows a lower impact for Oatly Barista from Ma'anshan in comparison to cow's milk. The land occupation of Oatly Barista from Singapore is similar to cow's milk (the 8% difference is below the significance threshold). 59-73% of the land occupation of Oatly Barista comes from oats cultivation, while 15-23% is caused by rapeseed cultivation.
- **Mineral resource scarcity** is linked to use of mineral fertilizers for crop cultivation (both for the oats and rapeseed used in Oatly Barista, and for the feed consumed by the cows), calcium phosphate additions in Oatly Barista, and the use of colorants in cardboard and aluminum [31] in packaging. Additionally, renewable electricity sources cause an increased impact on mineral resource scarcity due to the metals used to produce solar panels and wind turbines for electricity for the Ma'anshan factory and for the Singapore Oatbase factory.
- **Fossil resource scarcity** is linked to the use of fossil fuels for transport, heat, electricity generation, and packaging (material and production) for both systems. Negative values at EoL are due to generation of heat during incineration of packaging material, which substitutes the use of fossil fuels. The relatively high processing energy and long transport distance of the final product to the market contribute significantly to the impact of Oatly Barista, however Oatly still performs better due to the higher impact during cultivation of the feed crops and the higher packaging impact for cow's milk.
- **Water consumption**[32] is linked to irrigation at cultivation level, to water used during processing[33] and packaging manufacturing. The oats from Australia are more irrigated than in other countries, resulting in a higher footprint for the Barista product from Singapore (using 100% Australian oats) than the Ma'anshan product (using 13% Australian oats). Related to cow's milk production, in China more irrigation is applied for the cultivation of feed crops than in other countries. Maize, which makes up a relatively large share of the feed ration, is partly irrigated and contributes most to the water footprint of cow's milk in China.

[31] This aluminium is modelled as wrought alloy, representing mostly primary aluminium.
[32] Water consumption is the fraction of water use that is not returned to its original source. Water consumption at cultivation concerns irrigation water that evaporates or is taken up by the plant. Water consumption at processing concerns tap water use minus water that becomes available again after wastewater treatment.
[33] Water under the processing category includes: 1) Water used within the factory's four walls i.e. water for the formulation of the product and water for processing in the factory (e.g. for cleaning); 2) water consumption that occurs elsewhere but is attributed to the processing at the factory e.g. water consumed for energy production as used in the factory.


a. Fine particulate matter formation
Fine particulate matter (kg PM 2.5 eq/L)
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
-2.00E-03
6.57E-04
8.72E-04
4.57E-03
Oatly Barista Ma'anshan (CN)
Oatly Barista Singapore
Cow's milk CN
b. Terrestrial acidification
Terrestrial acidification (kg SO2 eq/L)
4.50E-02
4.00E-02
3.50E-02
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
-5.00E-03
1.85E-03
2.25E-03
2.00E-02
Oatly Barista Ma'anshan (CN)
Oatly Barista Singapore
Cow's milk CN
1. Raw materials
2. Transport to factory
3. Processing
4. Packaging
5. Distribution
6. Storage at DC & Retail
7. EoL packaging
c. Freshwater eutrophication
Freshwater eutrophication (kg P eq/L)
1.40E-03
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
2.63E-04
3.08E-04
6.60E-04
Oatly Barista Ma'anshan (CN)
Oatly Barista Singapore
Cow's milk CN
d. Marine eutrophication
Marine eutrophication (kg N eq/L)
3.00E-03
2.50E-03
2.00E-03
1.50E-03
1.00E-03
5.00E-04
0.00E+00
4.84E-04
1.37E-04
1.24E-03
Oatly Barista Ma'anshan (CN)
Oatly Barista Singapore
Cow's milk CN
1. Raw materials
2. Transport to factory
3. Processing
4. Packaging
5. Distribution
6. Storage at DC & Retail
7. EoL packaging


e. Land use
Land use (m2a crop eq/L)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
0.90
1.37
1.09
Oatly Barista Ma'anshan (CN)
Oatly Barista Singapore
Cow's milk CN
f. Land occupation
Land occupation (m2a/L)
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
1.01
1.48
1.37
Oatly Barista Ma'anshan (CN)
Oatly Barista Singapore
Cow's milk CN
1. Raw materials
2. Transport to factory
3. Processing
4. Packaging
5. Distribution
6. Storage at DC & Retail
7. EoL packaging
g. Mineral resource scarcity
Mineral resource scarcity (kg Cu eq/L)
6.00E-03
5.00E-03
4.00E-03
3.00E-03
2.00E-03
1.00E-03
0.00E+00
-1.00E-03
1.39E-03
1.44E-03
2.78E-03
Oatly Barista Ma'anshan (CN)
Oatly Barista Singapore
Cow's milk CN
h. Fossil resource scarcity
Fossil resource scarcity (kg oil-eq/L)
6.00E-01
5.00E-01
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
-1.00E-01
0.138
0.171
0.254
Oatly Barista Ma'anshan (CN)
Oatly Barista Singapore
Cow's milk CN

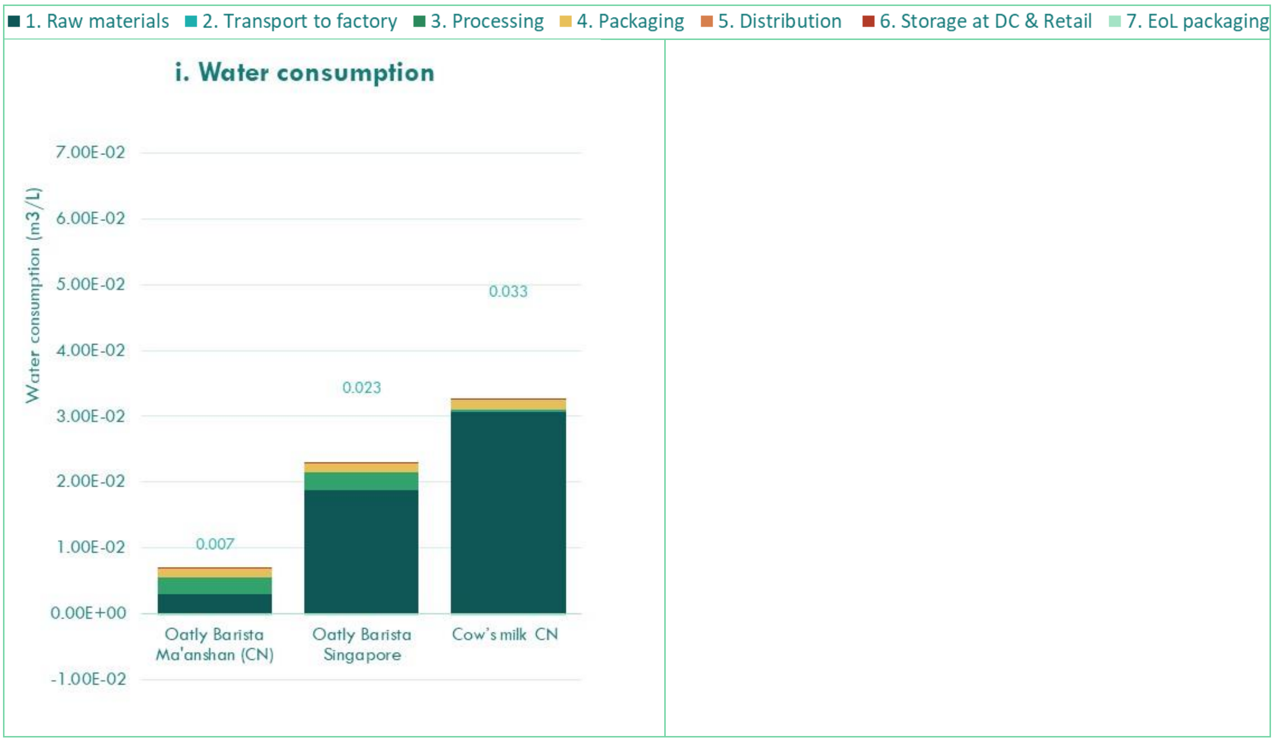


FIGURE 7: KEY IMPACT CATEGORIES OF 1L OATLY BARISTA AND COW'S MILK AT POINT OF SALE INCLUDING END-OF-LIFE (EOL) OF PACKAGING

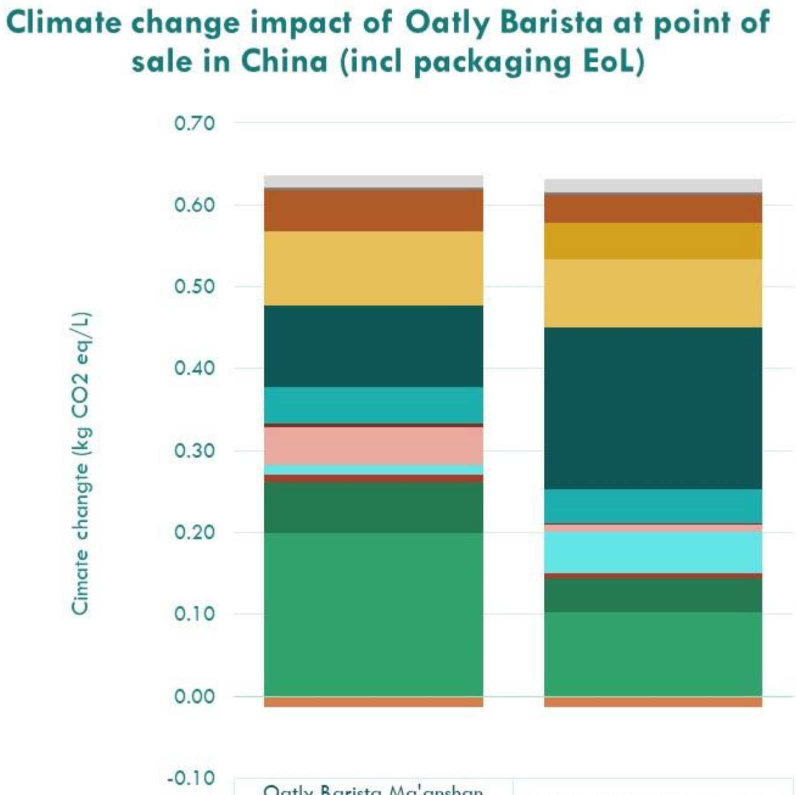
5.1.2 Oatly Barista

Figure 8 shows the contribution analysis for the climate change impact results for both Oatly Barista products in China. The total impact of both products is similar, but there are large differences in the contribution of the individual life cycle stages. The raw material stage is relatively high in Ma'anshan in comparison to Singapore, but this is compensated by lower impact in especially the processing stage.

Below some highlights for the main production stages are described.

- **Raw materials**: The production of oats from Australian origin as used in the Singapore and Ma'anshan factory, cause no significant emissions from land use change (LUC), but the oats from Finnish origin as used in the Ma'anshan factory do cause peat oxidation, as shown in Figure 9.A. Concerning the other ingredients (not shown in this graph), the rapeseed oil has a relatively high climate change impact due to its relative low yields at the country of cultivation.
- **Processing**: Figure 9B and Figure 9C shows that heat (from natural gas in Ma'anshan, from light fuel oil in Singapore) and electricity (only in the Singapore co-manufacturing factory; the Ma'anshan and Oatly Singapore factories use electricity from renewable sources) make up the largest share of the two processing stages.
- **Packaging**: The corrugated board box has the highest impact in the packaging climate change impact, as being the material with the highest weight in the total pack. The second highest impact is caused by the smallest amount of material: aluminum[31]. The third contributing material, even though its weight is also low (8%) compared to the total weight, is BioPE.
- **Distribution to retail/DC**: The main contributor to the climate change impact of the distribution of Oatly Barista in China differs for the two articles; for Oatly Barista from Ma'anshan, the hotspot is in the transport from distribution center to the retail locations, while for Oatly Barista from Singapore, the transport from the Singapore factory to the distribution center in China has a higher impact. In addition to the long transport distance from Singapore (5261 km), the fact that a part of the year (62%) refrigerated ships and trucks were used, also contributes to the distribution impact. Since December 2022, this refrigerated transport has stopped, which means the impact will be lower when assessing only 2023 and beyond.
- **Storage at retail/DC**: the impact of storage is 3% in comparison to the total climate change impact of Oatly Barista in China. It should be noted that this is based on US data, by lack of specific Chinese information, and thus is not an exact number.

- **End of Life** (EoL): the climate change impact from End of Life is similar for both production locations, even though the composition of the packaging is slightly different as was shown in Figure 9D. The similarity in the result for the End of Life stage is due to a similar approach in end of life modelling which consists of incineration with energy recovery, landfilling and, for some materials, recycling. This life cycle stage contributes only 2% to the total climate change impact.



	Oatly Barista Ma'anshan (CN)	Oatly Barista Singapore
Total	0.62	0.62
10. Packaging End of Life	-0.01	-0.01
09b. Storage at retail	0.02	0.02
09a. Storage at DC	0.00	0.00
08b. Distribution to Retail	0.05	0.03
08a. Distribution to DC	0.00	0.04
07b. Transport of packaging	0.00	0.00
07a. Packaging	0.09	0.08
06. Processing - Oatly Barista	0.10	0.20
05. Processing - Oat base	0.05	0.04
04b. Transport of other ingredients	0.00	0.00
04a. Transport of oats to factory	0.05	0.01
03. Oats milling	0.01	0.05
02. Oats transport to mill	0.01	0.01
01b. Other ingredient production	0.06	0.04
01a. Oat cultivation	0.20	0.10

FIGURE 8: CLIMATE CHANGE IMPACT OF AMBIENT OATLY BARISTA AT POINT OF SALE INCLUDING END-OF-LIFE (EOL) OF PACKAGING, SORTED FROM LOWEST TO HIGHEST IMPACT

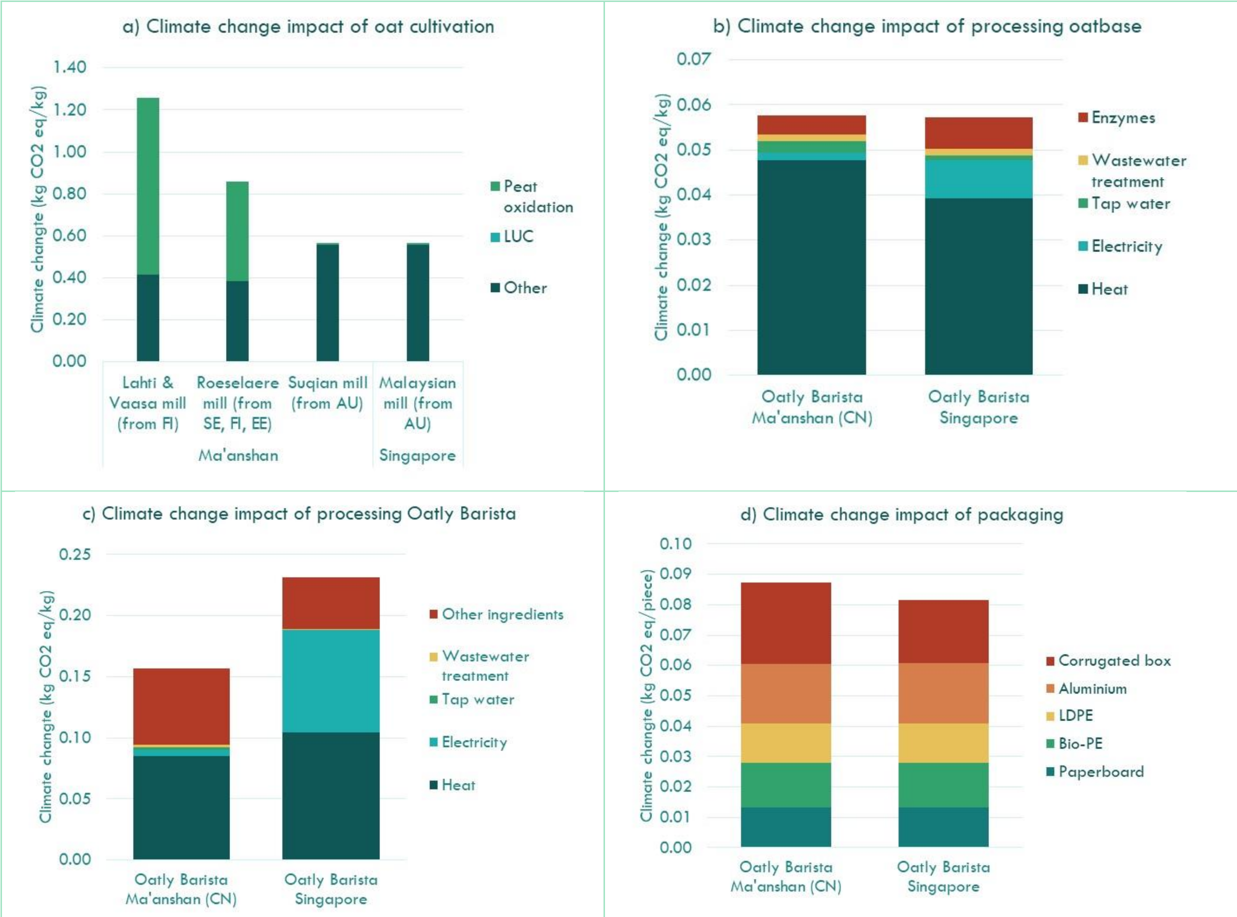


FIGURE 9: CLIMATE CHANGE IMPACT OF A) OAT CULTIVATION, B) OATBASE PROCESSING, C) OATLY BARISTA PROCESSING, AND D) PACKAGING

Until 2022, a part of Oatly Barista sold in China was imported from the Vlissingen factory located in the Netherlands. To better understand the impact of this change, Oatly wishes to analyse the differences between this previous configuration and the current one. Figure 10 shows the climate change impact of Oatly Barista sold in China and produced in three Oatly locations: Ma'anshan (CN), Vlissingen (NL) and Singapore (SG).

The results show that Oatly Barista produced in Vlissingen has only a 4% higher climate change impact than Oatly Barista from Ma'anshan and Singapore, despite the much higher distribution impact (105% more impactful than import from Singapore and 223% more impactful than the distribution from the Ma'anshan factory). This is because a large part of the savings from the distribution are counterbalanced by a higher impact from the transport of raw material to the Asian factories and a higher impact in terms of raw material production, transport of raw materials to the factories and, for Singapore, oat drink processing.

To improve the impact of the local factory configuration (Ma'anshan), the raw material sourcing locations and their related transport could be areas of opportunities. If the Ma'anshan factory would be optimized to reach lower impact for raw materials and transport (e.g. by sourcing all oats from Australia), the impact of Oatly Barista from Ma'anshan could be reduced to 0.56 kg CO_2 eq./L, meaning 15% lower than the impact for the product produced in Vlissingen and imported to China.

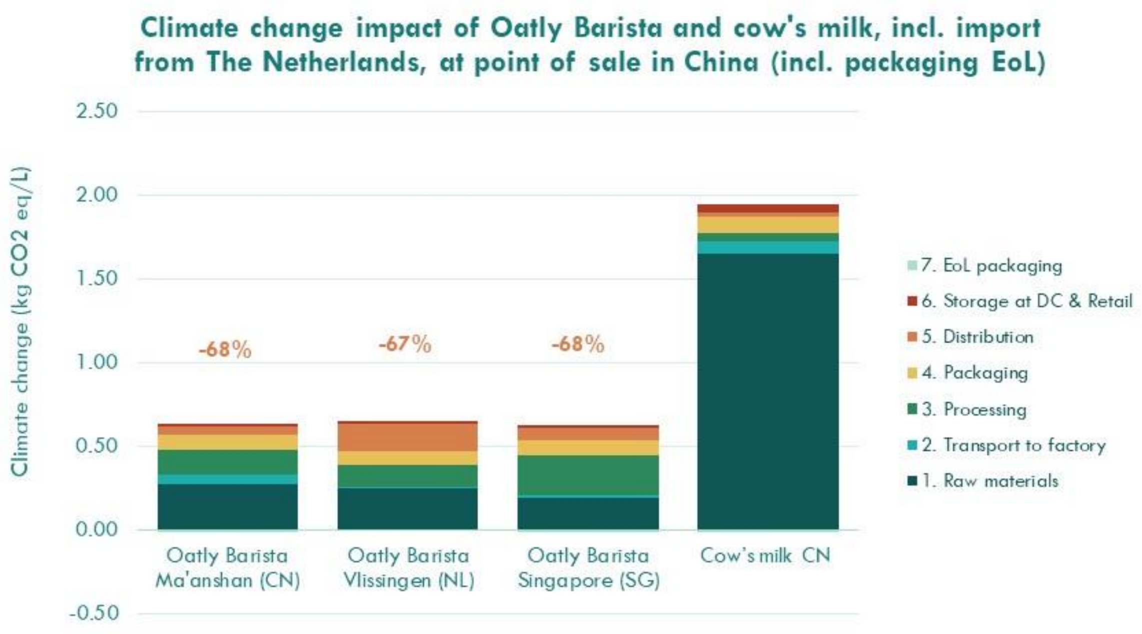


FIGURE 10: ANALYSIS FOR OATLY BARISTA SOLD IN CHINA AND PRODUCED IN MA'ANSHAN (CN), VLISSINGEN (NL) AND SINGAPORE (SG), COMPARED TO COW'S MILK SOLD AND PRODUCED IN CHINA. THE PERCENTAGES REFER TO THE IMPACT REDUCTION IN COMPARISON TO COW'S MILK.

5.1.3 Cow's milk

Figure 11 shows that the raw cow's milk is the main contributor to the climate change impact of cow's milk. The raw materials form the largest part of the climate change impact (85%), followed by relatively small contributions of packaging (5%), transport to factory (4%), storage at DC & retail (3%) and processing (3%).

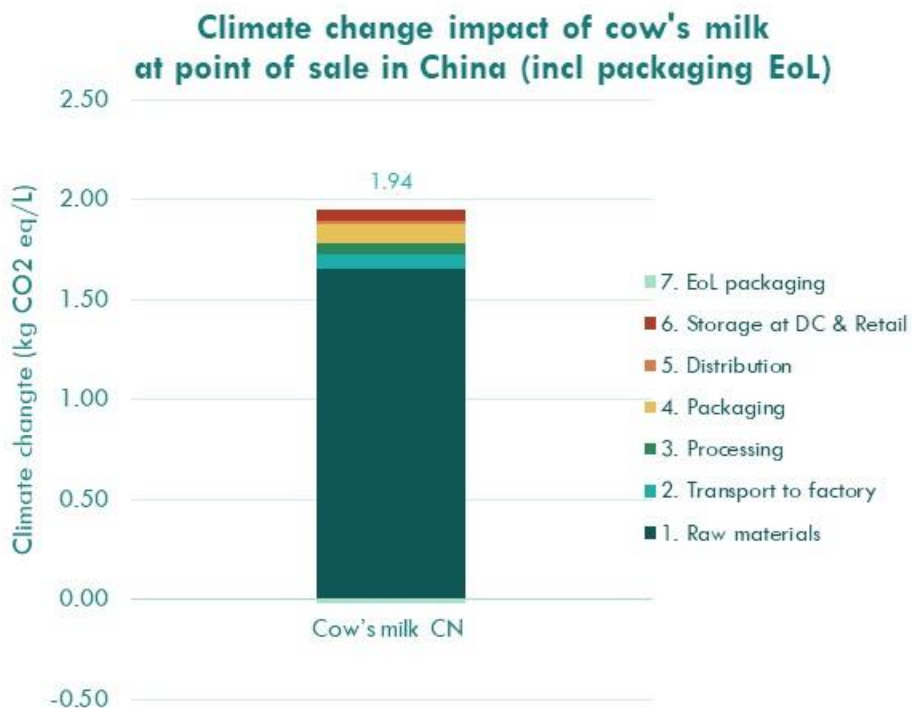


FIGURE 11: CLIMATE CHANGE IMPACT OF 1L COW'S MILK AT POINT OF SALE INCLUDING END-OF-LIFE (EOL) OF PACKAGING

Figure 12 below shows the climate change impact of raw cow's milk, the main contributor are the enteric fermentation (methane emissions, CH_4 from the cow 38%), followed by production of feed (31%). The climate change impact due to manure management emissions (N_2O from manure management), peat oxidation and land use change (LUC) are relatively small.

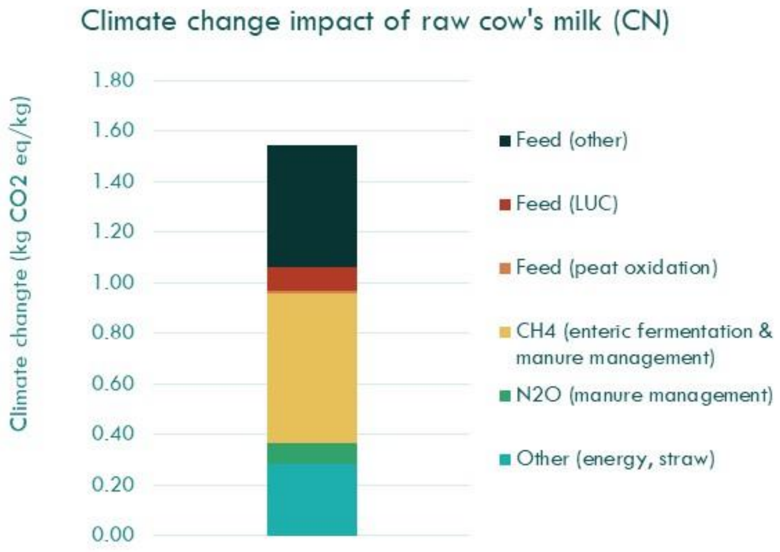


FIGURE 12: CLIMATE CHANGE IMPACT OF RAW COW'S MILK

5.2 Sensitivity analyses

The sensitivity analyses served to evaluate the robustness of the results by assessing the influence of several assumptions and modelling choices that have been made. Sensitivity analyses were performed to evaluate the choice of impact assessment method, the selection of the reference product (fat content), the modelling of the reference product (processing and overall results), the system boundaries (i.e. inclusion of use stage) and the market alternatives for Oatly in China (importing Oatly Barista from the Netherlands). Some sensitivity scenarios were already assessed in the Barista study (the choice of allocation, nutritional value, comparison to chilled products) and therefore, were not repeated here since the conclusions are expected to be similar for Oatly Barista. Next to that, an uncertainty analysis has been performed to determine the range in outcomes when considering uncertainties with regard to data quality and emission factors used in the dairy system.

All sensitivity analyses were performed for ambient Oatly Barista at point of sale (incl EoL packaging) compared to ambient cow's milk at point of sale (incl EoL packaging). The graphs shown in the sensitivity analyses mainly focus on the climate change impact. The results for all impact categories are included in Appendix IV. Percentages show the difference of Oatly Barista compared to cow's milk.

5.2.1 Alternative impact assessment methods

Endpoint impact assessment

The endpoint indicators that are part of the ReCiPe impact assessment method are a measure of the damage at the end of the cause-effect chain. They aggregate several midpoint indicators to provide a holistic overview of the impact of products on human health, resources, and ecosystems (see approach in Figure 13 below).

The unit used for human health is disability adjusted life years (DALYs), representing the years that are lost or that a person is disabled due to a disease or accident[34]. The unit for ecosystem quality is the local species loss

[34] Note that "human health" does not focus on the impact of consuming the product (i.e. the nutritional value), but addresses the impacts over the whole life cycle which affects human's health, like toxicity, climate change, etc.

integrated over time (species year). The unit for resource scarcity is the dollar, which represents the extra costs required for future mineral and fossil resource extraction (Huijbregts et al., 2016).

The results for all endpoint categories are provided in Figure 14. The detailed characterization per midpoint level is provided in Appendix IV.

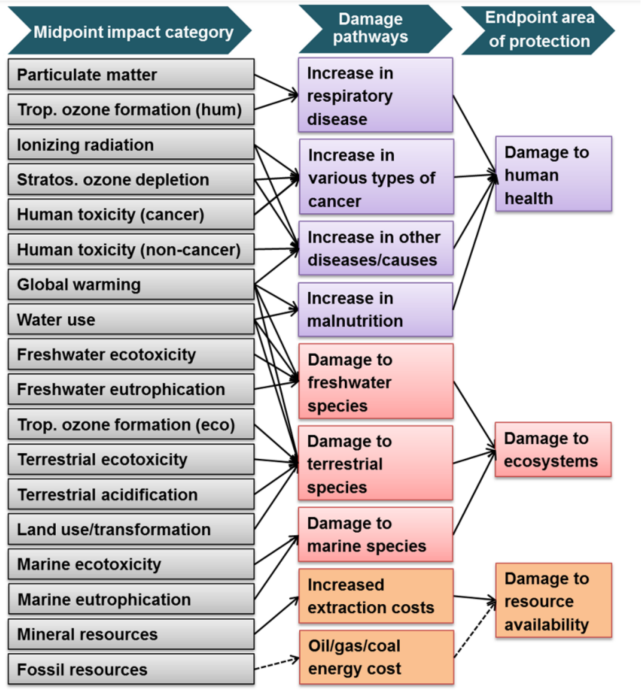
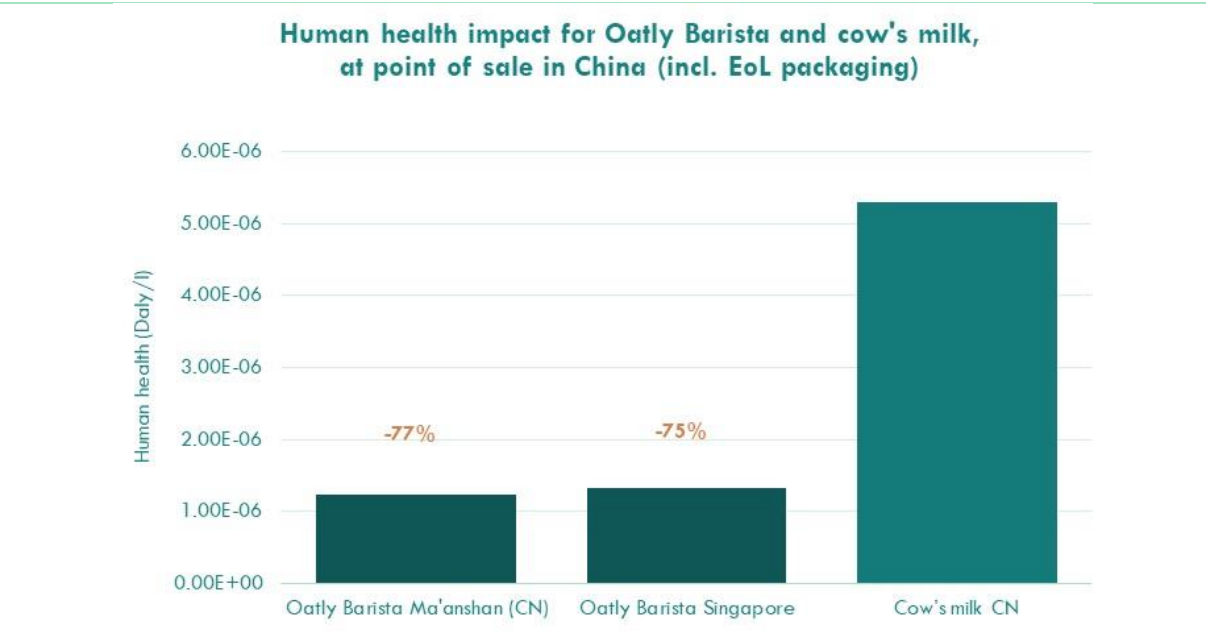


FIGURE 13: OVERVIEW OF THE IMPACT CATEGORIES THAT ARE COVERED IN THE RECIPE 2016 METHODOLOGY AND THEIR RELATION TO THE ENDPOINTS (HUIJBREGTS ET AL., 2016)

For both production locations of Oatly Barista China, the impact on all three endpoints is lower for Oatly Barista than for cow's milk. For the human health endpoint category, Oatly Barista also has the largest relative difference in comparison to cow's milk (75-77%), which is largely caused by lower climate change impacts of Oatly Barista in comparison to cow's milk, as was already shown in the core results.



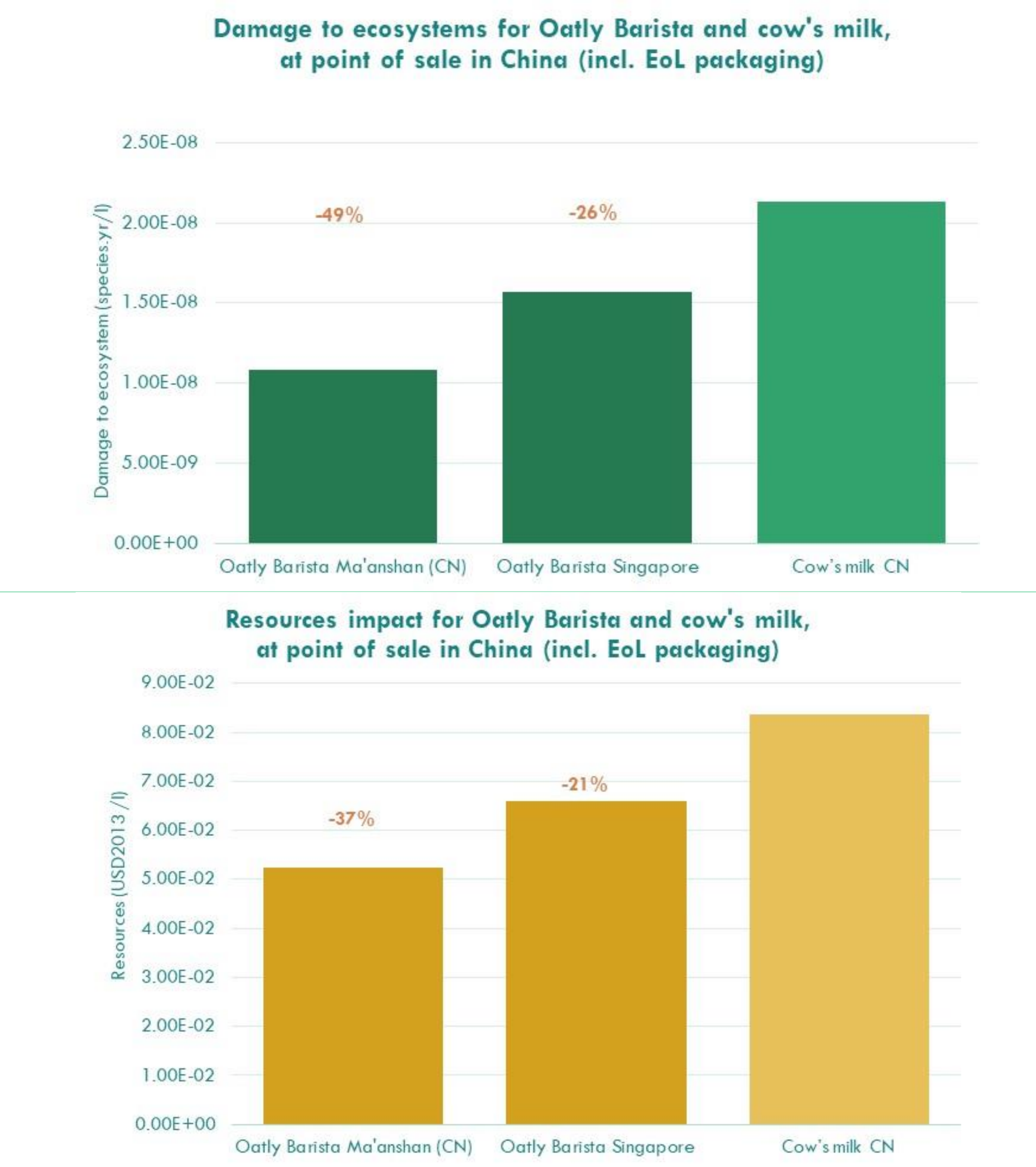


FIGURE 14: IMPACT FOR OATLY BARISTA AND COW'S MILK AT POINT OF SALE INCLUDING END-OF-LIFE (EOL) OF PACKAGING FOR THE THREE ENDPOINT CATEGORIES: A) HUMAN HEALTH, B) DAMAGE TO ECOSYSTEMS AND C) RESOURCES

IMPACT WORLD+ impact assessment

Table 14 shows the results when applying the environmental impact assessment method IMPACT WORLD+ which is a globally oriented method (Bulle et al., 2019), for all impact categories in scope. As can also be witnessed by the units, different methods are used to calculate the impact of most categories. Despite different underlying methods, relatively similar differences between Oatly Barista and cow's milk can be observed for all impact categories in scope as for the ReCiPe method (see Table 14), except for land occupation (biodiversity) and water scarcity for Oatly Barista from Singapore. This is again mainly caused by the high land occupation (low yield) from Australian oats.

For land occupation (biodiversity), both variants have significantly higher impacts than cow's milk, due to the higher characterization factors for land occupation in the IMPACT+ method in comparison to the ReCiPe method.

The high(er) water scarcity results are due to the inclusion of regional differences in the IMPACT WORLD+ method, in which water consumption in Australia is weighted 42 times heavier than water consumption in, for example, Finland. From a land and water use perspective, the Australian oats are thus influential on the total impact. On the other hand, it should be noted that these oats have shorter transport distances, resulting in a lower carbon footprint for the raw material transportation stage.

TABLE 14: RELATIVE DIFFERENCES OF OATLY BARISTA COMPARED TO COW'S MILK AT POINT OF SALE INCLUDING END-OF-LIFE (EOL) OF PACKAGING, USING THE IMPACT WORLD+ IMPACT ASSESSMENT METHOD. FOR EXAMPLE, -70% INDICATES THAT OATLY BARISTA HAS A 70% LOWER IMPACT COMPARED TO COW'S MILK. THE COLOUR SCALE USES GREEN TONES TO SHOW WHERE OATLY BARISTA HAS A SIGNIFICANTLY (>10%) LOWER IMPACT THAN COW'S MILK, AND RED TONES WHERE COW'S MILK HAS A SIGNIFICANTLY (>10%) LOWER IMPACT THAN OATLY BARISTA. YELLOW TONES ARE APPLIED FOR NON-SIGNIFICANT DIFFERENCES (<10%)

Factory	Climate change, short term *kg CO2 eq*	Climate change, long term *kg CO2 eq*	Fossil & nuclear energy use *MJ deprived*	Mineral resources use *kg deprived*	Terr. acidifi-cation *kg SO2 eq*	Land trans-formation, biodiv. *m2yr arable*	Land occu-pation, biodiv. *m2yr arable*	Freshw. eutrophi-cation *kg PO4 eq*	Marine eutrophi-cation *kg N eq*	PM forma-tion *kg PM2.5 eq*	Water scarcity *m3 world eq*
Ma'anshan (CN)	-70%	-60%	-45%	-33%	-86%	-61%	29%	-36%	-65%	-88%	-73%
Singapore	-70%	-61%	-33%	-40%	-88%	-92%	97%	-80%	-89%	-83%	6%

GWP20 instead of GWP100

Usually, GWP100 is used for analyses, which measures the warming potential of greenhouse gases over a 100-year timeframe. Another option is to take a 20-year time frame instead (Figure 15). The resulting GWP20 better reflects the impact of short-lived greenhouse gases. Methane for example, stays in the atmosphere for about 12 years, whilst CO_2 can remain there for over a hundred years. Using GWP20 can help identify measures that reduce GHG emissions in the short term. However, the risk of focusing solely on GWP20 is that less emphasis is put on reducing long-lived GHGs like CO_2 and N_2O, consequently leading to fewer measures that tackle the long-term effects and thus shifting the burden to future generations. Therefore, both should be taken into account.

As seen in Figure 15, the climate change impact of cow's milk increases significantly (75%) when applying GWP20, whereas the impact of Oatly Barista increased only 13%, leading to even bigger differences between the two systems as also indicated by the percentages in Figure 15. This is especially attributed to the methane emissions from manure management and enteric fermentation at the dairy farm.

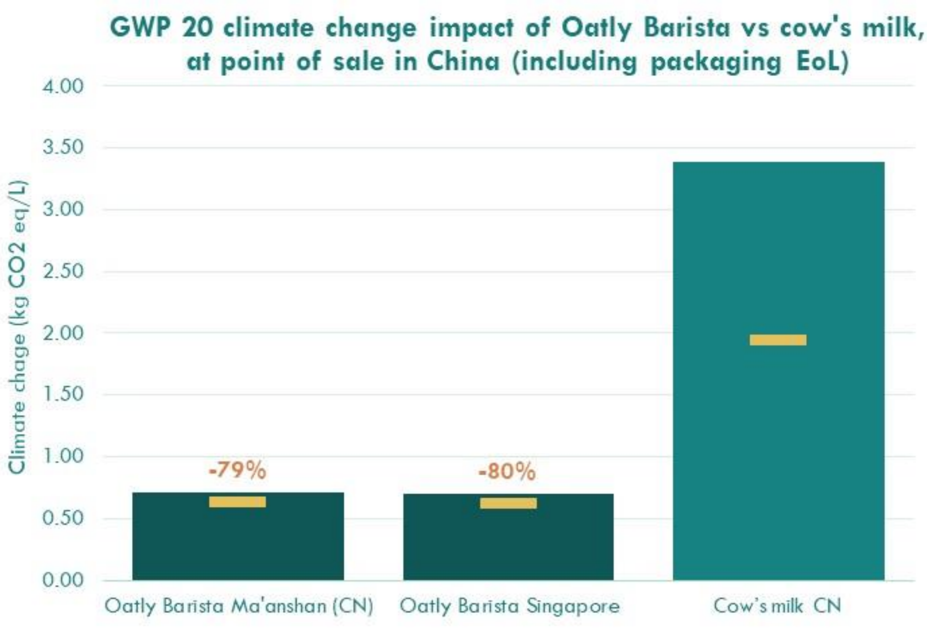


FIGURE 15: GWP20 CLIMATE CHANGE IMPACT OF 1L OATLY BARISTA AND COW'S MILK AT POINT OF SALE INCLUDING END-OF-LIFE (EOL) OF PACKAGING. THE YELLOW LINES INDICATE THE GWP100 RESULTS

5.2.2 Inclusion of use stage

The use phase adds between 27%-38% to the climate change impact of the Oatly Barista and cow's milk at point of sale, as can be seen in Table 15 and Figure 16. The largest share of this impact is attributed to heating the Oatly Barista and cow's milk, and to losses. Particularly, losses at use phase in China were considered 20% (same value assumed for cow's milk and Oatly Barista in the US), meaning that 1.20 l of cow's milk/Oatly Barista at point of sale is necessary to consume 1 liter. Furthermore, the energy use for refrigeration is adding to the total impact as well.

TABLE 15: CLIMATE CHANGE IMPACT INCL. AND EXCL. USE STAGE (INCL EOL PACKAGING) FOR OATLY BARISTA AND COW'S MILK. THE THIRD COLUMN INDICATES THE DIFFERENCE BETWEEN THE TWO. E.G. 19% MEANS THAT OATLY BARISTA INCLUDING USE STAGE HAS A 19% HIGHER IMPACT THAN OATLY BARISTA AT POINT OF SALE

Product	Climate change impact excl use stage (CO_2-eq)	Climate change impact incl use stage (CO_2-eq)	*Difference incl. vs excl. use stage*
Oatly Barista Ma'anshan (CN) factory	0.62	1.01	38%
Oatly Barista Singapore factory	0.62	1.00	38%
Cow's milk CN	1.94	2.65	27%

When comparing the impact of cow's milk to Oatly Barista including use stage, the differences between both products are 6 percent points lower than when considering their impact at the retail stage.

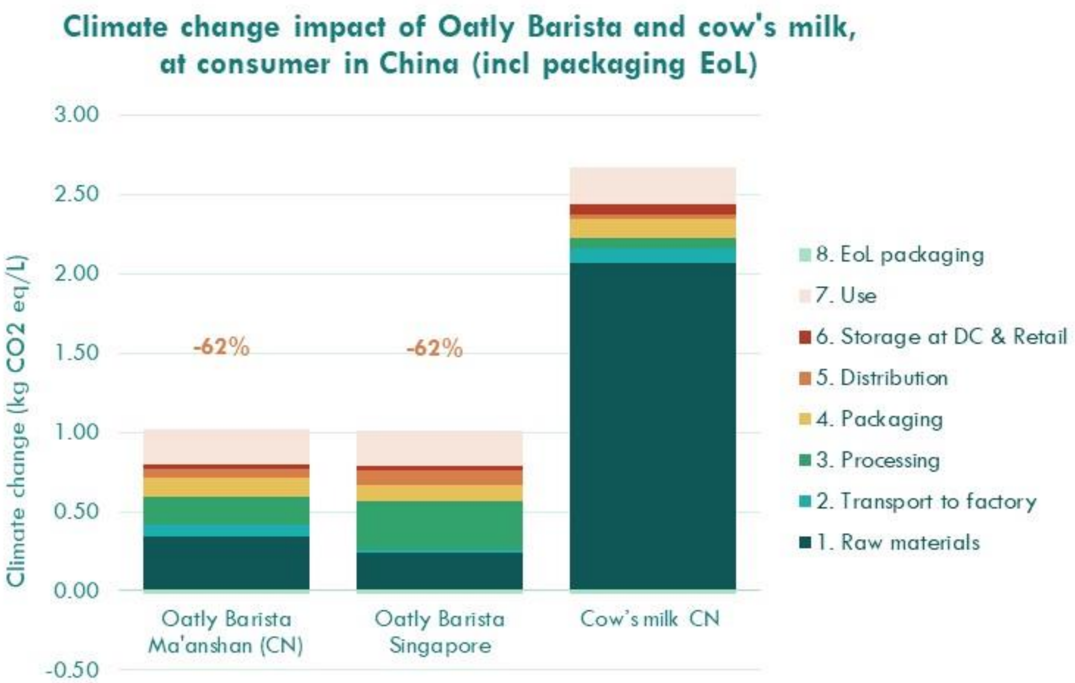


FIGURE 16: CLIMATE CHANGE IMPACT OF 1L OATLY BARISTA AND COW'S MILK AT THE USE STAGE (CONSUMER) INCLUDING END-OF-LIFE (EOL) OF PACKAGING

5.2.3 Cow's milk fat content

For the main analysis, Oatly Barista was compared to an average mix of skimmed, semi-skimmed and whole milk. This sensitivity analysis investigates how Oatly Barista performs in relation to each of the individual milk types.

Figure 17 shows that skimmed cow's milk has the lowest climate change impact of cow's milk types, because a larger share of the impact at processing is allocated to cream. Whole cow's milk has the highest impact. The climate change impact of Oatly Barista is lower than each of the milk types.

In terms of fat content, Oatly Barista would be most comparable to whole cow's milk. However, in the absence of concrete consumer insights, the average mix was selected to remove the assumption that Oatly drinkers are replacing cow's milk of the same fat content as it is possible that they are switching from semi-skimmed or skimmed milk.

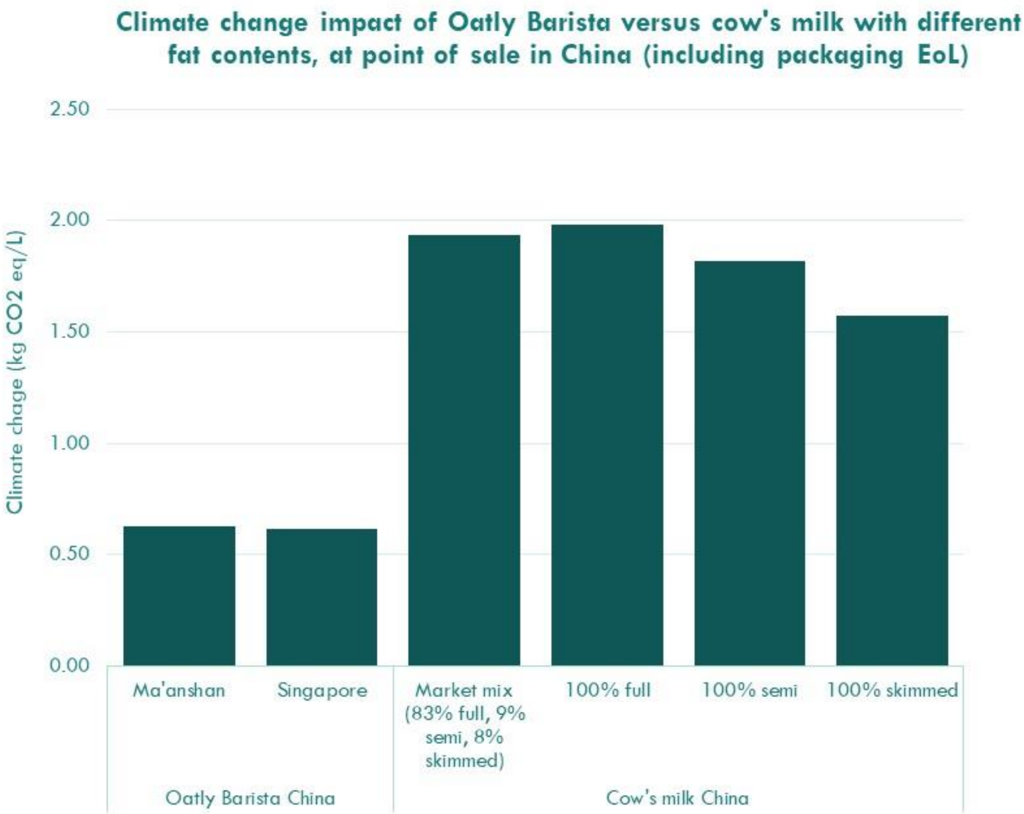


FIGURE 17: SENSITIVITY ANALYSIS FOR COW'S MILK WITH DIFFERENT FAT CONTENT

5.2.4 Cow's milk processing

Since there was no primary data available for cow's milk processing in China, US data were used to model the cow's milk processing, as US was the fall-back option for all data gaps in China. However, from the previous Barista study it is known that there are differences in milk processing amongst the different countries. Therefore, Chinese cow's milk was modeled in this sensitivity by means of the German data for UHT cow's milk processing.

Figure 18 gives an overview of the result of this sensitivity analysis. The German data leads to an increase of the climate change impact (+0.15 kg CO_2 eq./L, 8% difference with baseline calculations). This means that the difference between Oatly Barista and cow's milk would become even bigger than in the baseline calculations (70% lower instead of 68% lower).

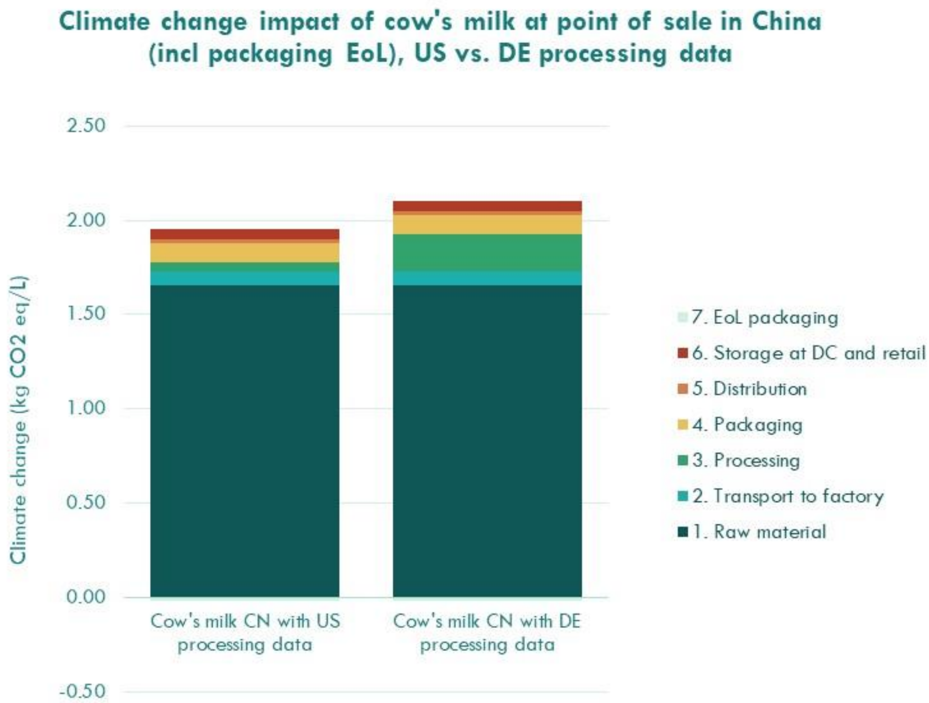


FIGURE 18 SENSITIVITY ANALYSIS FOR COW'S MILK PROCESSING WITH US DATA (BASELINE) AND GERMAN DATA (ALTERNATIVE)

5.2.5 Comparison of cow's milk results with other studies

Although there are multiple studies available which have assessed the climate change impact of Chinese milk production (see Table 16), no full dataset was available for this study, and therefore the modelling was based on the US cow's milk model in the previous Oatly studies, with specific adaptations for the Chinese situation.

The visual comparison of the results of the present study with the results from other studies, is shown in Figure 19. It shows that the results generated in this study are relatively high in comparison to multiple studies, but of similar order of magnitude as the biggest and most recent study (Dong & Wei, 2021). When comparing Oatly Barista in China to the lowest figure for cow's milk in this table (Zhao et al., 2018), the climate change impact reduction of Oatly Barista lowers from 68% (Figure 6) to 46%.

TABLE 16 LIST OF INVENTORIED STUDIES WITH CLIMATE CHANGE RESULTS FOR CHINESE MILK PRODUCTION

Authors	Type	Geographical scope	System boundaries	Sample size	Kg CO_2 eq./ kg FPCM	Comment
Dong & Wei, 2021	Working paper	Whole country	cradle to farm gate	181#	1.95	Regions in the north are observed to have a lower footprint than those in the south. NB there has also been an earlier version of this study, but we present only the most recent in order to avoid duplicates
L. Wang et al., 2019	Scientific paper	Southwest	cradle to farm gate	36#	1.13	The authors suggested that the low CF value might be caused by low transport distances but a satisfactory reason was not given.
X. Wang et al., 2018	Scientific paper	Northern plains	cradle to farm gate	25#	1.34	
Ledgard et al., 2019	Scientific paper	Shaanxi, Hebei & Beijing	cradle to farm gate	3#	1.08	
Zhao et al.,	Scientific	Southwest	cradle to point of	1#	1.12	

Authors	Type	Geographical scope	System boundaries	Sample size	Kg CO_2 eq./ kg FPCM	Comment
2018	paper		sale, incl. packaging EoL			
Carbon Cloud, (2023a)[35]	Database	Whole country	cradle to point of sale, excl. packaging EoL	?	1.6	1.5% fat (skimmed)
Carbon Cloud (2023b)[36]	Database	Whole country	cradle to point of sale, excl. packaging EoL	?	1.8	3% fat (semi skimmed)
This study	Report	Whole country	cradle to point of sale, incl. packaging EoL	n/a	1.87	Full life cycle

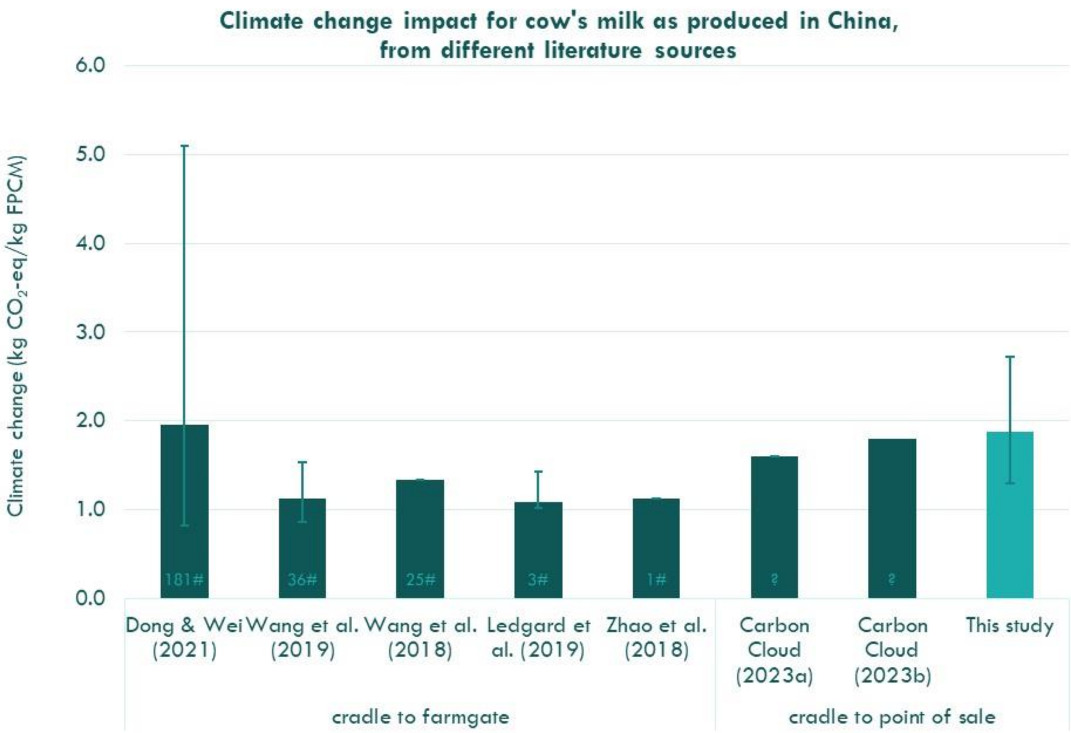


FIGURE 19 COMPARISON OF COW'S MILK RESULTS FROM MULTIPLE STUDIES. THE NUMBER WITH HASH REFLECTS THE NUMBER OF DATA POINTS IN EACH STUDY. THE VARIATION BAR FOR THE RESULTS OF THIS STUDY IS BASED ON THE UNCERTAINTY ANALYSIS (SEE FIGURE 20 IN NEXT SECTION).

5.3 Uncertainty analysis

Uncertainty in inventory data has been determined using the pedigree matrix, as described in section 2.4.1. With this data, a Monte Carlo analysis was run in SimaPro to assess the uncertainty range for each product. The Monte Carlo method is a sampling-based method, in which the calculation is repeated multiple times (in this case 1000 runs), in order to estimate the probability distribution of the result based on uncertainty ranges of input data.

Figure 20 shows the climate change impact results including uncertainty ranges for the 95% confidence interval; meaning that 95% of the results lay within this range. The graph shows a higher uncertainty range for cow's milk, which is caused by the higher uncertainty factors attributed to emissions from manure management and enteric

[35] https://apps.carboncloud.com/climatehub/product-reports/id/79203058369
[36] https://apps.carboncloud.com/climatehub/product-reports/id/79171082972

fermentation and to feed intake (see section 2.7.1), but also an overall higher uncertainty due to the lack of primary data for the Chinese situation. Oatly Barista has lower uncertainty ranges due to the use of primary (foreground) data for transport, milling, processing, packaging and distribution.

The graph gives an impression of how Oatly Barista compares to cow's milk when taking these uncertainties into consideration. According to the uncertainty analysis the difference in climate change impact between Oatly Barista and cow's milk consumed in China could range from -49% to -80%.

Generally speaking, if the error bars of the 95% uncertainty interval do not overlap, one can assume differences between products are statistically significant (Payton et al., 2003). It should be noted that this is just an approximation, as uncertainty was estimated for the data.

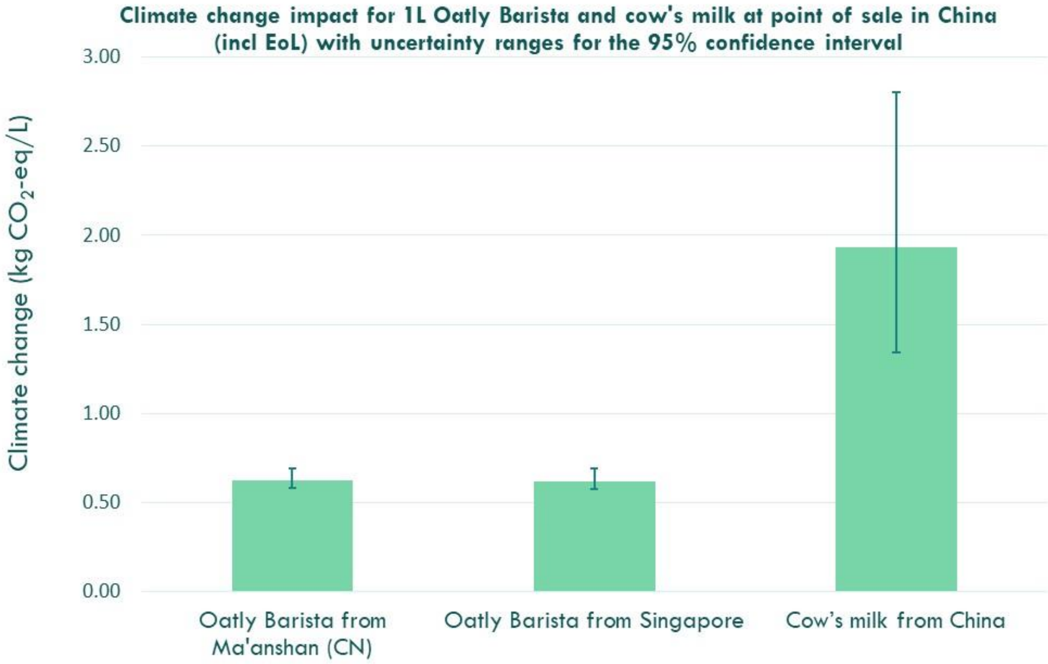


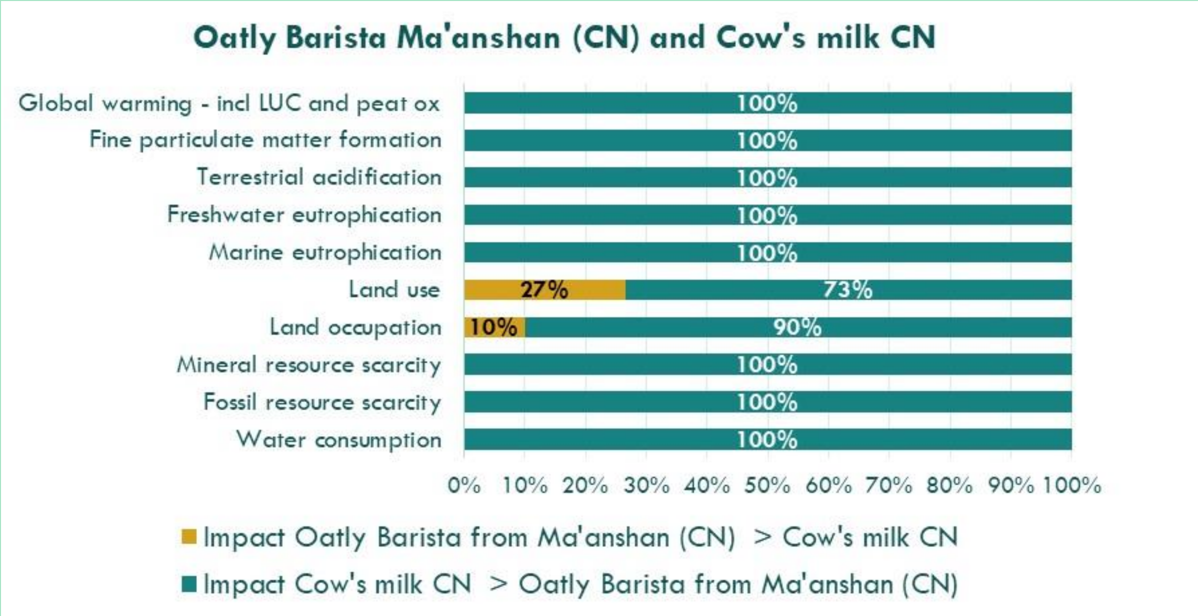
FIGURE 20: CLIMATE CHANGE IMPACT FOR 1L OATLY BARISTA AND COW'S MILK AT POINT OF SALE INCLUDING END-OF-LIFE (EOL) PACKAGING, WITH UNCERTAINTY RANGES FOR THE 95% CONFIDENCE INTERVAL

A more accurate way to compare two products is a paired Monte Carlo analysis, which considers the uncertainty of the difference between two products (thus accounting for correlation in data). The number of runs (from the total of 1000 runs) is counted in which product A has a higher impact than product B. In general it can be assumed that if >90% of the Monte Carlo runs are favorable for one product, the difference can be considered significant (Goedkoop et al., 2013).

Figure 21 below shows the outcome of this paired Monte Carlo analysis for all products in scope and for all impact categories. It shows that for climate change, fine particulate matter formation, terrestrial acidification, freshwater eutrophication, marine eutrophication, mineral resource scarcity and fossil resource scarcity, the impact of Oatly Barista is consistently and significantly (>10%) lower than the impact of cow's milk.

For water consumption, the results for Oatly Barista as produced in Ma'anshan were significantly lower than for cow's milk (100%), while the results from Oatly Barista from Singapore were not significantly lower (89%). This in line with the earlier observation that the water consumption impact for Oatly Barista from Singapore was already close to the water consumption of cow's milk (30%, see Figure 7), and the observation of the alternative impact assessment (section 5.2.1) which showed high water consumption impacts for Oatly Barista Singapore in comparison to cow's milk.

For land use and uncharacterized land occupation, the impact of Oatly Barista from Ma'anshan in comparison to cow's milk's impact is not significantly lower (respectively 27 and 10%). The impact of Oatly Barista from Singapore in comparison to cow's milk is higher in both categories (80 & 69%).



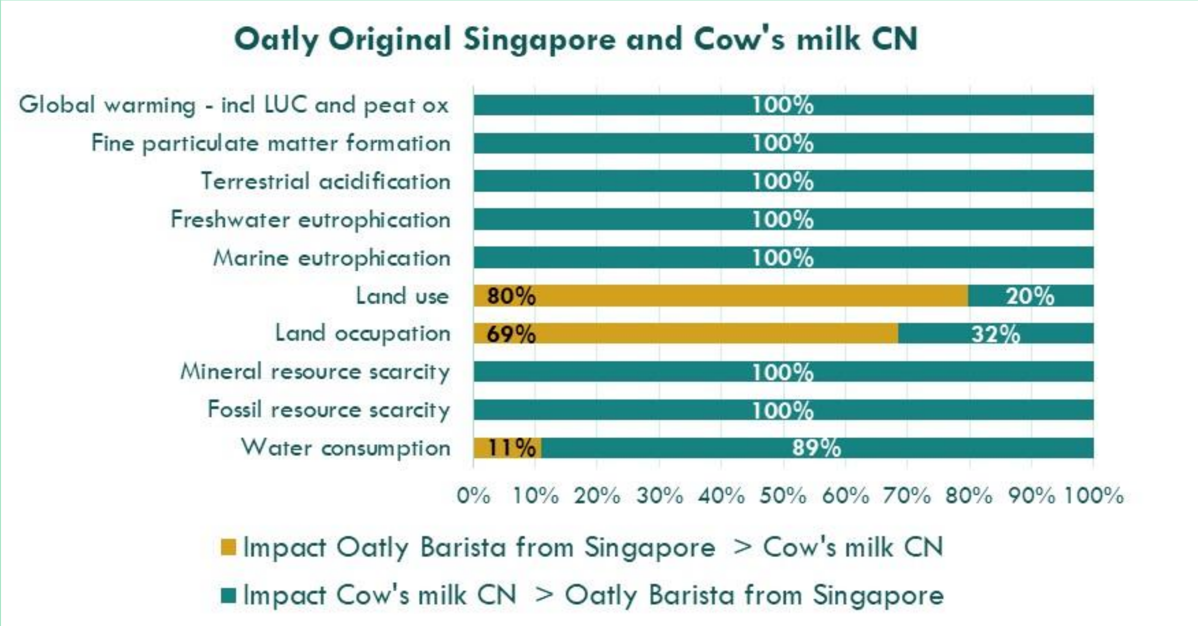


FIGURE 21: PAIRED MONTE CARLO ANALYSIS SHOWING THE PERCENTAGE OF MONTE CARLO RUNS IN WHICH ONE PRODUCT HAS A HIGHER IMPACT THAN THE OTHER. FOR EXAMPLE: FOR CLIMATE CHANGE, OATLY BARISTA MA'ANSHAN HAS A LOWER IMPACT THAN COW'S MILK FOR 100% OF THE 1000 MONTECARLO SIMULATIONS PERFORMED.

6. Conclusion

Overall results

A Life Cycle Assessment has been performed to compare the environmental performance of Oatly Barista (oat-based drink) as produced in Singapore and China[37] and sold in China, to cow's milk as both produced and distributed in China. In addition, the study has identified the drivers and opportunities for the environmental impact of Oatly Barista. The study has been performed and critically reviewed according to ISO 14040/14044/14071 standards for comparative assertions to be disclosed to the public and is in line with LCA guidelines including the European Product Environmental Footprint Category Rules (PEFCR).

This study builds on the foundations of the previous LCA study for Oatly, investigating Oatly Barista in multiple countries(te Pas & Westbroek, 2022). Primary data on oatbase production and oatdrink production has been supplied by Oatly, as well as updated information on packaging materials and distribution of the product. All other product stages are kept equal to the Barista study, in order to keep results stable and comparable. For dairy production in China, representative data were not publicly available. Based on recommendations from an expert familiar with the Chinese dairy sector[24] who was consulted in October 2023, milk production for packaged milk was modelled with the US milk production model as developed in the previous Barista study, but with adjustments to reflect Chinese yields (Dong & Wei, 2021), most common Chinese manure management (100% solid storage), and feed sources adjusted to China production where available.

The results show that for the impact categories climate change, fine particulate matter formation, terrestrial acidification, freshwater eutrophication, marine eutrophication, mineral resource scarcity, fossil resource scarcity and water consumption, both variants of Oatly Barista have a lower impact than cow's milk in China. For land use impact (both characterized as well as uncharacterized), only Oatly Barista from the Ma'anshan factory has a lower impact than cow's milk. Oatly Barista from Singapore has a higher impact than cow's milk in the characterized results, but a similar impact in the (uncharacterized) land occupation category.

Drivers and opportunities for Oatly Barista

For both production locations of Oatly Barista as distributed in China (Ma'anshan and Singapore), the oat cultivation stage is among the highest contributing factors to the climate change, fine particulate matter, terrestrial acidification, freshwater eutrophication, marine eutrophication, land use, land occupation, mineral resource scarcity and water consumption impact categories. Collecting data at cultivation level, could help Oatly to gain a better understanding of the main opportunities to reduce impacts at this stage, such as through more efficient fertilizer application and water use, intercropping and other measures to reduce inputs or increase yields. This could be valuable not only for oat cultivation, but also for rapeseed, which is the second biggest contributor to these impact categories. Oatly might also consider the trade-offs between the different oat cultivation sources. For example, the oats from Australian origin show relative high land and water impacts, but the short distance leads to relative low impact (in several impact categories) of transport in comparison to the European oats. Import from the Netherlands, as was occurring until 2022, generates a 4% higher climate change impact than the products produced in Ma'anshan and Singapore. Shifting to a more local approach (using 100% Australian oats, all processed in the Ma'anshan factory) could reduce the total climate change impact with 15% in comparison to import from the Netherlands.

For Oatly Barista produced in China and Singapore, oat cultivation as well as the combustion of fossil fuels during processing are the highest contributing factors to the climate change impact category. Third is the transport of the finished product from the factory to the point of sale, which is also the highest contributing factor for the fine particulate matter impact category.

Energy consumption at the factory is the main contributing factor to the fossil resource scarcity impact in both factories, even though renewable energy sources have been applied in the Oatly factories of Ma'anshan and Singapore. The processing stage is also a large contributor with respect to water consumption.

Packaging is the third or fourth most contributing life cycle stage in most impact indicators. The corrugated board box has the highest impact in the packaging climate change impact, as being the material with the highest weight

[37] As of 2023, these two factories produce 100% of the 1 L ambient Oatly Barista product sold in China. Before 2023, Oatly Barista was also imported from the Netherlands (Vlissingen factory). The impact of this configuration change was investigated in an additional analysis.

in the total pack. The second highest impact is caused by the smallest amount of material: aluminum. The third contributing material, even though its weight is also low (8%) compared to the total weight, is BioPE.

The impact at the consumer stage (refrigeration, food waste, heating) showed that the primary driver of the use phase is linked to heating the product and to food waste. Due to lack of consumer data, food waste percentages were based on defaults and were considered the same for both cow's milk and Oatly Barista.

Robustness of results

Several sensitivity analyses have been carried out to test the robustness of the results, specifically to evaluate the effect of assumptions made and uncertainties present in input data and models.

The effect of using different characterization methods has been evaluated by performing an endpoint analysis, using a different impact assessment method (IMPACT WORLD+) and by considering GWPs for a 20-year timeframe. All analyses confirm the overall higher environmental footprint (considering both midpoint and endpoint results) of cow's milk compared to Oatly Barista as both produced and distributed in China, except for land occupation (biodiversity) and water scarcity evaluated by the IMPACT WORLD+ method, due to the Australian oat cultivation system.

Considering different product characteristics (inclusion of use stage for both systems, cow's milk with different fat content and alternative processing data), does not lead to different conclusions on the environmental footprint of Oatly Barista compared to cow's milk. When changing the modelling of the cow's milk to a different fat content or other processing data, this leads to higher impact of the cow's milk compared to the baseline calculations, and thus has no influence on the conclusions. The comparison of the results with other studies which investigated the carbon footprint of Chinese milk production, lead to the conclusion that the results generated in this study are relatively high in comparison to multiple studies, but of similar order of magnitude as the biggest and most recent study (Dong & Wei, 2021). This makes the results not improbable, despite the lack of primary data for the Chinese situation.

Uncertainty in data has been assessed by a single and a paired Monte Carlo analysis, which determines the probability distribution of the results based on uncertainty ranges of input data. According to the uncertainty analysis the difference in climate change impact between Oatly Barista and cow's milk consumed in China could range from -49% to -80%. The paired uncertainty analysis confirms a significant (>10%) difference in impact for the environmental impact categories climate change, fine particulate matter formation, terrestrial acidification, freshwater eutrophication, marine eutrophication, mineral resource scarcity and fossil resource scarcity. For water consumption, the results for Oatly Barista as produced in Ma'anshan were significantly lower than for cow's milk, while the results from Oatly Barista from Singapore were comparable. For land use and uncharacterized land occupation, the impact of Oatly Barista from Ma'anshan in comparison to cow's milk's impact is comparable, while the impact of Oatly Barista from Singapore in comparison to cow's milk is higher in both categories.

Using the ReCiPe Endpoint impact methodology, resulted in similar conclusions for all three endpoint categories, where Oatly Barista had a lower impact than cow's milk. When considering the climate change category only, the difference between Oatly Barista and cow's milk is bigger than when considering the ecosystem impact as a whole. When applying the globally oriented IMPACT WORLD+ method, similar differences between Oatly Barista and cow's milk can be observed for all impact categories in scope as for the ReCiPe method, except for land occupation (biodiversity) and water scarcity for Oatly Barista from Singapore. This is again mainly caused by the high land occupation (low yield) from Australian oats and the regional specifications in the methodology.

Conclusions and recommendations presented here are subject to the assumptions and limitations addressed in this report. Any comparative assessment intended to be disclosed to the public, should transparently refer to the conclusions of the study, and be accompanied by the critical review statement.

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Appendix I Characterisation methods used

TABLE 17: RECIPE2016 IMPACT CATEGORIES

Impact category	Description
Climate Change	All inputs or outputs that result in greenhouse gas emissions. The greatest contributor is generally the combustion of fossil fuels such as coal, oil and natural gas. The consequences include increased average global temperatures and sudden regional climatic changes. Climate change is an impact affecting the environment on a global scale. Unit of measurement: Kilogram of Carbon Dioxide equivalent (kg CO2 eq). During the calculations, the global warming potential of all greenhouse gas emissions are compared to the amount of the global warming potential of 1 kg of CO2
Ozone depletion	The stratospheric Ozone (O3) layer protects us from hazardous ultraviolet radiation (UV-B). Its depletion can have dangerous consequences in the form of increased skin cancer cases in humans and damage to plants. The stratospheric ozone depletion is an impact which affects the environment on a global scale. Unit of measurement: kilogram of CFC-11 equivalent (kg CFC-11 eq). During the calculations, the potential impacts of all relevant substances for ozone depletion are converted to their equivalent of kilograms of Trichlorofluoromethane (also called Freon-11 and R-11).
Particulate matter – respiratory inorganics	The adverse impacts on human health caused by emissions of Particulate Matter (PM) and its precursors (e.g. NOx, SO2). Usually, the smaller the particles are, the more dangerous they are, as they can go deeper into the lungs. Unit of measurement: kilogram of Particulate Matter 2.5 equivalent (kg PM 2.5 eq). The potential impact of respiratory inorganics is converted into the equivalent of a kilogram of particulate matter of a diameter of 2.5 micrometres or less.
Ionising radiation	Ionising radiation is radiation which is released by atoms, which travels as electromagnetic waves or particles. When the atom has sufficient energy it can cause ionisation or remove electrons from an atom. Ionizing radiation can be dangerous. When living cells become ionised they can die or mutates incorrectly and become cancerous. Radioactive substances exist naturally, examples are rocks and soil, however these levels are rather low. Most common source of ionising radiation is the extraction and use of radioactive materials for nuclear power generation. Reference unit for ionising radiation is kBq CO-60 equivalents.
Photochemical ozone formation	While stratospheric ozone protects us, ozone on the ground (in the troposphere) is harmful: it attacks organic compounds in animals and plants, it increases the frequency of respiratory problems when photochemical smog ('summer smog') is present in cities. Photochemical ozone formation is an impact which affects the environment at local and regional scale. Unit of measurement: kilogram NOx eq.
Terrestrial acidification	Changes in acidity of the soil are caused by atmospheric deposition of acidic substances. Serious changes are harmful for specific species. In the ReCiPe 2016 methodology three acidifying emissions are taken into account. These emissions are: NOx, NH3 and SO2. NOx is mainly formed during combustion processes. Agriculture is the main source for NH3. Energy combustion (coal) counts mainly for SO2 emissions. Unit of measurement: kilogram SO2 eq.
Freshwater and marine eutrophication.	Eutrophication impacts ecosystems due to substances containing nitrogen (N) or phosphorus (P). These nutrients cause a growth of algae or specific plants and limit growth in the original ecosystem. Eutrophication is an impact which affects the environment at local and regional scale. Unit of measurement: kg N eq for Marine Eutrophication and kg P eq for Freshwater eutrophication.
Land use	Occupation refers to the use of a land cover for a certain period, and it is measured as area-time (m2*yr) crop equivalents.
Land occupation	Occupation refers to the use of a land cover for a certain period but does not include conversion to crop equivalents, so it is measured as area-time (m2*yr).
Water consumption	The withdrawal of water from lakes, rivers or groundwater can contribute to the 'depletion' of available water. Water consumption is the fraction of water use that is not returned to its original source. Unit of measurement: cubic metres (m3).
Mineral resource scarcity	The earth contains a finite amount of non-renewable resources, such as metals and minerals. The basic idea behind this impact category is that extracting a high concentration of resources today will force future generations to extract lower concentration or lower value resources. Unit of measurement: kg Cu eq.

Fossil resource scarcity	The earth contains a finite amount of non-renewable resources, such as fossil fuels like coal, oil and gas. The basic idea behind this impact category is that extracting a high concentration of resources today will force future generations to extract lower concentration or lower value resources. Unit of measurement: kg oil eq.
Human toxicity – carcinogenic	The toxicity potential (TP), expressed in kg 1,4-dichlorobenzeneequivalents (1,4DCB-eq), is used as a characterization factor at the midpoint level for human toxicity, freshwater aquatic ecotoxicity, marine ecotoxicity and terrestrial ecotoxicity. A more elaborate explanation on toxicity can be found in (Huijbregts et al., 2016).
Human toxicity – non-carcinogenic	The toxicity potential (TP), expressed in kg 1,4-dichlorobenzeneequivalents (1,4DCB-eq), is used as a characterization factor at the midpoint level for human toxicity, freshwater aquatic ecotoxicity, marine ecotoxicity and terrestrial ecotoxicity. A more elaborate explanation on toxicity can be found in (Huijbregts et al., 2016).
Eco-toxicity – fresh water acquatic	The toxicity potential (TP), expressed in kg 1,4-dichlorobenzeneequivalents (1,4DCB-eq), is used as a characterization factor at the midpoint level for human toxicity, freshwater aquatic ecotoxicity, marine ecotoxicity and terrestrial ecotoxicity. A more elaborate explanation on toxicity can be found in (Huijbregts et al., 2016).
Ecotoxicity – marine	The toxicity potential (TP), expressed in kg 1,4-dichlorobenzeneequivalents (1,4DCB-eq), is used as a characterization factor at the midpoint level for human toxicity, freshwater aquatic ecotoxicity, marine ecotoxicity and terrestrial ecotoxicity. A more elaborate explanation on toxicity can be found in (Huijbregts et al., 2016).
Ecotoxicity – terrestrial	The toxicity potential (TP), expressed in kg 1,4-dichlorobenzeneequivalents (1,4DCB-eq), is used as a characterization factor at the midpoint level for human toxicity, freshwater aquatic ecotoxicity, marine ecotoxicity and terrestrial ecotoxicity. A more elaborate explanation on toxicity can be found in (Huijbregts et al., 2016).

TABLE 18: IMPACT WORLD+ IMPACT CATEGORIES

Impact category	Unit
Climate change, short term	kg CO2 eq
Climate change, long term	kg CO2 eq
Fossil and nuclear energy use	MJ deprived
Mineral resources use	kg deprived
Photochemical oxidant formation	kg NMVOC eq
Ozone layer depletion	kg CFC-11 eq
Freshwater ecotoxicity	CTUe
Human toxicity cancer	CTUh
Human toxicity non-cancer	CTUh
Freshwater acidification	kg SO2 eq
Terrestrial acidification	kg SO2 eq
Freshwater eutrophication	kg PO4 eq
Marine eutrophication	kg N eq
Particulate matter formation	kg PM2.5 eq
Ionizing radiation	Bq C-14 eq
Land transformation, biodiversity	m2yr arable
Land occupation, biodiversity	m2yr arable
Water scarcity	m3 world eq
Ozone layer depletion	kg CFC-11 eq
Freshwater ecotoxicity	CTUe

Appendix II Dairy production modelling

A dairy economist familiar with modern Chinese dairy production[24] recommended (in October 2023) modeling analogous to US production, with minor adjustments. This is because modern Chinese dairies (those marketing for retail packaged milk) have been designed to replicate US production. Thus, the US dairy model developed in a previous Oatly project was used as the starting point for China dairy production. Milk yields, manure management, and feed origin were adapted as described below. The tables below highlight the data used as well as calculations and assumptions made to model dairy systems in US as was done in the previous Barista study and the adaptations made for the Chinese situation.

General system description and data quality

In this section, a short description of the milk production system is provided. A more detailed description on the modelling of dairy systems can be found in the documentation of APS footprint (Blonk Consultants, 2020a).

The APS-footprint framework enables users to perform environmental footprint calculations based on background datasets, parameters defined by the user and modelling of emissions according to specified standards and guidelines. Dairy systems may vary in design and environmental performance due to differences in herd composition, grazing periods, housing types, feeding regimes and manure management systems. The dairy APS module enables a user to model these different characteristics and investigate how they influence environmental impacts. The methodological framework regarding allocation, functional units, boundary definitions and emission modelling are based on published and recognized international guidelines (European Commission, 2018; European Environment Agency, 2016; IPCC, 2006b).

Below are the main parameters used to model the dairy systems in APS are described.

Herd composition

In the APS dairy module, it is necessary to define the animal population (animal type and number) associated with the production system. With APS-footprint, it is also possible to include data based on statistics. This means that the overall population, within a country might be considered as the total herd. The total herd should be presented in a system equilibrium. All inputs should be scaled towards the total herd.

In the dairy module of the APS-footprint tool, four animal types are defined:

Dairy Cow Dairy cows include the milk-producing cattle. Dairy cows start producing milk after giving birth to their first calf, which is usually during their third year of life. Dairy cows are slaughtered at around 4-5 years of age. This animal category includes both dairy cow in lactation and dairy cow in dry period. The weight of dairy cows can vary. Since APS-footprint assumes a system at equilibrium and an average dairy cow weight, it is assumed that there is no weight accumulation of the herd in this stage.

Calves < 1 year Female calves that are not slaughtered are further raised for future replacement of dairy cows. In their first year of life, the weight grows from circa 50 kg to around 300 kg.

Calves 1-2 years In this stage, female calves are raised from 1 year up to 2 years of age. Animals in this stage grow from approximately 300 kg to 600 kg.

Heifers In this stage, female calves are raised from 2 year of age up to calving age. The latter is the age in which it gives birth to calves for the first time, followed by its first lactation period. Calving age varies from 24 up to 26 months in average. This means that heifers are considered as such for a short period of time (few months).

Bulls Sometimes bulls are present on a farm. The average lifespan of bulls varies between 3 to 5 or more years. They usually weigh more than the dairy cows, and their population is very small since one bull can inseminate many cows. In modern systems, bulls might not present since artificial insemination is a common practice. Artificial insemination is not modelled in the dairy APS module. Because of their negligible contribution to the overall impact of the dairy system, bulls are not taken into account.

The number of animals at farm is based on a production period of one year and the average number of present animals is requested as input for APS-footprint. For each animal type, this is called Annual Average Population (AAP).

Feed

Information on feed amount and nutrient content are required as input for the calculations. The feed inputs need to be defined as kg feed (as is) for every AAP for 1 year. Two types of feed are distinguished in the dairy APS module: compound feeds and single ingredients:

- Compound feeds are defined in the compound feed module of the APS-footprint tool. The compound feed formulation can be defined together with inbound (from ingredient production to compounding feed mill) and outbound (from compounding feed mill to farm) transportation and energy use.
- For this project, feed ingredients (crops) are derived from Agri-footprint 6. When a certain region is not covered in APS, the crop (mix) is modelled afterwards in SimaPro.
- The production of single feed ingredients is also based on Agri-footprint 6 (Van Paassen et al., 2019a). This concerns fodder which are directly fed to animals, without the process of including them in a compound feed. This usually happens since they are produced at farm. These include roughages (fresh grass, grass silage, maize silage, straw and hay), wet co-products (spent brewers and distillers' grain) and crops (grains, beets and legumes).

Besides the different types of feed, some feed nutrition related characteristics have to be defined. These characteristics encompass digestibility, overall gross energy (GE) intake, amount of silage and crude protein content in overall diet. Such characteristics should be calculated as a weighted average of the overall diet based on the characteristics at product level. These feed characteristics influence various emissions (such as methane, nitrous oxide, and ammonia) from manure storage and pre-treatment.

Water

There are multiple types of water consumption on the dairy farm. Water is consumed by the animals as drinking water. Water is also used on the farm for management purposes like cleaning the milking area. In practice, water can also be used for irrigation of crops. Irrigation water is already included in the background LCI, such that the total water input on the dairy farm is equal to all water use except the water used for irrigation of crops.

Bedding

Bedding is used in the stable of the dairy cows. Two types of bedding can be selected in APS-footprint: saw dust and straw. These types of bedding are commonly used in typical dairy systems.

Energy

There are several types of energy use on the dairy farm. A main source of energy is electricity (cooling is important), but other fuels, like natural gas and diesel are also used. Electricity use includes all types of farm associated activities. Typical activities are cooling, lighting, ventilation, automated feed and water rationing, automated milking systems, and water recirculation. In APS-footprint, electricity production is based on ecoinvent processes that reflect the national grid. Specific production technologies (e.g. wind or solar electricity) can be altered after exporting the process to SimaPro. Natural gas and diesel are mainly used for the heating system or farm machinery (including the machinery used to store and collect roughage). Diesel used for machines during crop cultivation are not considered here, since this is already included in the cultivation background LCI.

Output

The main output of the dairy APS is raw milk. Required parameters are the yearly farm milk production, the fat content, and the protein content of the milk. Milk losses at farm and milk that is not suitable for consumption (e.g. milk discarded because contaminated by antibiotics or high microbial load) is not accounted in the raw milk output.

The dairy APS module also accounts for live animal leaving the farm. Dairy cows are removed from the herd for various reasons, usually connected to decrease in productivity. These are usually culled. A dairy farm also produces male calves and quite often some surplus female calves which are also co-products of the dairy farm system. These can be slaughtered directly or can be sold for further growth in other production systems. The total amount of liveweight (kg) leaving the dairy APS is required (including both replaced cows and calves).

Mortality output is currently not considered in the dairy APS module, in terms out mortalities (kg) and the fate of mortalities (e.g. rendering, composting, incineration). However, mortality is considered when establishing the steady-state herd size.

Functional unit

The functional unit used in APS is 1 kilogram of Fat-Protein Corrected Milk (FPCM) (corrected to 4% fat and 3.3% protein) as calculated in PEFCR dairy guidelines (European Commission, 2018b):

$$FPCM\ (kg/yr) = Production\ (\ kg/yr)\ x\ (0.1226\ x\ True\ Fat\% + 0.0776\ x\ True\ Protein\% + 0.2534)$$

Where:

- FPCM is the amount of Fat-Protein Corrected Milk (kg/year);
- Production is the amount of milk produced (kg/year);
- True fat is the content of fat present in the produced milk (%);
- True protein in the content if protein in the produced milk (%);

Since this study considers a functional unit of 1 liter of milk "as is" with different fat contents (whole, (semi)skimmed), this FPCM is converted back to milk "as is".

Allocation at farm

Allocation is used to distribute the overall environmental impacts to the different outputs: milk and animal liveweight (aggregate of replaced dairy cows and sold calves). The dairy module of APS-footprint uses biophysical allocation to calculate the environmental impact of the two co-products. This type of allocation is extensively used in the dairy sector. It was developed by the International Dairy Association (IDF, 2010) and was suggested by the dairy PEFCR (European Commission, 2018):

$$AF = 1 - 6.04\ x\ (Mmeat\ /\ Mmilk)$$

Where AF is the Allocation Factor of milk, $Mmeat$ is the mass of live weight of all animal sold including calves and culled mature animals per year, and $Mmilk$ is the mass if FPCM sold per year.

The allocation for Meat can be calculated as 1 - AF. According to the dairy PEFCR, manure can be considered as a residual product, a co-product or waste. In the APS footprint, manure is treated as a residual product. This means that manure is exported from the farm as product with no economic value. There is no allocation: burden is allocated to other products produced at farm, including pre-treatment of manure.

Chinese milk production (modeled to replicate US, with adaptations)

The National Inventory Report (NIR) of the USA (United States Environmental Protection Agency, 2021) is taken as the leading source of the data. The reference year listed in this source is 2019. Important parameters, such as the milk output, the average liveweight of animals in different age groups, the share of manure management systems, and the share of grazing and non-grazing periods are retrieved from the NIR.

The total livestock to slaughter weight is based on the USDA Quickstat database (2022). Total livestock amounts (heads) include the total amount and average weight of dairy cows and dairy calves sent to slaughter. The total amount of livestock slaughtered does not include heifers sent to slaughter, because the type of heifers (beef breed or dairy breed) could not be distinguished from the source.

The average on-farm resource use is retrieved from "Greenhouse Gas Emissions from Production of Fluid Milk in the US," an unpublished paper by Thoma et al. (Thoma, 2010). The on-farm resource use is a weighted average, based on three archetypical farms as presented in the paper.

Data on feed rations is based on (Thoma, Popp, Shonnard, et al., 2013a), as more recent data was not available. Thoma et al. provide detailed feed consumption data per state and per animal type, which was converted to a weighted national average.

Data retrieved from Blonk Consultant's Californian dataset created for APS footprint (Blonk Consultants, 2020a) was used for bedding material, and some components of the feed ration (protein mix and partial mix ration).

More details on the sources used and assumptions made can be found in the table below.

Data point		Value (per year)	Explanation
General details			
Farming method		Conventional	
Year		2019-2021	
Geography		United States, adjusted for China	
Average annual temperature		8.55	Wikipedia (2020)
Total herd size		18803000	NIR (2021)
OUTPUTS			
Milk (total weight) (kg)		159,825,500,000	Total herd size from NIR (2021) multiplied by milk yield from (Dong & Wei, 2021)
Protein content (%)		3.25%	(Dong & Wei, 2021)
Fat content (%)		3.92%	based on "Environmental assessment of United States dairy farms" (Rotz et al. 2021) averaged for all regions
Total livestock to slaughter (liveweight) (kg)		2250457129	based on USDA (2022) Quickstat, year 2019
RESOURCE USE			
Electricity use (MJ)		5946555785	from Thoma et al. (Thoma, 2010)
Heat (MJ)		6692629818	from Thoma et al. (Thoma, 2010)
Diesel use (MJ)		20346732702	from Thoma et al. (Thoma, 2010)
Water consumption (kg)		4.03872E+11	Based on APS Californian dataset
HOUSING SYSTEMS			
Housing - Heifers		3270000	Heifers and calves 1-2y
Housing - Calves <1 year		6189000	
Housing - Dairy cows		9344000	
Housing system dairy cows			
RATION (kg as is)			Ration for grazing and non-grazing seasons per region and per animal type obtained from Thoma (2013b), corrected for the length of grazing and non-grazing season, then multiplied by number of animals per region (based on NIR) to obtain weighted average diet per animal type per year. Top 15 feed ingredients are included (extrapolated to match total weight), adjusted for higher milk production in 2020.
Pasture		3089	
Corn Silage		3686	
Corn		1503	Chinese data set
Alfalfa Silage		742	
Alfalfa Hay		678	
Partial Mix Ration		704	modelled based on compound feed from Californian dairy, where available, adjusted with Chinese data sets
Corn, HM		658	high moisture corn, Chinese data set
Grain Mix		525	Chinese data set
Ddg, Dry		454	
Protein Mix		341	modelled based on compound feed from Californian dairy , where available, adjusted with Chinese data sets
Cottonseed		305	
Soybean Meal		290	Chinese data set
Supplement		245	
Corn Gluten Feed		221	Chinese data set
Canola Meal		154	Chinese data set
Total feed intake (kg/animal)		13596	Based on Thoma (2013b), as is
Gross energy intake (MJ/animal)		153887	NIR
Digestibility (% of GE)		66.70%	NIR

Crude protein in diet (% of DM)	16%	CGIAR, 2021
Percentage of silage (% of GE)	18%	Based on feed from Thoma, on NE instead of GE
HOUSING		
Straw for bedding (kg/animal)	250	Based on APS Californian dataset: 250 kg/dairy cow
Saw dust (kg/animal)	125	Based on APS Californian dataset: 125 kg/dairy cow
Type (e.g. housed/ free ranging)	housed	Based on APS Californian dataset
MANURE MANAGEMENT		
Manure management system		100% solid storage
TIME SPENT DISTRIBUTION		
Time spent grazing (%)	0%	Expert judgment
Time spent in open yard areas (%)	25%	Expert judgment
Time spent in buildings (%)	75%	Expert judgment
Housing system heifers and calves 1-2 years		
RATION (kg as is)		Ration for grazing and non-grazing seasons per region and per animal type obtained from Thoma (2013b), corrected for the length of grazing and non-grazing season, then multiplied by number of animals per region (based on NIR) to obtain weighted average diet per animal type per year. Top 15 feed ingredients are included (extrapolated to match total weight), adjusted for higher milk production in 2020.
Pasture	2210	Based on grass dataset from Californian dataset
Corn Silage	2454	
Alfalfa Hay	407	
Corn	370	Chinese data set
Wheat Straw	280	Chinese data set
Supplement	263	
Grass Hay	265	
Partial Mix Ration	209	modelled based on compound feed from Californian dairy; where available, adjusted with Chinese data sets
Alfalfa Silage	148	
Ddg, Dry	163	Maize distillers grains
Soybean Meal	135	Chinese data set
Grain Mix	120	Chinese data set
Protein Mix	81	modelled based on compound feed from Californian dairy (APS Californian dataset), where available, adjusted with Chinese data sets
Corn Gluten Feed	63	Chinese data set
Oat Hay	47	Chinese data set
Total feed intake (kg/animal)	7215	Based on Thoma (2013b)
Gross energy intake (MJ/animal)	69411	NIR
Digestibility (% of GE)	63.70%	NIR
Crude protein in diet (% of DM)	18.49%	Calculated based on ration and feed tables from Thoma (2013)
Percentage of silage (% of GE)	21%	Based on feed from Thoma, on NE instead of GE
HOUSING		
Straw for bedding (kg/animal)	0	Based on AFP Californian dataset
Saw dust (kg/animal)	0	Based on AFP Californian dataset
Type (e.g. housed/ free ranging)	housed	Based on AFP Californian dataset
MANURE MANAGEMENT		
Manure management system		100% solid storage
TIME SPENT DISTRIBUTION		
Time spent grazing (%)	0%	Expert judgment
Time spent in open yard areas (%)	25%	Expert judgment
Time spent in buildings (%)	75%	Expert judgment
Housing system calves < 1 year		
RATION (kg as is)		Ration for grazing and non-grazing seasons per region and per animal type obtained from Thoma (2013b), corrected for the length of grazing and non-grazing season, then multiplied by number of animals per region (based on NIR)

		to obtain weighted average diet per animal type per year. Top 15 feed ingredients are included (extrapolated to match total weight), adjusted for higher milk production in 2020.
Pasture	1104	
Corn Silage	843	
Alfalfa Hay	297	
Alfalfa Silage	270	
Barley	217	Chinese data set
Partial Mix Ration	194	modelled based on compound feed from APS Californian dataset; where available, adjusted with Chinese data sets
Wheat Straw	123	Chinese data set
Grass Hay	120	
Wheat Silage	113	
Corn	107	Chinese data set
Oat Silage	108	Chinese data set
Ddg, Dry	86	
Cotton Gin Trash	88	
Sorghum Silage	91	Chinese data set
Supplement	76	
Total feed intake (kg/animal)	3835	Based on Thoma (2013b)
Gross energy intake (MJ/animal)	8598	NIR
Digestibility (% of GE)	63.70%	NIR
Crude protein in diet (% of DM)	18.36%	Calculated based on ration and feed tables from Thoma (2013)
Percentage of silage (% of GE)	23%	Based on feed from Thoma, on NE instead of GE
HOUSING		
Straw for bedding (kg/animal)	0	APS Californian dataset - no straw
Saw dust (kg/animal)	0	APS Californian dataset - no saw dust
Type (e.g. housed/ free ranging)	housed	APS Californian dataset
MANURE MANAGEMENT		
Manure management system		100% solid storage
TIME SPENT DISTRIBUTION		
Time spent grazing (%)	0%	Expert judgment
Time spent in open yard areas (%)	*25%*	Expert judgment
Time spent in buildings (%)	*75%*	Expert judgment

Appendix III Oatly production modelling (confidential data)

This appendix is not available in this version of the report due to confidential data.

Appendix IV Full LCIA results, ReCiPe 2016 and IMPACT WORLD+

Oatly Barista and cow's milk at point of sale in China (incl EoL packaging), per liter

Impact category	Unit	Oatly Barista from Ma'anshan (CN)	Oatly Barista from Singapore	Oatly Barista from Vlissingen	Cow's milk from China
Climate change - incl LUC and peat ox	kg CO2 eq	6.24E-01	6.18E-01	6.48E-01	1.94E+00
Climate change - excl LUC and peat ox	kg CO2 eq	4.84E-01	6.08E-01	5.17E-01	1.81E+00
Climate change - only LUC	kg CO2 eq	2.14E-02	9.35E-03	1.83E-02	1.12E-01
Climate change - only peat ox	kg CO2 eq	1.18E-01	1.06E-03	1.13E-01	1.15E-02
Stratospheric ozone depletion	kg CFC11 eq	2.89E-06	1.77E-06	3.08E-06	9.27E-06
Ionizing radiation	kBq Co-60 eq	1.97E-02	2.01E-02	3.31E-02	3.17E-02
Ozone formation, Human health	kg NOx eq	1.90E-03	2.37E-03	3.46E-03	5.78E-03
Fine particulate matter formation	kg PM2.5 eq	6.57E-04	8.72E-04	9.46E-04	4.57E-03
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.94E-03	2.20E-03	3.73E-03	4.92E-03
Terrestrial acidification	kg SO2 eq	1.85E-03	2.25E-03	3.28E-03	2.00E-02
Freshwater eutrophication	kg P eq	2.63E-04	3.08E-04	2.42E-04	6.60E-04
Marine eutrophication	kg N eq	4.84E-04	1.37E-04	6.28E-04	1.24E-03
Terrestrial ecotoxicity	kg 1,4-DCB	2.19E+00	4.18E+00	8.60E-01	6.85E+00
Freshwater ecotoxicity	kg 1,4-DCB	8.83E-02	1.34E-01	2.64E-02	2.43E-01
Marine ecotoxicity	kg 1,4-DCB	3.43E-02	4.72E-02	1.80E-02	1.02E-01
Human carcinogenic toxicity	kg 1,4-DCB	1.83E-02	1.70E-02	1.51E-02	3.33E-02
Human non-carcinogenic toxicity	kg 1,4-DCB	5.77E-01	5.76E-01	5.22E-01	1.39E+00
Land use	m2a crop eq	9.00E-01	1.37E+00	7.08E-01	1.09E+00
Land occupation	m2a	1.01E+00	1.48E+00	8.13E-01	1.37E+00
Mineral resource scarcity	kg Cu eq	1.39E-03	1.44E-03	1.00E-03	2.78E-03
Fossil resource scarcity	kg oil eq	1.38E-01	1.71E-01	1.46E-01	2.54E-01
Water consumption	m3	7.07E-03	2.29E-02	7.60E-03	3.27E-02

Oatly Barista and cow's milk at point of sale in China (incl EoL packaging), per kg

Impact category	Unit	Oatly Barista from Ma'anshan (CN)	Oatly Barista from Singapore	Cow's milk from China
Climate change - incl LUC and peat ox	kg CO2 eq	6.04E-01	5.98E-01	1.88E+00
Climate change - excl LUC and peat ox	kg CO2 eq	4.68E-01	5.88E-01	1.76E+00
Climate change - only LUC	kg CO2 eq	2.07E-02	9.05E-03	1.09E-01
Climate change - only peat ox	kg CO2 eq	1.14E-01	1.02E-03	1.12E-02
Stratospheric ozone depletion	kg CFC11 eq	2.80E-06	1.71E-06	9.00E-06
Ionizing radiation	kBq Co-60 eq	1.91E-02	1.94E-02	3.08E-02
Ozone formation, Human health	kg NOx eq	1.84E-03	2.29E-03	5.61E-03
Fine particulate matter formation	kg PM2.5 eq	6.36E-04	8.44E-04	4.43E-03

Impact category	Unit	Oatly Barista from Ma'anshan (CN)	Oatly Barista from Singapore	Cow's milk from China
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.88E-03	2.13E-03	4.78E-03
Terrestrial acidification	kg SO2 eq	1.79E-03	2.17E-03	1.94E-02
Freshwater eutrophication	kg P eq	2.55E-04	2.98E-04	6.41E-04
Marine eutrophication	kg N eq	4.68E-04	1.32E-04	1.20E-03
Terrestrial ecotoxicity	kg 1,4-DCB	2.12E+00	4.04E+00	6.65E+00
Freshwater ecotoxicity	kg 1,4-DCB	8.54E-02	1.30E-01	2.36E-01
Marine ecotoxicity	kg 1,4-DCB	3.32E-02	4.57E-02	9.92E-02
Human carcinogenic toxicity	kg 1,4-DCB	1.77E-02	1.65E-02	3.23E-02
Human non-carcinogenic toxicity	kg 1,4-DCB	5.59E-01	5.58E-01	1.35E+00
Land use	m2a crop eq	8.71E-01	1.33E+00	1.06E+00
Land occupation	m2a	9.75E-01	1.43E+00	1.33E+00
Mineral resource scarcity	kg Cu eq	1.34E-03	1.40E-03	2.70E-03
Fossil resource scarcity	kg oil eq	1.33E-01	1.66E-01	2.47E-01
Water consumption	m3	6.84E-03	2.22E-02	3.17E-02

Oatly Barista and cow's milk at consumer in China (incl. EoL packaging), per liter

Impact category	Unit	Oatly Barista from Ma'anshan (CN)	Oatly Barista from Singapore	Cow's milk from China
Climate change - incl LUC and peat ox	kg CO2 eq	1.01E+00	9.99E-01	2.65E+00
Climate change - excl LUC and peat ox	kg CO2 eq	8.32E-01	9.86E-01	2.50E+00
Climate change - only LUC	kg CO2 eq	2.68E-02	1.17E-02	1.40E-01
Climate change - only peat ox	kg CO2 eq	1.48E-01	1.32E-03	1.44E-02
Stratospheric ozone depletion	kg CFC11 eq	3.68E-06	2.28E-06	1.17E-05
Ionizing radiation	kBq Co-60 eq	2.89E-02	2.93E-02	4.40E-02
Ozone formation, Human health	kg NOx eq	2.99E-03	3.58E-03	7.88E-03
Fine particulate matter formation	kg PM2.5 eq	1.15E-03	1.42E-03	6.06E-03
Ozone formation, Terrestrial ecosystems	kg NOx eq	3.06E-03	3.38E-03	6.82E-03
Terrestrial acidification	kg SO2 eq	3.06E-03	3.55E-03	2.58E-02
Freshwater eutrophication	kg P eq	3.88E-04	4.43E-04	8.70E-04
Marine eutrophication	kg N eq	6.10E-04	1.76E-04	1.55E-03
Terrestrial ecotoxicity	kg 1,4-DCB	3.37E+00	5.86E+00	9.19E+00
Freshwater ecotoxicity	kg 1,4-DCB	1.23E-01	1.80E-01	3.16E-01
Marine ecotoxicity	kg 1,4-DCB	5.90E-02	7.52E-02	1.43E-01
Human carcinogenic toxicity	kg 1,4-DCB	3.54E-02	3.38E-02	5.45E-02
Human non-carcinogenic toxicity	kg 1,4-DCB	8.83E-01	8.82E-01	1.90E+00
Land use	m2a crop eq	1.13E+00	1.72E+00	1.37E+00
Land occupation	m2a	1.27E+00	1.86E+00	1.71E+00
Mineral resource scarcity	kg Cu eq	2.30E-03	2.37E-03	4.04E-03
Fossil resource scarcity	kg oil eq	2.26E-01	2.68E-01	3.74E-01
Water consumption	m3	9.24E-03	2.90E-02	4.13E-02

ReCiPe Endpoints (H) – results for all products (per liter)

Impact category	Unit	Oatly Barista from Ma'anshan (CN)	Oatly Barista from Singapore	Cow's milk from China
Global warming, Human health	DALY			
Global warming, Human health	DALY	5.94E-07	5.84E-07	1.97E-06
Global warming, Terrestrial ecosystems	species.yr	1.79E-09	5.86E-07	5.93E-09
Global warming, Freshwater ecosystems	species.yr	4.89E-14	1.77E-09	1.62E-13
Stratospheric ozone depletion	DALY	1.53E-09	4.83E-14	4.92E-09
Ionizing radiation	DALY	1.67E-10	9.39E-10	2.69E-10
Ozone formation, Human health	DALY	1.68E-09	1.70E-10	5.06E-09
Fine particulate matter formation	DALY	4.30E-07	2.14E-09	2.85E-06
Ozone formation, Terrestrial ecosystems	species.yr	2.47E-10	5.41E-07	6.34E-10
Terrestrial acidification	species.yr	3.82E-10	2.82E-10	4.15E-09
Freshwater eutrophication	species.yr	1.77E-10	4.82E-10	4.43E-10
Marine eutrophication	species.yr	8.22E-13	2.07E-10	2.11E-12
Terrestrial ecotoxicity	species.yr	2.50E-11	2.33E-13	7.81E-11
Freshwater ecotoxicity	species.yr	6.13E-11	4.76E-11	1.69E-10
Marine ecotoxicity	species.yr	3.60E-12	9.30E-11	1.07E-11
Human carcinogenic toxicity	DALY	6.09E-08	4.96E-12	1.11E-07
Human non-carcinogenic toxicity	DALY	1.32E-07	5.64E-08	3.17E-07
Land use	species.yr	7.99E-09	1.31E-07	9.66E-09
Mineral resource scarcity	USD2013	3.21E-04	1.22E-08	6.42E-04
Fossil resource scarcity	USD2013	5.22E-02	3.34E-04	8.30E-02
Water consumption, Human health	DALY	4.30E-09	6.58E-02	3.63E-08
Water consumption, Terrestrial ecosystem	species.yr	1.16E-10	6.92E-09	2.17E-10
Water consumption, Aquatic ecosystems	species.yr	1.79E-14	6.50E-10	9.49E-14

IMPACT WORLD+ – results for all products (per liter)

Impact category	Unit	Oatly Barista from Ma'anshan (CN)	Oatly Barista from Singapore	Cow's milk from China
Climate change, short term	kg CO2 eq	6.41E-01	6.32E-01	2.13E+00
Climate change, long term	kg CO2 eq	6.05E-01	5.98E-01	1.51E+00
Fossil and nuclear energy use	MJ deprived	6.81E+00	8.31E+00	1.24E+01
Mineral resources use	kg deprived	6.62E-03	5.91E-03	9.81E-03
Terrestrial acidification	kg SO2 eq	7.48E-06	6.53E-06	5.54E-05
Freshwater eutrophication	kg PO4 eq	1.21E-04	3.84E-05	1.90E-04
Marine eutrophication	kg N eq	1.16E-03	3.63E-04	3.36E-03
Particulate matter formation	kg PM2.5 eq	1.89E-04	2.72E-04	1.59E-03
Land transformation, biodiversity	m2yr arable	4.97E-04	9.90E-05	1.27E-03
Land occupation, biodiversity	m2yr arable	9.22E-01	1.41E+00	7.12E-01
Water scarcity	m3 world eq	3.50E-01	1.38E+00	1.31E+00

ReCiPe Individualist at Midpoint (with latest GWP20 factors for climate change) – results for all products (per liter)

Impact category	Unit	Oatly Barista from Ma'anshan (CN)	Oatly Barista from Singapore	Cow's milk from China
GWP20 - fossil	kg CO2-eq	0.62	0.62	1.31
GWP20 - biogenic	kg CO2-eq	0.07	0.07	1.96
GWP20 - land transformation	kg CO2-eq	0.02	0.01	0.11
Total	kg CO2-eq	0.71	0.70	3.39

Cow's milk at retail in China (incl. EoL packaging) with different fat contents & alternative processing, per liter

Impact category	Unit	Cow's milk CN 100% full fat	Cow's milk CN 100% semi skimmed	Cow's milk CN 100% skimmed	Cow's milk CN German data for processing
Climate change - incl LUC and peat ox	kg CO2 eq	1.98E+00	1.82E+00	1.57E+00	2.08E+00
Climate change - excl LUC and peat ox	kg CO2 eq	1.86E+00	1.70E+00	1.47E+00	1.96E+00
Climate change - only LUC	kg CO2 eq	1.15E-01	1.06E-01	9.12E-02	1.12E-01
Climate change - only peat ox	kg CO2 eq	1.19E-02	1.08E-02	9.18E-03	1.15E-02
Stratospheric ozone depletion	kg CFC11 eq	9.52E-06	8.67E-06	7.39E-06	9.30E-06
Ionizing radiation	kBq Co-60 eq	3.22E-02	3.06E-02	2.83E-02	3.33E-02
Ozone formation, Human health	kg NOx eq	5.92E-03	5.43E-03	4.68E-03	6.20E-03
Fine particulate matter formation	kg PM2.5 eq	4.68E-03	4.28E-03	3.66E-03	4.88E-03
Ozone formation, Terrestrial ecosystems	kg NOx eq	5.04E-03	4.63E-03	4.00E-03	5.37E-03
Terrestrial acidification	kg SO2 eq	2.05E-02	1.87E-02	1.60E-02	2.07E-02
Freshwater eutrophication	kg P eq	6.74E-04	6.25E-04	5.50E-04	7.07E-04
Marine eutrophication	kg N eq	1.27E-03	1.16E-03	9.93E-04	1.25E-03
Terrestrial ecotoxicity	kg 1,4-DCB	7.02E+00	6.42E+00	5.52E+00	6.93E+00
Freshwater ecotoxicity	kg 1,4-DCB	2.49E-01	2.27E-01	1.95E-01	2.45E-01
Marine ecotoxicity	kg 1,4-DCB	1.05E-01	9.62E-02	8.34E-02	1.05E-01
Human carcinogenic toxicity	kg 1,4-DCB	3.40E-02	3.17E-02	2.83E-02	3.78E-02
Human non-carcinogenic toxicity	kg 1,4-DCB	1.43E+00	1.31E+00	1.13E+00	1.49E+00
Land use	m2a crop eq	1.12E+00	1.02E+00	8.80E-01	1.09E+00
Land occupation	m2a	1.40E+00	1.29E+00	1.13E+00	1.37E+00
Mineral resource scarcity	kg Cu eq	2.84E-03	2.63E-03	2.32E-03	2.82E-03
Fossil resource scarcity	kg oil eq	2.60E-01	2.40E-01	2.10E-01	2.83E-01
Water consumption	m3	3.35E-02	3.06E-02	2.63E-02	3.30E-02

Appendix V Critical Review Statement and Report

Critical Review Statement

The life cycle assessment (LCA) study LCA of Oatly Barista China and comparison with cow's milk was commissioned by Oatly (commissioner of the study) and carried out by Blonk Consultants (practitioner of the LCA study). Blonk Consultants commissioned a panel of external experts to review the study LCA of Oatly Barista China and comparison with cow's milk. The study was critically reviewed by an international panel of experts comprising:`

- Jasmina Burek (chair): Assistant Professor, University of Massachusetts Lowell, United States
- Jens Lansche: LCA expert and project manager, Switzerland
- Joanna Trewern: Food Systems and Sustainable Diets expert, United Kingdom
- Hayo van der Werf: LCA expert, France

All members of the review panel were independent of any party with a commercial interest in the study. The following is a final statement by the external review panel based on the review of the Draft Report, a version of the document submitted on February 15, 2024.

Critical Review Process

The critical review was performed based on ISO 14044:2006 standard, by a panel of interested parties (ISO 14044, 2006). The critical review panel followed the ISO/TS critical review process guidelines (ISO/TS, 2014). All reviewers' comments were performed after LCA practitioners provided the full draft of the LCA report to the critical review panel. The review excluded an assessment of the LCI models developed by Blonk for this project and hence all the findings of the critical review are based solely on the LCA report that was made available to the panel during the critical review. However, the LCI was made available to the reviewers as an annex to the report, which is excluded from the published report because of confidentiality.

The critical review panel found the LCA study to be in conformance with ISO 14040 and ISO 14044 standards (ISO 14040, 2006; ISO 14044, 2006) including:

- the methods used to carry out the LCA were consistent with the applicable international standards
- the methods used to carry out the LCA were scientifically and technically valid
- the data used were appropriate and reasonable in relation to the goal of the study
- the interpretations reflected the limitations identified and the goal of the study, and
- the study report was transparent and consistent.

The critical review did not verify nor validate the goals that are chosen for an LCA by the commissioner of the LCA study, nor the ways in which the LCA results are used (ISO/TS, 2014). Finally, following the ISO/TS standard (ISO/TS, 2014) this critical review in no way implies an endorsement of any comparative assertion that is based on an LCA study. The panel asserts conformity with the ISO standards followed (ISO 14040, 2006; ISO 14044, 2006;

ISO/TS, 2014) and a scientifically and technically valid methodological approach and results interpretation.

The critical-review process involved the following:

- a review of a draft report according to the above criteria and recommendations for improvements to the study and the report; and
- a review of the final version of the report, in which the authors of the study fully addressed the points as suggested in the draft critical review.

Because the *LCA of Oatly Barista China and comparison with cow's milk* study builds on the foundations of the previous LCA studies study for Oatly, i.e., *LCA of Oatly Barista and comparison with cow's milk*, reviewed by the same external review panel, all reviewers' comments were provided via email including:

- January 28, 2024 - reviewers provided comments on the draft of the final LCA report via email.
- February 15, 2024 - reviewers provided additional (editorial) comments on the draft of the final LCA report via email.

After each review, the LCA practitioner responded and/or and documented the adopted changes and implementation in the next version of the draft report. The Critical Review Report (Appendix V) includes panel review comments and recommendations, and the corresponding responses given by the practitioner of the LCA study.

The review panel concludes based on the goals set forth to review this study, that the study generally conforms to the applicable ISO standards as a comprehensive study that may be disclosed to the public.

The reviewers recognize the tremendous work of the LCA practitioners and stakeholder in completing this study.

February 15, 2024

Dr. Jasmina Burek	Dr. Jens Lansche	Dr. Joanna Trewern	Dr. Hayo van der Werf
Panel Chair	Panel Member	Panel Member	Panel Member

LCA of Oatly Barista China and comparison with cow's milk

Version of the document submitted on February 15, 2024

Critical Review Report

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Switzerland

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1. Introduction

The **Critical Review Report** is the summary report documenting the critical review process according to the ISO/TS 14071:2014 Standard - Environmental management -- Life cycle assessment -- Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006. The **Critical Review Report** provides details of the complete review process (ISO/TS, 2014) and includes all review comment iterations of the study "*LCA of Oatly Barista China and comparison with cow's milk*". The study "*LCA of Oatly Barista China and comparison with cow's milk*" was commissioned by Oatly and life cycle assessment (LCA) was performed by Blonk Consultants. The critical review was commissioned by the practitioners of the LCA study. A critical review was carried out by a panel of reviewers, as defined in ISO 14044:2006 (ISO 14044, 2006). The **Critical Review Report** was prepared by the critical review panel. The **Critical Review Report** applies to final version "*LCA of Oatly Barista China and comparison with cow's milk*" published on February 15, 2024.

2. Critical Review Process

The critical review panel followed the ISO/TS critical review process guidelines (ISO/TS, 2014). Because this LCA study includes results which are intended to be used to support a comparative assertion intended to be disclosed to the public, per critical review process guidelines (ISO/TS, 2014), the critical review was conducted by a panel.

All sets of review comments (total 2) were performed after LCA practitioners provided the full draft of the LCA report to the critical review panel. The critical review report includes panel review comments and recommendations, and the corresponding responses given by the practitioner of the LCA study.

Per critical review process guidelines (ISO/TS, 2014), the goal of this critical review was to verify that:

- the methods used to carry out the LCA study are consistent with the 14040/14044 International Standards (ISO 14040, 2006; ISO 14044, 2006),
- the methods used to carry out the LCA are scientifically and technically valid,
- the data used are appropriate and reasonable in relation to the goal of the study,
- the interpretations reflect the limitations identified and the goal of the study,
- the study report is transparent and consistent.

However, critical review can neither verify nor validate the goals that are chosen for an LCA by the commissioner of the LCA study, nor the ways in which the LCA results are used (ISO/TS, 2014). Finally, following the ISO/TS standard (ISO/TS, 2014) this critical review in no way implies an endorsement of any comparative assertion that is based on an LCA study.

The review was performed by an independent expert panel composed of four members. The critical-review process involved the following:

- a review of a draft report according to the above criteria and recommendations for improvements to the study and the report; and
- a review of the final version of the report, in which the authors of the study fully

addressed the points as suggested in the draft critical review.

3. Critical Review Results

This section includes a summary of the critical review. A complete list of comments addressing specific statements on the draft LCA report provided by the critical review panelists and subsequent revisions is provided in Appendix V.

The reviewers recognize the remarkable effort by the LCA practitioners (Blonk Consultants) in conducting the comparative LCA study as well as the stakeholder (Oatly) that provided primary data as well as critical comments. The critical review panel pointed out both the strengths as well as key areas of improvement necessary to conform to the 14040/14044 International Standards (ISO 14040, 2006; ISO 14044, 2006).

3.1 Consistency with 14040/14044 International Standards

The final LCA report is consistent with the 14040 and 14044 International Standards (ISO 14040, 2006; ISO 14044, 2006) and the European Product Environmental Footprint Category Rules (PEFCR) (European Commission, 2017). The authors appropriately defined the goal of the study and functional unit for comparison of one-liter Oatly Barista and cow's milk products produced in the China. The sensitivity analysis was performed using an alternative functional unit based on the nutritional density of the Oatly Barista and cow's milk products. The study is comprehensive in scope and contains a wealth of information and data related to Oatly Barista product supply chains in their respective production countries. The authors provided information why the critical review is being undertaken and what data collection covered and to what level of detail and how comparison with the milk was conducted in addition to performing sensitivity analyses and uncertainty analysis.

3.2 Life Cycle Assessment Approach and Life Cycle Impact Assessment Method

The authors computed results following the attributional LCA approach. In a baseline scenario, Oatly Barista was compared to 1 l of cow's milk at the point of sale. The life cycle impact assessment was performed using nine key midpoint environmental impact categories from the ReCiPe 2016 impact assessment method (Huijbregts et al., 2016). The choice of impact assessment method was tested using sensitivity analysis with endpoint environmental impact categories from the ReCiPe 2016 and alternative midpoint environmental impact categories from EF 3.0 (European Commission, 2017).

Sensitivity and scenario analyses that were performed for earlier LCA study of Oatly Barista were not included in the study for Oatly Barista supply chain for China, because the conclusions made there regarding sensitivity and scenario analysis are valid for Oatly Barista supply chain for China. A sensitivity analysis was performed on alternative life cycle impact assessment methods, inclusion of use stage, cow's milk fat content, and cow's milk processing. Also, the study includes a comparison of cow's milk results with other studies. Uncertainty analysis has been performed to determine the range in outcomes when considering uncertainties in the input data.

Overall, the methodology and the selection of the sensitivity, and uncertainty analyses to evaluate the results of the impact assessment and support conclusion are considered appropriate for the goal and scope of the study.

3.3 Data Used for Life Cycle Inventory in Relation to the Goal of the Study

Overall, the data used is considered appropriate and reasonable for the goal and scope of the study. In parallel to proprietary stakeholder life cycle inventory (LCI) data necessary to perform LCA of Oatly Barista in China, the study included Chinese cow's milk supply chain LCI data from recent literature and LCI database. The authors of the final report clearly described LCIs and data sources. Also, the authors provided information about robustness and limitations of the data used for Oatly Barista and cow's milk product LCI and assumptions for sensitivity and uncertainty analyses.

3.4 Interpretation and Limitations within the Goal of the Study

The authors present a large variety of results addressing various aspects of the study. The selected results help to understand study's conclusions and adequately support derived interpretation. Sensitivity, and uncertainty analyses further provide insights of the methodological and data choices and their influence on results, robustness of the conclusions, and the limitations of the results. Overall, interpretation of results and limitations of the study discussed in the report are considered appropriate for the goal of the study.

3.5 Transparency and Consistency of the Final Report

The authors provided an extensive report following the 14040/14044 International Standards (ISO 14040, 2006; ISO 14044, 2006) and supplemental information with information concerning the data and methodology used. The main report describes LCA framework including goal and scope, LCI, LCIA, results and interpretation, sensitivity analyses, uncertainty analysis, and conclusion. The key aspects of the data used is described in the LCI section and accompanied with the supplemental information, which provides more details on the data sources. Overall, the information given in the documentation is considered appropriate for under- standing the methodology and data basis for most topics.

Literature

European Commission, 2017. Product Environmental Footprint Category Rules Guidance. PEFCR Guid. Doc. - Guid. Dev. Prod. Environ. Footpr. Categ. Rules (PEFCRs), version 6.3, December 2017. 238.

Huijbregts, M.A.J., Steinmann, Z.J.., Elshout, P.M.F., Stam, G., Verones, F., Vieira, M.D.., Zijp, M., van Zelm, R., 2016. ReCiPe 2016: A harmonized life cycle impact assessment method at midpoint and enpoint level - report 1 : characterization, National Institute for Public Health and the Environment.

ISO/TS, 2014. ISO/TS 14071:2014 - Environmental management -- Life cycle assessment -- Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006 [WWW Document]. URL https://www.iso.org/standard/61103.html (accessed 6.21.19).

ISO 14040, 2006. ISO 14040:2006 - Environmental management - life cycle assessment - principles and framework [WWW Document]. ISO. URL https://www.iso.org/standard/37456.html (accessed 2.22.17).

ISO 14044, 2006. Environmental management - Life cycle assessment — Requirements and guidelines (International Organization for Standardization).

4. List of Specific Reviewer Comments Recommendations and Corresponding Responses

Critical Review Panel provided comments on 2 iterations of the draft report. These comments were addressed and/or incorporated in the final version of the report by the LCA partitioners. The review statement and review panel report including comments of the experts and any responses to recommendations made by the reviewers or by the panel have been included in the final LCA report.

Reviewer[1]	Line number	Clause/ Subclause	Paragraph/ Figure/ Table/	Type of comment[2]	Comments	Proposed change	Response of the commissioner& practitioner	Final reviewer statement
HW	164-165			Ed.	*Shifting to a more local approach (100% Australian oats, all produced in the Ma'anshan 164 factory) could reduce the total impact with almost 20% in comparison to import from the Netherlands.*	This sentence seems to suggest "could reduce" that the shift to a more local approach has not yet occurred. However, the report indicates that this shift is already in place. Can you clarify?	Done. This has not fully occurred, since at the moment there is supply to China from both Singapore and Ma'anshan (instead of 100% Ma'anshan in this scenario) and there is currently a mix of origins from the oats (not 100% Australian yet). Therefor it is mentioned "could" and not "does"	OK
HW			Table 2	Te.	Product name "Cow's milk"	Could you add the specification "country-average mix" ?	Done	OK
HW	437-438			Ed.	(Pas & Westbroek, 2022)	Please reduce font size.	Done	OK
HW			Table 8	Ed.	*verified (by EY, with limited assurance)*	Not clear what this means, what is EY, what is meant by "with limited assurance"?	Done, explained in the report	OK
HW			Table 8		*Specific data on yields*	Could you specify: are the crop yields, forage yields, milk per cow yields?	Done	OK
HW			Table 9		Oatly Barista China contains 3% fat, 6.5% carbohydrates, 0.8% fiber and 1.0% protein. So probably rapeseed contributes significantly to its dry matter. It would be good to add information on rapeseed cultivation and rapeseed processing to Table 9, in the same way as information is supplied on oat cultivation and oat milling and processing.	Please add information on rapeseed as proposed.	Done	OK
HW	532-533			Te.	A sensitivity analysis considering a nutritional functional unit was conducted in a previous Oatly Barista study. This analysis did not alter the conclusions of the study, it was therefore not repeated in	I can agree with this decision. However, it would nevertheless be good to include a table presenting the nutritional information for Barista China, to provide a more	Done	OK

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					this study.	complete characterisation of the product. This information could be given in section 1.3.1, where the product is described.		
HW	593-594			Ed.	*this life cycle stage was observed to be lower* You probably mean: *this life cycle stage was observed to contribute less to overall impacts*	Could you adjust formulation of the sentence?	Done	OK
HW	595			Te.	*a sensitivity analysis was executed to compare the results as with processing data from Germany*	Could you explain why the processing data from Germany were chosen? E.g. was it the country with the lowest impacts for processing?	Done	OK
HW			Table 10	Te.	*Rapeseed oil (from inner Mongolia for the Ma'anshan production, and from Malaysian origin for the Singapore production)* Table in appendix at line 1420 indicates that rapeseed for Oatly Barista at Singapore is from Canadian rapeseed.	Can you clarify this?	Done, this was a typing mistake	OK
HW	747-749			Te.	It would be of interest to present the contribution of rapeseed production and transformation to the climate change impact as is done for oats.	Could you add information as proposed?	Done	OK
HW	767-775			Te	It would be of interest to present the contribution of rapeseed production and transformation to the land use and land occupation impacts..	Could you add information as proposed?	Done	OK
HW			Section 5.2.5	Te.	This comparison with other studies is interesting and essential. I have several comments: • It would be good to explicitly state	Could you take into account these comments?	Done	OK

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					whether these studies have the same system boundaries i.e. from cradle to retail. As presented in the table, only the Ledgard et al study seems to have a different system boundary. • Zhao et al and Wang et al have much lower values for the climate change impact. I think these results warrant doing a sensitivity analysis with a lower value (e.g. 1.2 kg CO2-eq/kg FPCM as the reference for milk. • Fig 19 caption reads "Sensitivity analysis", it does not show results of a sensitivity analysis, but results of a comparison of studies.			
HW	1046			Ed.		Change "United States" to "China".	Done	OK
HW	1077			Ed.		Change "produced" to "transformed".	Done (changed to "processed")	OK
HW	1418-1421			Te.	Producing 1 kg of Oatly Barista requires [redacted] kg oatbase, [redacted] kg rapeseed oil and [redacted] dm3 tap water at Manshan, it requires [redacted] kg oatbase, [redacted] kg rapeseed oil and [redacted] dm3 tap water at Singapore. Why are these input amounts different, since they yield the same products? In particular differences for tap water and rapeseed oil are large. Why are these input amounts different, since they yield the same products? In	Can you clarify?	There are several explanations: 1. The amount of rapeseed was a reporting mistake. Actually it was quite similar for both factories; see new appendix. 2. The slight difference in Oatbase can be attributed with differences in Oatbase dry matter, and efficiencies of each factory. Similar to the case in the US, sometimes a factory adds more oats than necessary to the reactors to achieve the same finished product. 3. We found a data point missing (water to discharge was unknown	OK

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					particular differences for tap water and rapeseed oil are large.		and therefore the water balance was not met); we have corrected this in the final version by means of estimation of the same water use ratios as for Ma'anshan. This was also crosschecked with US factories, and showing similar water consumption ratios.	
JT	304-306			Ed.	"By lack of information on Chinese milk packaging except that Tetra Pak is a major supplier (Tang et al., 2022), the modelling of the packaging was kept equal to Oatly Barista's packaging in China, which is supplied by Tetra Pak" Do you mean that data (Tang et al., 2022) suggests that Tetra Pak is a major supplier of cow's milk packaging in China, therefore packaging was assumed to be the same for cow's milk and Oatly?	Can this be reworded to clarify meaning?	Done	OK
JT	454			Ed	CFF	Spell out acronym.	Done	OK
JT	675			Ed	"those marketing for retail packaged milk" – what does this mean? Dairy suppliers providing cow's milk for the packaged retail market?	Clarify meaning.	Done	OK
JT			Table 11	Te	"By lack of primary data, packaging was presumed similar to packaging of Oatly Barista China". Phrasing earlier in the report (lines 304-306, see previous comment) indicates that this assumption was also made as data suggest Tetra Pak is the main supplier of packaging for cow's milk in the China market.	Review and align with earlier section of report.	Done	OK

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JT	765-766			Ed	"Marine eutrophication is linked to nitrate from the application of fertilizers and manure during cultivation of oats, rapeseed, and cow's feed crops" It could be added that marine eutrophication impact is lower for Oatly produced in Singapore due to lower fertiliser application in oat production in Australia.	Consider adding extra line on lower marine eutrophication impact of Oatly produced in Singapore.	Done	OK
JT	916-917			Ge	It is good to see the IMPACT+ method used in sensitivity analysis, particularly for assessing water impact, given scarcity-weighted water use is regarded as a far more accurate indicator for assessing the impact of water use. It is used e.g., in Poore & Nemecek 2018, as seen here in Our World in Data: https://ourworldindata.org/grapher/scarcity-water-per-kg-poore	No change needed.	Thank you	
JL	102-104			Ed	"The second method employed (uncharacterized) land occupation category shows comparable impact for Oatly Barista from Singapore and Chinese cow's milk." In the previous sentences, the relative difference (percentage value) is always given in brackets, which is not the case here.	Even if all values are included in the table, I would recommend including the deviation (8%) in the text for reasons of consistency.	Done	OK
JL	Page 6 Page 12	Footnote 2 1.3.2 System boundaries		Te	" The data collected for this study refers to this configuration for the Ma'anshan location for the period September 2022 to September 2023" No information on the temporal system boundaries	It would be helpful to include a paragraph on the temporal system boundaries in the chapter on system boundaries and to clearly define the period of the study. This can then be compared in Table 8 together with the data collection periods in order to	Done, added in scope section and aligned in other sections	OK

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Template for CR comments and commissioner & practitioner responses

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Reviewer[1]	Line number	Clause/ Subclause	Paragraph/ Figure/ Table/	Type of comment[2]	Comments	Proposed change	Response of the commissioner& practitioner	Final reviewer statement
	460-462 504	Table 8			"The primary data (mass, water & energy balance, inputs and auxiliary materials, transport modes & distances, and packaging data) was delivered by Oatly for the complete year 2022 for two production locations (Ma'anshan and Singapore). "The Oatly supply chain and processing data for Oatly from Singapore was derived from the complete year 2022 and for Oatly Barista from Ma'anshan for September 2022 to September 2023." Information on the period of data collection or the study's observation period appears at various points. These are not completely consistent and the chapter on system boundaries does not contain any information on the temporal system boundaries.	assess the temporal representativeness.		
JL	164-165			Ed	"Shifting to a more local approach (100% Australian oats, all produced in the Ma'anshan 164 factory) could reduce the total impact with almost 20% in comparison to import from the Netherlands."	Replace "could" by "allowed" to avoid misunderstandings.	Adjusted differently, see comment above	OK
JL	169-170 811-812 1089-1090			Te	"The second highest impact is caused by the smallest amount of material: aluminum."	Add as additional information whether it is primary or secondary aluminium	Added in results discussion, but not added in executive summary & conclusions	OK
JL	182-183			Te	"Oatly Barista has a lower impact than cow's milk for the two main production facilities for the Chinese market included in this study (Ma'anshan and Singapore)"	Please specify what proportion of total production for the Chinese market these two production sites account for (alternatively: how many other	Added to first part of the executive summary, 1.2 goal and conclusions	OK

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						production sites there are).		
JL	Page 12	Footnote 8		Ed	"Based on recommendations from an expert familiar with the Chinese dairy sector: Jelle Zijlstra, Dairy Economist, Wageningen Livestock Research, Wageningen University & Research."	Add when this information was retrieved.	Done	OK
JL	467			Te	"Transport: Agri-footprint 6 is used, …"	Add version number.	Done	OK
JL	504	Table 8		Te	"The data used refers to Oatly's end-to-end production at Ma'anshan (China), and production in Singapore which represents the full production in 2022 for this specific product." Have production capacities resp shares changed in 2023? If so, how?	Refer to 2023 as well regarding production shares of the two facilities under study.	The production has shifted from the Netherlands to Ma'anshan over the course of 2022. However, this study has the aim to reflect the most recent situation, and that is a 50-50 contribution of the Ma'anshan and Singapore factories in 2023. We assessed the impact of Barista coming from the Dutch factory as an additional assessment in 5.1.2. We added this explanation to the report, as explained in one of the previous comments.	OK
JL	Page 19	Footnote 12		Ed	"Jelle Zijlstra, Dairy Economist, Wageningen Livestock Research, Wageningen University & Research."	Add when this information was retrieved.	Done	OK
JL	644	2.Oats transport to mill		Ed	"DWT"	Spell out acronym.	Done	OK
JB		Abbreviations		Ed	Missing abbreviations or abbreviations not spelled out at first mentioning	Check that all abbreviations in the document are listed. Also check that at first mention the abbreviation is spelled-out. For example, UHT	Done	OK
JB	119			Ed	life cycle impact assessment	LCIA	Abbreviation added	OK

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JB	126			Ed	"The climate impact of cow's milk"	To be consistent replace climate impact with climate change impact	Done	OK
JB	128	"the biggest and most recent study (Dong & Wei, 2021)."		Ed	What does "the biggest study" mean?	I suggest clarifying "biggest study". Perhaps most comprehensive?	Done	OK
JB	148	partially caused by low fertilizer application		Ge	Does Australia have different fertilizer application limits from other regions and if so why?	Explain further potential reasons for difference in fertilizer application	The specific reason for this difference is unknown. The data on fertilizer application in the background database (Agri-footprint) comes from FAO data, without further explanation on the agriculture practises. We added this as a footnote.	OK
JB	239	Oatly's Singapore and Ma'anshan factory		Ed	2 factories or one for both?	If two factories than should be plural i.e., factories.	Done	OK
JB	245			Ed	climate change is missing impact	climate change impact.	Done	OK
JB	444			Ed	at Ma'anshan and Singapore factory	If two factories than should be factories	Done	OK
JB	438	(Pas & Westbroek, 2022)		Ed	Formatting – larger font	Make sure formatting is consistent (font type and size)	Done	OK
JB		by EY, with limited assurance	Table 8	Ed	Who or what is EY	Clarify EY	Done	OK
JB	620-627	Production in Ma'anshan, China		Te	There are multiple factories, but it is not clear if their weighted average was used or some other approach	In cases where there are multiple factories reported and may need to be aggregated, it should be specified how the data was aggregated to LCI data input	There has been no aggregation.	OK

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JB	684			Te	Here it appears that the national-average data is used, but to my understanding at least for cow milk it was based on U.S.	Make sure that limitations reflect the assumptions and data presented.	Done	OK
JB	683	Assumptions and limitations		Te	From data reported it appears that there should be more assumptions and limitations listed here	Make sure that all limitations and assumptions are included	Done	OK
Panel Review February 2024								
HW	313			Ed.		The sentence starting with "Oatly Barista is" should be the first sentence of a new paragraph.	Done	OK
HW			Table 13	Te	Table 13 does not give the same relative values as Table 1 for terrestrial acidification, freshwater eutrophication and marine eutrophication. This seems to be the case because the values for cow milk for these impact categories seem to be wrong in Table 13, i.e. they are different from the values given in Figure 7.	Can you correct this?	Done. This was caused by a spreadsheet mistake, not by a calculation mistake. None of the other tables/graphs have changed. During this check, we found that the value for terr. Acidification from oatly Singapore was not yet updated (from 81 to 89%); we corrected this as well	OK
HW			Table 13	TE	The table in the annexes between lines 1454 and 1455 has been corrected, input of rapeseed oil has increased. However, more rapeseed oil requires more land, but values for land use and land occupation have not changed.	Can you check this?	Rapeseed oil was incorrectly reported in the previous version of the report. We corrected only the report, not the results, so it is correct that all graphs are still the same.	OK

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5. Self-declaration of independence

I, the signatory, hereby declare that:

- I am not a full-time or part-time employee of the commissioner or practitioner of the LCA study
- I have not been involved in defining the scope or carrying out any of the work to conduct the LCA study at hand, i.e. I have not been part of the commissioner's or practitioner's project team(s)
- I do not have vested financial, political, or other interests in the outcome of the study

I declare that the above statements are truthful and complete.

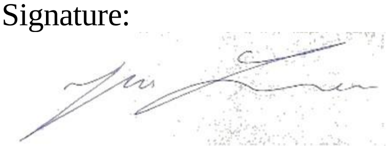
Date: February 15, 2024

Name: Jasmina Burek

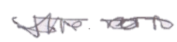
Signature:

Name: Jens Lansche

Signature:



Name: Joanna Trewern

Signature: 

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Signature:

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