Life Cycle Assessment of Apeel Produce

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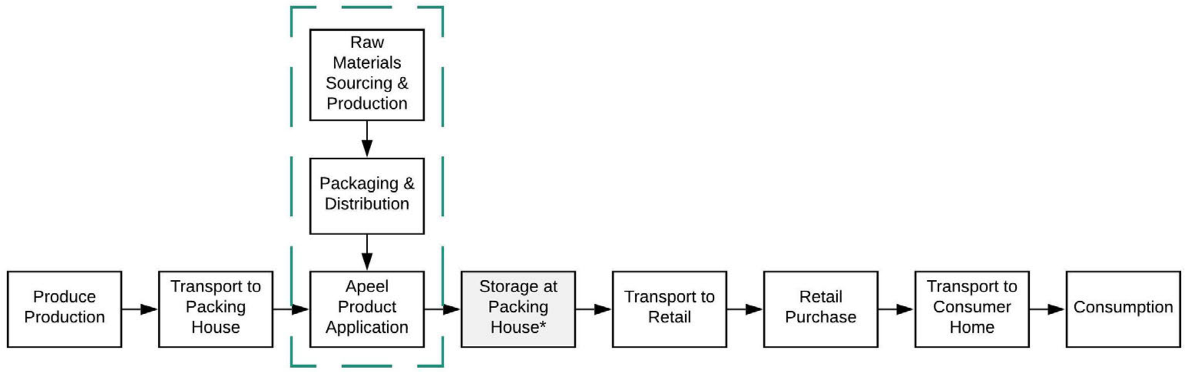
Executive Summary

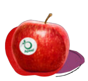
Apeel Sciences completed a life cycle assessment (LCA) study in May 2020 to quantify the environmental impacts of incorporating its plant-derived coating to extend the shelf-life of fresh fruits and vegetables into the supply chains for several produce categories: avocados, limes, apples, mandarins, and oranges. The following report describes the methodology, assumptions, and data sources utilized to estimate the potential environmental impacts associated with baseline produce versus that of the Apeel Produce, i.e. produce treated with the Apeel product. This assessment relies on the best available LCA-related information on food and agriculture production and has been conducted according to the requirements of ISO 14040 and 14044.

System Boundary for Apeel Produce



*Note: Only apples and mandarins are typically stored at the packing house following Apeel product application

This scope of this study was cradle-to-grave, including all stages of the produce and Apeel product's life cycles. The processes in the dotted line are Apeel-specific processes integrated into the baseline produce system boundary. The complete results indicate that the Apeel Produce had a lower environmental impact by 10% – 25% in a majority of cases. The table below shows the baseline and Apeel Produce environmental impacts across all five major impact categories, as well as the % environmental impact reduction with Apeel. These results and those for other impact categories are explored further in the main text.

		Climate Change Total (kg CO2-eq)	Freshwater and Terrestrial Acidification (mol H+-Eq)	Freshwater Eutrophication (kg P-eq)	Fossil Resources (MJ)	Cumulative Water Withdrawal (m3)
Avocados: EU End Market 	Baseline	1.92	1.76E-02	3.70E-04	20.9	1.17
	Apeel	1.66	1.48E-02	3.30E-04	18.3	0.993
	Percent Change with Apeel	**-13.6%**	**-15.7%**	**-10.8%**	**-12.4%**	**-15.3%**
Avocados: US End Market 	Baseline	3.26	1.42E-02	4.60E-04	29.4	1.30
	Apeel	2.37	1.14E-02	3.70E-04	23.9	1.05
	Percent Change with Apeel	**-27.4%**	**-19.4%**	**-19.6%**	**-18.6%**	**-19.6%**
Spanish Oranges 	Baseline	1.22	9.78E-03	2.00E-04	14.7	0.208
	Apeel	1.07	8.46E-03	1.70E-04	13.0	0.183
	Percent Change with Apeel	**-12.1%**	**-13.5%**	**-15.0%**	**-11.9%**	**-12.0%**
Spanish Mandarins 	Baseline	1.09	9.20E-03	1.91E-04	14.0	0.205
	Apeel	0.962	7.92E-03	1.70E-04	12.5	0.179
	Percent Change with Apeel	**-11.6%**	**-13.9%**	**-11.0%**	**-11.1%**	**-12.7%**
Mexican Limes 	Baseline	1.89	1.29E-02	3.40E-04	21.8	0.854
	Apeel	1.45	1.04E-02	2.80E-04	18.2	0.686
	Percent Change with Apeel	**-23.7%**	**-19.0%**	**-17.6%**	**-16.8%**	**-19.6%**
Apples: US End Market 	Baseline	2.10	9.64E-03	4.01E-04	23.5	0.300
	Apeel	1.59	7.82E-03	3.26E-04	19.4	0.242
	Percent Change with Apeel	**-24.3%**	**-18.9%**	**-18.7%**	**-17.4%**	**-19.6%**

Introduction

Apeel Sciences has developed a plant-derived coating that helps USDA Certified Organic and conventional fresh food growers, suppliers and retailers maintain produce quality and extend shelf life, which minimizes food waste across the produce value chain. Today, in-market results indicate that Apeel formulations have been proven effective at reducing the rate of spoilage for dozens of produce categories,[1] and the company works with partners ranging from smallholder farmers and local organic growers to the world's largest food brands and retailers.

Produce treated with Apeel has a thin, edible, plant-derived coating that slows the rate of water loss and oxidation – the primary causes of spoilage – and can keep the produce fresh two to three times longer compared to produce without Apeel. While there are many ways to preserve the freshness of fruits and vegetables during storage and distribution, many of these approaches are only effective for a portion of the supply chain (e.g., cold storage, controlled atmosphere shipping containers, modified atmosphere intermediate packaging, etc.) and can result in significant environmental impacts[2]. While these methods have been effective at reducing food losses between agricultural production and retail stores, there is still a significant amount of food waste that occurs at the retail and consumer stages[3]. Figures 2 and 3 in the following section demonstrate how areas with cold chain infrastructure have minimized upstream losses, but there is still a significant amount of waste later in the supply chain.

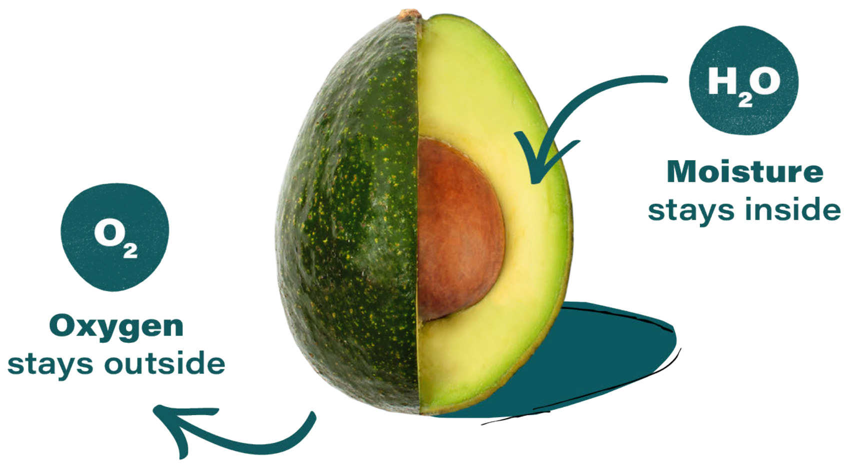


Figure 1. Illustration of Apeel Product Mechanism on Produce

[1] Apeel is not currently able to externally disclose specific product performance testing metrics and has not formally published product testing results due IP concerns. However, Apeel has gathered sufficient in-market data from retailer customers to prove product performance and efficacy. In addition, this time-lapse video shows the shelf life of produce with and without Apeel. https://apeelsciences.com/time/

[2] S.J. James & C. James, The food cold-chain and climate change, (Food Research International, 43, 2010), 1944-1956.

[3] Porter, S.D., Reay, D.S., Higgins, P. & Bomberg, E. 2016. A half-century of production-phase greenhouse gas emissions from food loss & waste in the global food supply chain. *Science of the Total Environment,* 571: 721-729

Globally one-third to half of all food produced for consumption goes to waste, and fresh produce has particularly high food waste rates due to its high perishability.[4] While this waste occurs throughout the produce supply chain, the existence of robust cold chain infrastructure plays a role in where a majority of the losses occur. In regions like sub-Saharan Africa a significant amount of fresh produce is lost between the farm and the market; however, in areas such as the United States where cold chain infrastructure and other technologies are effective at minimizing food waste from the farm to the market, a large portion of the waste occurs at the retail and consumer stages (see Figures 2 and 3).

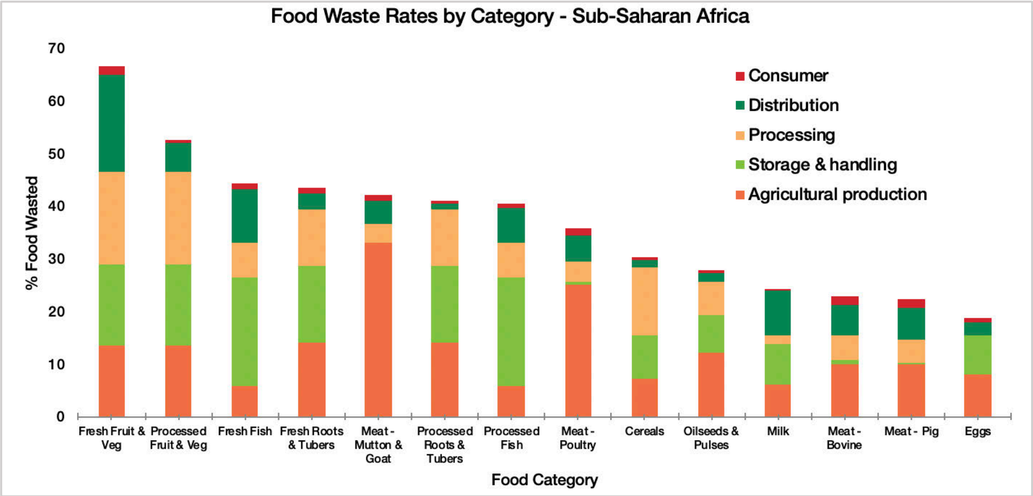


Figure 2. Food Waste Rates by Food Category in Sub-Saharan Africa[5]

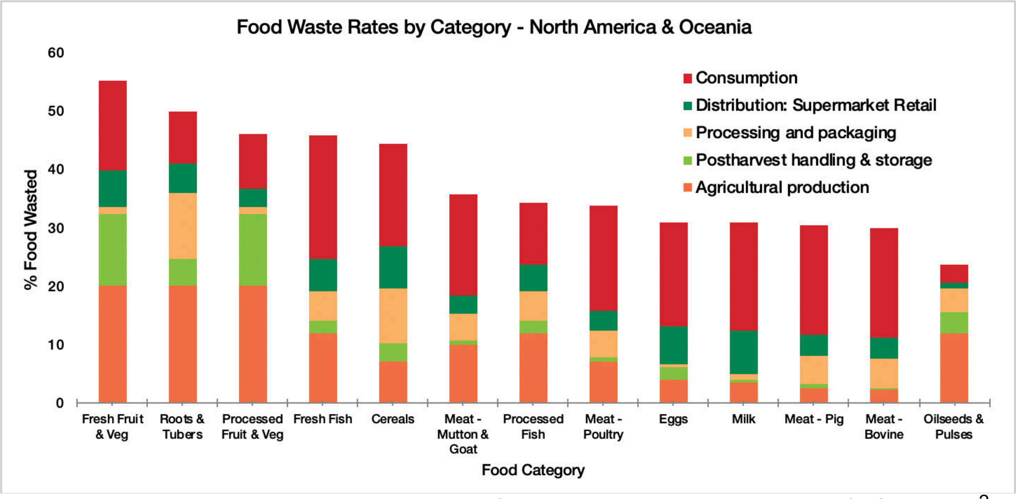


Figure 3. Food Waste Rates by Food Category in North America & Oceania[2]

[4] UN FAO. 2011. *Global food losses and food waste – Extent, causes and prevention.* Rome

[5] Porter, S.D., Reay, D.S., Higgins, P. & Bomberg, E. 2016. A half-century of production-phase greenhouse gas emissions from food loss & waste in the global food supply chain. *Science of the Total Environment,* 571: 721-729.

Apeel's technology has the potential to reduce losses in both scenarios, enabling more produce to reach markets in the absence of the cold chain and reducing retail and consumer waste by providing more time to consume the produce at its ripe condition. By reducing loss and waste throughout the produce supply chain, the Apeel technology can effectively increase yields across the supply chain, simultaneously reducing the embodied emissions and resource consumption associated with that otherwise wasted food.

This study will focus on five of Apeel's products (i.e., produce treated with the Apeel product):

- Apeel Avocados
- Apeel Limes
- Apeel Apples
- Apeel Oranges
- Apeel Mandarins

These five Apeel products have already been brought to market, which means enough trials have been conducted and product efficacy data exists to make informed assumptions about in-market product performance. Details about the supply chain locations and distribution for each category will be described in the System Characterization and Data Sources section. This study will assess the implications of introducing the Apeel solution into supply chains for these produce categories on each produce type's environmental footprint. Since the baseline waste rate in a given supply chain and the reduction of waste enabled by the Apeel product both vary based on a number of factors (e.g., existing supply chain structure, retailer practices, produce category perishability, etc.), the study will consider a number of different outcome scenarios. Using the life cycle assessment (LCA) methodology, this study seeks to understand in better detail the environmental impacts of the Apeel product itself and whether the efficiencies gained from introducing Apeel are justified by the added burdens within the produce supply chain.

Goal of the Study

Apeel Sciences was founded on a mission “to make better quality, more sustainable produce possible”.[6] With an overarching objective to reduce food waste and otherwise improve efficiency of the produce supply chain, there is inherently a strong alignment between this mission and the success of the Apeel products in market. However, reducing food waste and other efficiency gains alone do not achieve this mission, as the added burdens associated with the means to achieve these outcomes (i.e. the environmental impacts of the production and application of the Apeel product itself) should be considered to determine if net environmental impact reductions indeed exist. This study seeks to provide clarity on the overall environmental impacts of Apeel Produce, with particular attention to the trade-offs between the addition of the Apeel product to several produce supply chains and the reduction of wasted food and resources throughout the system.

The results of this study will be used by Apeel Sciences in two different ways:

(1) internally to make strategic business decisions to reduce environmental impacts in the areas identified as the largest hotspots in the Apeel product’s life cycle, and
(2) externally to communicate the net environmental benefits of Apeel Produce to customers and consumers.

This LCA compares the environmental impact of several types of produce with and without the use of the Apeel coating but does not seek to make comparative claims with other products.

[6] https://apeelsciences.com/our-story/

Scope and System Boundaries

The functional unit for this analysis is 1kg of Apeel-treated produce (also referred to as "Apeel Produce") consumed in US or EU households. This will be compared to a baseline 1kg of produce (without Apeel) consumed in US or EU households. The purpose of this study is to understand the difference between these two scenarios, as well as to analyze the environmental impacts associated with the Apeel product itself. All results presented will be in relation to this same functional unit, even if a subset (e.g., only the impacts at the application stage) is presented on its own.

General Description of the Product Studied

The Apeel product is manufactured in a powder form. The powder is packaged and shipped to a customer integration site (i.e., a produce packing house owned by a grower, packer, importer or distributor) where the powder is mixed in solution with water and sprayed onto the produce before it is packed and distributed to retail stores. This process is typically in-line with the standard sorting and packing procedures of the produce packing houses. Figure 4 outlines the entire system boundary for this study, including the stages specific to the Apeel product life cycle surrounded by a dashed line. The baseline (i.e., without Apeel) produce scenario is simply represented by the six or seven remaining stages alone: produce production, transport to packing house, storage at packing house (apples and mandarins only), distribution to retail, retail purchase, transport to household, and consumption. The inputs and outputs for each of these unit processes will vary slightly for each produce category and will be described in further detail in the following sections.

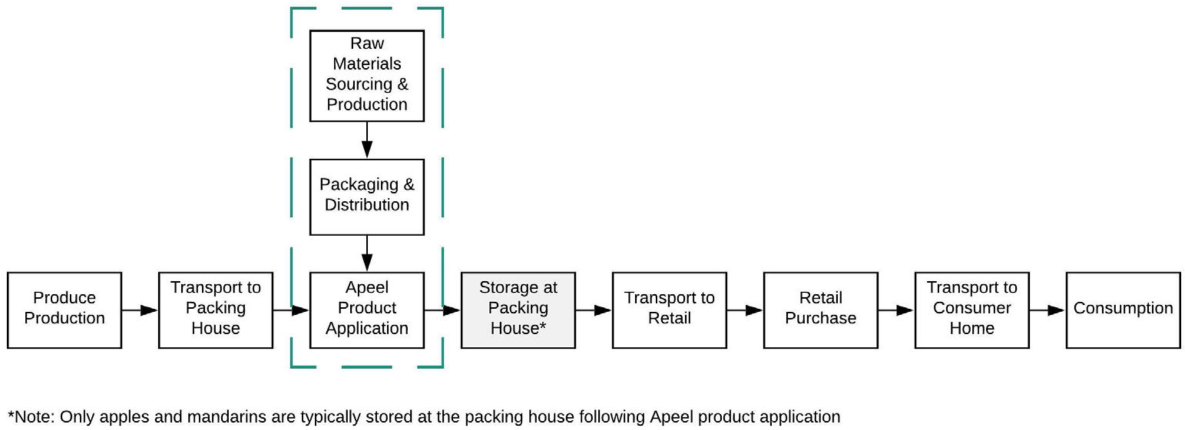


Figure 4. System Boundary for Apeel Produce (Apeel-specific processes surrounded by the dashed line)

The function of the Apeel coating on fresh produce is to extend the shelf-life so that there is more time for retailers to sell it and more time for consumers to enjoy it before it spoils and is wasted. This product efficacy can be measured in a number of ways. There is no standard measurement of "shelf-life" for fruits and vegetables, as consumer preference plays a large role in what does or does not get consumed. Since different types of produce spoil in different ways, produce quality and Apeel product performance is measured differently for each of the five produce categories in this study.

Figure 5 describes the quality indicator(s) and Apeel product performance for in-market Apeel produce categories. A combination of these measurements can be used to approximate the total shelf-life and edible shelf-life of produce. The product performance of the Apeel coating listed in Figure 5 is based on commercial data and large product trials to date, Apeel expects these product performance metrics to be consistent across all large commercial supply chains that typically have refrigeration infrastructure and modern logistics technologies. Apeel will continue to assess how product performance differs in other types of supply chains; future LCA studies will consider these factors.

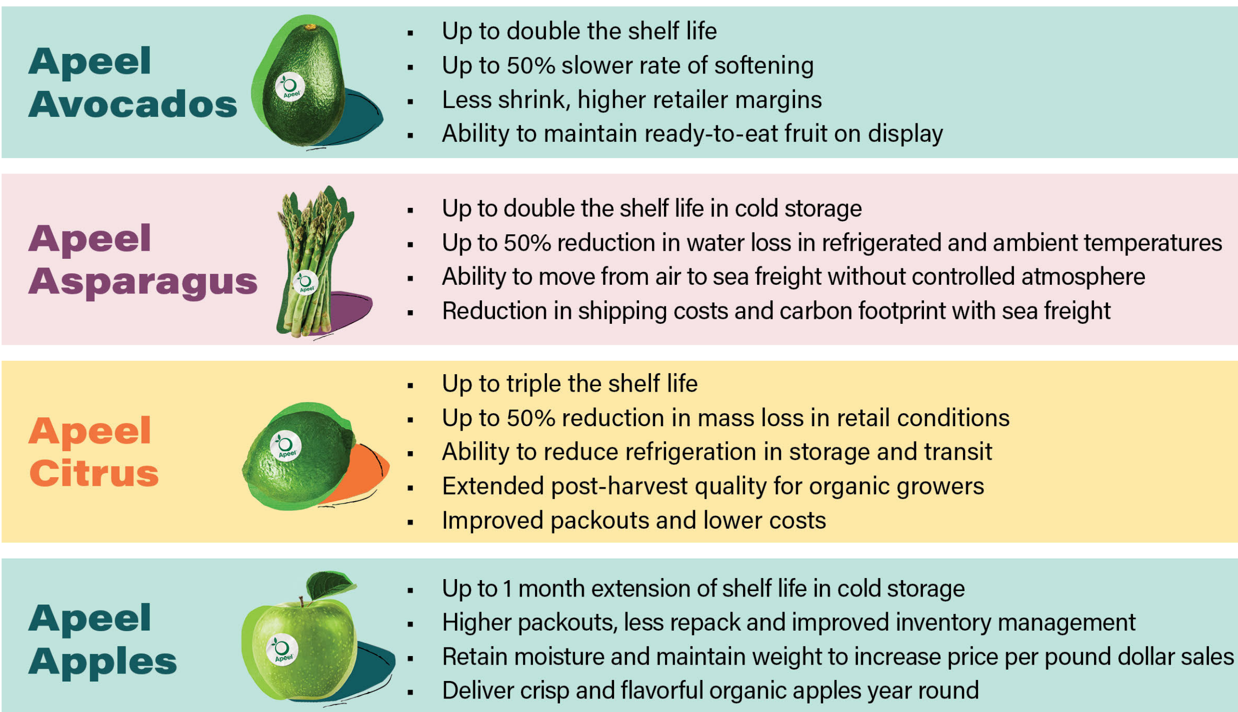


Figure 5. Examples of Product Performance Metrics for Apeel Produce

While the direct effect of the Apeel coating is to slow the rate of spoilage and extend the shelf-life of the produce, the indirect benefit is to reduce food waste and improve efficiency throughout the produce's supply chain. As demonstrated in Figures 2 and 3, fresh fruits and vegetables are wasted at different stages in the supply chain. The Apeel coating can also be applied at different stages in the supply chain; and therefore, the measurable impact on food waste and other supply chain improvements can be different under different scenarios. For example, Apeel has the potential to reduce storage and transport waste if the Apeel coating is applied in the agricultural region of production. However, the storage period or transport distance must be sufficiently long for a significant amount of waste to occur in the baseline scenario. In other instances, shorter supply chains efficiently move produce from the region of production to the region of final sale and consumption. In those instances, Apeel does not have a measurable impact on storage and transport food waste simply because very little occurs in these shorter, faster supply chains.

Figure 6 displays all of the supply chains that are considered in this report, and Tables 1 and 2 describe the location in those supply chains where the Apeel application occurs and the scope of impact included in this study for each produce category. These scenarios are representative of Apeel's current operations; however, future integrations of the Apeel product could be located at different stages in the fresh produce supply chain.

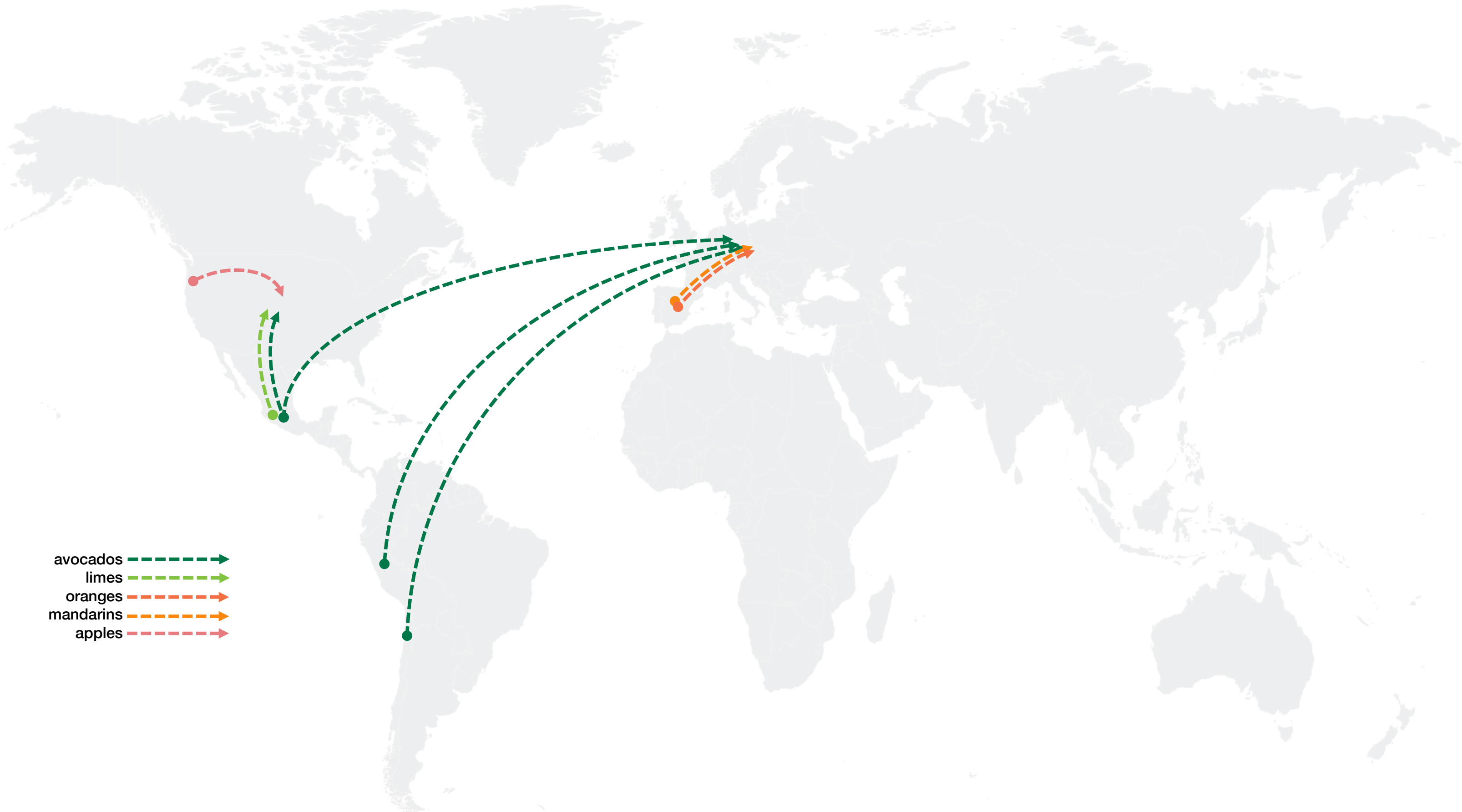


Figure 6. Produce Supply Chains Included in this Report

Table 1. Supply Chain Application Location for Each Produce Type in this Study

Produce Category	Apeel Application in Agricultural Production Region	Apeel Application at Import in Retail Market Region
Avocados	X	X
Limes	X	X
Apples	X	
Mandarins	X	
Oranges	X	

Table 2. Apeel's Scope of Impact for Each Produce Category

Produce Category	Food waste reduced at retail and in consumer homes.	Food waste reduced during storage or transport	Postharvest wax avoided (replaced by Apeel coating)
Avocados	X		
Limes	X		X
Apples	X	X	
Mandarins	X	X	X
Oranges	X		X

Based on these scenarios, there are six different measurable effects that the Apeel product may have, each of which is dependent on the produce type and supply chain:

(1) Reduced food waste in retail stores
(2) Reduced food waste in consumers' homes
(3) Reduced food waste during produce storage or transport
(4) Elimination of postharvest wax
(5) Shift logistics to a less emission-intensive distribution mode (i.e., air to sea freight)
(6) Elimination of single use plastic packaging

Each of these effects are measured differently in the study scenarios. Effects (1)-(4) above are particularly relevant for the produce categories included in this report. Table 3 describes how each effect is quantified, and more detail is provided in the System Characterization and Data Sources section.

Table 3. Descriptions of Apeel Product Benefits

Apeel Effect	Measurement Methodology
Reduced food waste in retail stores	Apeel works with retail partners to collect "shrink" data. Shrink is the supermarket retail term for the amount of produce that was shipped to the grocery store but never sold, which may be also defined as waste. For in-market products, Apeel has collected primary data for baseline shrink and the shrink reduction enabled by the Apeel product. For products that have not been launched or are only in the pilot-testing phase Apeel estimated baseline shrink by performing an analysis of a major US retailer's inventory tracking and management system. The Apeel shrink reduction is estimated based on performance observed with in-market produce categories: avocados, apples, limes, oranges, and mandarins.
Reduced food waste in consumers' homes	At this time, Apeel has not collected primary data on how the Apeel product impacts food waste rates in consumers' homes. However, literature values for food waste rates – specifically for fresh fruits and vegetables – in US and EU homes can be used as a baseline. The barrier properties (i.e., the ability to prevent water and gases to transfer across the coating into and out of the fruit) do not change once Apeel is applied; therefore, this study assumed that the waste reduction in consumers' homes occurs at the same rate as the measurable food waste reduction in retail stores. This assumption is analyzed further in the sensitivity analysis by varying the Apeel effect on food waste rates in US homes.
Reduced food waste during produce storage or transportation	In most instances, produce is packed and distributed immediately after the Apeel coating is applied. In these instances, there is no expected effect on food waste during storage. In some cases, however, if the produce can be preserved long enough, it is stored in inventory so supply can be managed to better meet demand. Of the categories included in this study, only apples and US mandarins are typically managed this way. Baseline waste rates during storage and the projected rate of waste with Apeel was collected from large product demonstrations and trials with apple and mandarin packing houses.
Elimination of postharvest wax	Some produce is treated with postharvest wax, which can also include a fungicide that prevents the onset of mold. Consumer preference has contributed to the decrease in use of postharvest wax products in recent years. While Apeel's product does not contain any synthetic fungicides, the extension of shelf-life maintains the moisture content longer, and several customers have opted to eliminate the use of wax when applying Apeel.
Shift logistics from air to sea freight, enabling a less emission-intensive distribution mode	The distribution of fresh produce to retail stores is dictated largely by the perishability of the individual category and the technologies available to preserve the produce during transport and storage. By extending the shelf-life, the Apeel opens up additional opportunities to utilize less emission-intensive (and costly) distribution modes, as well as optimize the storage and logistics within the supply chain. For example, a large portion of asparagus imported from Peru into the United States is shipped using air freight[7]. Apeel asparagus treated in Peru can sent to the US by sea freight. Since no shifts in modes of transport were observed in the produce categories evaluated in this report, future studies will evaluate the potential for environmental savings via shifts to less carbon intensive distribution modes.
Elimination of single use plastic packaging	Some produce categories have traditionally used plastic shrink-wrap to modify the atmosphere around the fruit or vegetable to maintain the shelf-life, especially for categories with low turnover in the grocery store. For example, one of Apeel's partners is planning to eliminate the use of shrink wrap on their English cucumbers when they start applying the Apeel product (based on product performance during pre-launch trials). Future studies will evaluate the environmental implications of this shift, since Apeel is not eliminating plastic packaging for any of the produce categories included in this report.

[7] Data for percent of produce exported from Peru via air freight sourced from Fresh Cargo Peru dataset http://freshcargoperu.com.pe/

The data and parameters used in this report are representative of the supply chains in which Apeel has established or has plans to establish integrations. As Apeel continues to grow its customer base, data will be collected to understand the implications of product integrations for different product categories, geographies, and stages in the supply chain. Additionally, Apeel-treated produce could be sold into a variety of markets (i.e., meal delivery kits, food service, etc.); however, this study only considers Apeel Produce that is sold at retail stores and consumed at home.

Manufacturing of machinery and equipment, as well as other process that are expected to contribute less than 1% of the total environmental impacts are not included in the foreground data in this assessment. Justification for the cut-off criteria will be provided in the Assessment Methodology section. Infrastructure and other capital equipment processes are already included within some of the ecoinvent datasets used as background data in the analysis. Capital equipment manufacturing is often included in ecoinvent datasets; [8] however, these foreground processes (e.g., Apeel's application equipment) have been shown to be so insignificant that their inclusion is not warranted in the foreground system boundary (see the *Cut-off Criteria* section for more details). To remain consistent with this methodological choice, Apeel also removed capital equipment and infrastructure processes from key datasets such as agricultural production for all produce types.

[8] Overview and methodology Data quality guideline for the ecoinvent database version 3, https://www.ecoinvent.org/files/dataqualityguideline_ecoinvent_3_20130506.pdf

System Characterization and Data Sources

The foreground data used in this study was gathered both from within Apeel Sciences and from supplier and retail partners who measured the implications of the product on food waste rates in their stores and other facilities. Literature values and assumptions were used to fill in data gaps when necessary, and these methodological decisions are described in the following sections. Background data was sourced from the ecoinvent v3.5, allocation – cut off by classification, unit database.[9] Version 3.5 was selected, since it is the most up-to-date and comprehensive version of the ecoinvent database. Whenever possible, unit processes were selected based on regional specificity. In the absence of country-specific or region-specific dataset availability, global inventories were used and adapted to include relevant regional processes when data availability allowed. The processes specific to the Apeel product are considered confidential and are not disclosed in this report. These unit processes include: *Apeel Raw Materials Sourcing & Production*, *Packaging & Distribution*, and A*peel Product Application*. The following sections describe the remaining produce-specific processes that are included in the study.

[9] Ecoinvent Centre. Ecoinvent data v3.1. Available at: http://www.ecoinvent.org

Produce Production

Since this study intends to evaluate the effect of introducing the Apeel treatment into conventional produce supply chains, generalizable data sets for the life cycle inventory of cradle-to-farm-gate avocado, lime, orange, mandarin, and apple were utilized. These data sets – and much of the additional background data used throughout – was drawn from the ecoinvent v3.5 life cycle inventory (LCI) database. The production regions utilized in this study were selected based on the supply chains within which Apeel either already has integrations or has plans to complete integrations. Figure 6 displays these production regions and the associated retail markets for each trade lane considered.

Appendix A includes the ecoinvent v3.5 data sets used to model the produce production processes for each supply chain. Background data for the regional produce production process was not available in most cases, so the modelling is often based on global produce production processes and adapted to incorporate the regionally specific electricity production and irrigation processes for each produce category. One other notable adjustment is that lemon production was utilized as a proxy for limes, since data did not exist in ecoinvent or elsewhere in the literature for lime production and production of the two crops is very similar. Additionally, major infrastructure processes were removed from the direct and upstream produce production processes (see the *Assessment Methodology* section for more information about this methodology decision).

Lastly, land use parameters were adjusted based on Apeel's knowledge of the growing regions and/or suppliers considered in this study. Within ecoinvent v3.5, agricultural production processes include parameters that govern land occupation assumptions. Such assumptions are based on land transformation patterns within a given country. At a process level, these inputs rely on regionalized "market for land tenure" provider processes. These processes govern country-specific proportions for the amount of land use for crop production (estimated based on the land already in use for annual crop production or perennial crop production), as well land use change from primary or secondary undeveloped ecosystems. Apeel modifies these proportions to fit the land use practices of its produce partner suppliers. In most cases, these modifications are for crops where perennial crop production has been taking place in a given region for many decades, yet the ecoinvent land occupation assumptions are such that a large portion of the land area for perennial crops was transformed from annual crop production. More information about the land use change methodology within this study is included in the *Assessment Methodology* section.

Produce Transportation: Farm to Packing House

The processes, inputs, outputs and data sources governing the transportation of produce from the farm to the Apeel treatment location are included in Appendix B for all supply chain scenarios in this study. In addition to understanding the transportation distances and modes of transport between different supply chain nodes, the loss of produce due to spoilage during processing and distribution to the packing houses needs to be taken into account. This parameter was gathered from the ecoinvent v3.5 database, which indicates that an additional

0.12kg of produce is transported from the farm for every 1kg of fruit or vegetable sent to market (this parameter is consistent across all produce types in ecoinvent v3.5). Essentially, this means that 12% of produce grown is either discarded or spoils before shipped to retail stores, which is consistent with other literature values for food waste of fresh produce during post-harvest storage, handling and processing.[10] The additional 11% production and associated waste process are also included in the processes included in Appendix B.

In the case of apples, Apeel gathered sufficient information from produce suppliers to modify this early supply chain waste parameter. Since the apple season is relatively short, apples are picked, transported to packinghouses, and then placed in controlled atmosphere storage rooms for many months following harvest. As much as 10 months can pass between apple harvest and transport to retail stores, and apple suppliers have shared that 25% of apples go to waste during this time. Since this 25% encompasses the waste the ecoinvent v3.5 parameter was designed to include, baseline and Apeel apples do not include the 11% production waste parameter; instead the 25% waste is applied during the controlled atmosphere storage process. This step in the supply chain is further explained in the Produce Packing House Storage & Processing section below.

For lorry transport, a ratio of 9:1 of lorries carrying reefers (i.e. intermodal containers with cooling) to refrigerated trucks was assumed based on the parameters used in ecoinvent v3.5 for transport of produce to market. The operation of the reefer while it is loaded but not being transported is also modeled based on the parameters included in the ecoinvent v3.5 process for transport of produce to market (these values are also consistent across produce types). This operation of the reefer is estimated at roughly 2.5 hours of total sitting time while the produce is kept cool inside the reefer either before transport from the starting location or upon arrival at the end location. For some of the categories in this study, the produce production process is co-located with the packing house; therefore, no transportation processes are included in this stage for certain categories. However, because spoilage at this stage is known to happen during storage and when transporting produce off the farm, the same 12% waste rate is still applied between farm and packing house across all categories.

Produce Packing House Storage & Processing

For most categories, packing house storage and processing do not vary between the baseline and Apeel scenario (aside from the Apeel treatment processes), and depending on the produce category, certain types of processing may occur at the packing house. In the case of apples, both baseline and Apeel apples are stored in “controlled atmosphere” chambers where the temperature, CO_2, and oxygen concentrations are closely regulated over a one- to ten-month storage period. This process is meant to slow down apple respiration so that apples picked during a relatively short harvest period August-October can be enjoyed year-round.

Appendix C contains information on the inputs during this storage phase. Electricity is used to power refrigeration and air handling equipment, with estimates provided in a recent paper from

[10] Porter, S.D., Reay, D.S., Higgins, P. & Bomberg, E. 2016. A half-century of production-phase greenhouse gas emissions from food loss & waste in the global food supply chain. *Science of the Total Environment,* 571: 721-729.

Boschiero et al.[11] Apeel suppliers have shared that often 25% of apples placed in controlled atmosphere storage end up spoiling over the extended time period. Since Apeel is applied after this storage period, there is currently no opportunity for Apeel to reduce waste. However, Apeel is working with suppliers to potentially apply the product prior to controlled atmosphere storage. The effects of this change will be explored in future reports.

In several instances, there is an alternative processing step or process that exists in the baseline scenario that is avoided with the introduction of Apeel.

Oranges and mandarins are typically treated with a postharvest wax that is removed with the use of Apeel. The production processes for these wax materials and overall baseline scenario are included in Appendix C.

In addition to in the retail and consumer stages, waste during storage at the packinghouse following Apeel application can be prevented with the use of Apeel, as is the case with apples. Appendix D contains the baseline and Apeel scenario accounting for this waste reduction during the packing house storage stage.

Produce Transport: Packing Houses to Market

The transportation between the Apeel treatment locations and retail locations is also reflected in the processes outlined in Appendix B. The produce supply chains are consistent across the baseline and Apeel produce product systems for all produce types. The same ratio of 9:1 of lorries carrying reefers (i.e. intermodal containers with cooling) to refrigerated trucks and the same assumptions about reefer operation before/after transport that was used in the transport from farm to distribution center was utilized in these processes. Intermediate packaging materials in the form of corrugated board boxes are used to transport all produce categories between the packing house and retail. The size and total amount of produce per box varies by category, and these material inputs are included in the processes in Appendix B.

Produce Sale to Consumers at Retail

Very little processing occurs once the produce reaches retail stores, and all produce displays are assumed to be in ambient conditions in the produce section of the grocery stores in this study. The only processes considered at this stage are the quantity of produce shipped from the distribution center to the stores, the percentage of that produce that is sold to consumers, and the percentage of that produce that goes to waste. The term used to describe this wastage rate within a produce retail environment is “shrink”. Apeel works with retail partners to collect shrink data for in-store Apeel produce. Apeel has collected primary data for baseline shrink and the shrink reduction enabled by the Apeel product for products that have already been launched commercially. For products that have not been launched, or are only in the pilot-testing phase, baseline shrink rates are utilized and the Apeel shrink reduction is estimated based on

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[11] Boschiero et al 2019. Greenhouse gas emissions and energy consumption during the post-harvest life of apples as affected by storage type, packaging and transport. *Journal of Cleaner Production*, 220: 45-56.

performance observed with in-market produce categories. These values also take into account any primary data collected by Apeel's Product and Sales Teams from current or potential customers. The baseline shrink rates and Apeel shrink rates for each supply chain scenario are included in Appendix E.

The unit processes for the baseline and Apeel scenarios are described in Appendix F and can be applied to each produce category. The inputs and outputs are generally the same, but with different parameters based on the shrink values in Appendix E. In the EU, all produce sent to waste at retail is treated as "market for biowaste", whereas in the US, Apeel has been able to collect more granular data on the distribution of end-of-life scenarios for fresh produce wasted at retail stores (i.e., animal feed, sanitary landfill, anaerobic digestion, etc.). These ratios and the background processes and underlying assumptions for estimating the end of life impacts of retail produce waste disposal are included in Appendix F.

Produce Transport to US Households

To estimate the inputs and outputs during the transport of the produce from the retail store to a consumer's home, several pieces of data needed to be collected. The total weight of plastic or paper in two single-use bag options were included in this process.[12] The model uses an assumption that paper is used 50% of the time and plastic the other 50% of the time, and that each bag would hold about 10lbs of food total. Since the passenger car process only accounts for distance traveled, the average weight of groceries per trip needed to be estimated to determine how much of the environmental burden of the transport should be allocated to the functional unit. A 2016 – 2017 study of U.S. grocery shopping behavior showed that in-store shoppers spent an average of $55 per trip.[13] The average wholesale price of food is $1.67 per pound,[14] and retail markup is typically around 30%.[15] Therefore, the average weight of groceries per trip was estimated as 25lbs, or 11.4kgs. The average distance that a consumer drives to the grocery store in a passenger car in each region, 3 km[16] for EU consumers and 6.1 km[17] for US consumers, was also included in this process, and all data inputs and sources are included in Appendix B.

Produce Consumed in US Households

Similar to in the retail environment, all produce at home was assumed to be stored in ambient conditions. The plastic or paper single-use grocery bags are assumed to be disposed of in the home and sent to a municipal solid landfill. The baseline food waste rates for fresh fruits and vegetables in US and EU households, as well as the expected waste reduction with Apeel are

[12] http://www.allaboutbags.ca/papervplastic.html
[13] https://www.onespace.com/blog/2018/08/online-grocery-food-shopping-statistics/
[14] https://www.feedingamerica.org/ways-to-give/faq/about-our-claims
[15] https://www.canr.msu.edu/news/pricing_your_food_product_for_profit
[16] https://www.ymparisto.fi/en-US/Maps_and_statistics/The_state_of_the_environment_indicators/Communities_and_transport/Services_move_further_away(28838)
[17] https://usa.streetsblog.org/2015/04/10/5-things-the-usda-learned-from-its-first-national-survey-of-food-access/

included in Appendix E. Since the Apeel product is an end-to-end solution in that it continues to slow the rate of spoilage as the avocado moves throughout the supply chain, the technology can reduce waste at the consumer stage in addition to retail in this scenario. A 50% reduction from Apeel is employed based on waste reductions documented elsewhere in the supply chain. Both of these assumptions will be explored in the sensitivity analysis. As with food waste from retail, all consumer food waste in the EU is treated as "market for biowaste." In the US, Apeel relies on published EPA data[18] on the percentage of consumer waste sent to various end of life scenarios (i.e., compost, sanitary landfill, incineration, etc.). These ratios and the background processes and underlying assumptions for estimating the end of life impacts of consumer produce waste disposal are included in Appendix F. Appendix F describes the unit processes and data sources uses for this last process in the Apeel Produce life cycle system boundary.

[18] https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials

Assessment Methodology (LCIA)

Allocation Methodology

The ecoinvent life cycle inventory system model applied in this study is “cutoff by classification”, which is used for product systems that donate or receive resource or energy inputs from upstream or downstream processes.[3] This economic allocation approach is commonly used for multi-product systems, and is generally considered the most straight-forward attributional approach. Given the low-degree of complexity in the Apeel Produce product system, the cutoff by classification LCI system model is an appropriate selection. With this selection, Apeel does not account for the benefits of alternative waste treatment processes for food waste and there is no reason to believe that a different system model choice would significantly change the results.

Cut-off Criteria

Processes may be excluded from the system boundary if their contributions are expected to be less than 1% of the total environmental impact of the system. In this study, all product components and production processes are included when the necessary information is readily available, or a reasonable estimate can be made. A few examples of items that are excluded from this study and are expected to contribute less than 1% of the total environmental impact of the system include the production of capital equipment for the blending and packaging of the Apeel powder, the production of capital equipment for the Apeel solution formation and application onto the avocados, intermediate packaging of raw materials, shipping pallets, and other services not directly linked to the product system such as business services and research and development.

To justify these exclusions, a simple analysis was completed to understand how significantly capital equipment for the Apeel application system contributes to the overall Apeel Avocado environmental impacts (this was the omission that was expected to be the largest). A majority of the application system (i.e., solution mixer, heater, conveyors, dryers and air blowers) is made from stainless steel, with a total weight of approximately 2,000 kg. The application systems have an expected lifetime of 10 years. Assuming the system is running about 260 days per year and that 12,000kg of avocados are treated per day (estimated based on data from a large pilot program with a US retailer), the environmental impacts of the application system contribute roughly 0.01% or less to the overall environmental impacts of Apeel Avocados.[19] The contribution of capital equipment is expected to be just as insignificant for other produce categories, since similar data, assumptions and methodology are employed in these other analyses.

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[19] This analysis used the ecoinvent process “market for metal working, average for chromium steel product manufacturing – GLO” and included the following impact categories: aquatic eutrophication, aquatic acidification, land occupation, non-renewable energy, and global warming (IMPACT 2002+).

Land Use Change Methodology

Within ecoinvent v3.5, agricultural production processes include parameters that govern land occupation assumptions. Such assumptions are based on land transformation patterns within a given country. However, in some cases Apeel has chosen to alter those assumptions, and the resulting land tenure parameters, within the product systems when Apeel was able to gather sufficient primary data from upstream in its product supply chain, and from the produce suppliers it partners with.

In these cases, Apeel has altered the provider processes for “land use change, perennial crop” or “land use change, annual crop” input flows that are common in ecoinvent agricultural production processes. These inputs utilize regionalized “market for land tenure” as the provider processes, which include country-specific proportions for the amount of land use change for crop production that results from land already in use for annual crop production or perennial crop production, as well land use change from primary or secondary undeveloped ecosystems.

As stated previously, in some cases Apeel has more granular data from raw material suppliers and produce supplier partners on the specific land tenure practices in agricultural production. These individual flows govern the emissions of soil carbon to atmosphere associated with each type of land tenure. Altering which provider process is used will affect the total greenhouse gas emissions that result from the land occupation input in the agricultural production process. Apeel modified the three flows listed above to adjust the land use change parameters for Spanish oranges, Spanish mandarins, and Mexican limes. These changes are noted in Appendix A for each category where changes have been made. These parameter alterations are made at the Apeel product system level, with the original integrity of the ecoinvent assumptions maintained at the process level.

For example, Apeel partners with orange suppliers who have produced oranges for multiple decades within the same area of land, with virtually no expansion into non-agricultural lands nor any transition to or from annual crops. In this case, Apeel has altered parameters in the “market for land tenure” process for the producing country such that 100% of the land tenure comes from land already devoted to perennial crop production.

Impact Assessment

Life cycle impact assessment (LCIA) is the process of classifying and combining the input and output flows of materials, energy, and emissions for the product system in terms of their type of impact on the environment. There are a number of different peer-reviewed and internationally recognized LCIA methodologies. This study utilizes the ILCD 2.0 2018 midpoint methodology, in addition to using the life cycle inventory to quantify cumulative water withdrawals across the product systems. Nineteen of the potential impact categories (midpoints) that can be evaluated using ILCD 2.0 2018 are included in the results; however, the results and discussion will focus on those categories that are particularly relevant for the food system: climate change (the reported total includes biogenic, fossil, and land use and land use change impacts), ecosystem quality (freshwater and terrestrial acidification, and freshwater eutrophication), resources

(fossil), and water use (assessed as water withdrawals based on the cumulative LCI).[20,21] The climate change impact category in the ILCD methodology has four impact categories displayed in OpenLCA: climate change (biogenic), climate change (fossil), climage change (land use and land use change), and climate change (total) which takes all 3 of the previous categories into account. Apeel selected the climate change (total) category to evaluate the results in this report and use the term climate change (total) to distinguish this choice throughout. Descriptions of these either potential impact categories, as well as the cumulative water use metrics, are provided in Table 4 below, and a comprehensive description of the ILCD methodology itself can be found here: https://eplca.jrc.ec.europa.eu/uploads/ILCD-Recommendation-of-methods-for-LCIA-def.pdf (original methodology)
and https://eplca.jrc.ec.europa.eu/permalink/TR_SupportingCF_FINAL.pdf (updated 2018).

Table 4. Primary Impact Categories Included in the Main Results (ILCD 2.0 2018)

Impact Category (Midpoint)	***Unit of Measurement***	***Indicator***	***LCIA Method***
Climate Change, Total	kg CO_2 equivalent	Radiative forcing as Global Warming Potential (GWP100)	Baseline model of 100 years of the IPCC (based on IPCC 2013)
Acidification	mol H+-Eq	Accumulated Exceedance (AE)	Accumulated Exceedance (Seppala et al. 2006, Posch et al. 2008)
Eutrophication	g P-Eq	Fraction of nutrients reaching freshwater end compartment (P)	EUTREND model (Struijs et al 2009) as implemented in ReCiPe
Resources, Fossil	MJ	Abiotic resource depletion – fossil fuels (ADP-fossil)	CML Guinee et al. (2002) and van Oers et al. (2002)
Water Use	m^3	Cumulative Water Withdrawal (LCI)	N / A

There are limitations associated with methodology behind each of these measurements. Apeel has quantified water withdrawal to get a sense of water use across the product system, since water consumption relies on more specific knowledge of the system to accurately estimate damages. Future studies will consider incorporating water use impact categories, such as the AWARE methodology.

The results are presented here only as midpoints and cumulative LCI. No weighting or normalization is used in presenting the results with the exception of presenting the results from one scenario on a relative basis (%) compared to a baseline reference. The LCA results represent an estimation of the potential impacts that can occur and do not represent a

[20] Schaubroeck, T., Ceuppens, S., Duc, A., Benetto, E., Meester, S. De, Lachat, C., Uyttendaele, M. 2018. A pragmatic framework to score and inform about the environmental sustainability and nutritional profile of canteen meals, a case study on a university canteen. *Journal of Cleaner Production.* 187, 672-696.
[21] Heard, B.R., Bandekar, M., Vassar, B., Miller, S.A. 2019. Comparison of Life Cycle Environmental Impacts from Meal Kits and Grocery Store Meals. *Resources, Conservation and amp; Recycling.* https://doi.org/10.1016/j.resconrec.2019.04.008

measurement of actual environmental impacts that have occurred. They are relative expressions, which are not intended to predict the final impact, or whether standards or safety margins are exceeded. Additionally, these categories do not cover all the environmental impacts associated with human activities. Insufficient methodological development for some impacts – such as noise pollution or odor production – prevent these impact categories from being considered within the scope of this study.

Calculation Tool

The OpenLCA 1.10.0 open-source software program, developed by GreenDelta,[22] was used to facilitate the modeling, link the reference flows and foreground data from Apeel with ecoinvent v3.5 background data, compute the complete life cycle inventory for the system and utilize the ILCD 2.0 2018 methodology to compute the LCIA results. Ecoinvent is the most widely used, published and reviewed third-party database; and therefore, is the best selection for the background data. Regionally-specific data was used whenever available, either by including geographically-specific processes or by adapting global processes to include more regionally-specific electricity production and resource use processes (e.g., irrigation, heat, etc.).

Contribution Analysis

In additional to the main results, a contribution analysis is included for the five primary metrics to understand the extent to which each process contributes to the overall results. The contribution analysis is particularly valuable in helping to inform Apeel's internal decision making, since identifying the top contributors will highlight the biggest areas for improvement. In addition, the contribution analysis will highlight the relative importance of each process and will help to guide the data quality analysis.

Inventory Data Quality Analysis

The inventory data used in this study is assessed to determine whether the data quality is adequate to meet the goals of the study. Using the pedigree matrix approach derived from Weidema & Wesnaes (1996),[23] the highest contributing processes are assessed along five different dimensions: reliability, completeness, temporal differences, geographical differences, and further technological differences. Table 5 outlines how the data sets are scored based on each of these criteria.[24] Processes and flows representing a cumulative 95% of the impacts for each category will be included in the data quality analysis.

[22] https://www.greendelta.com/software/

[23] Weidema, B., & Wesnaes, M. 1996. Data quality management for life cycle inventories – an example of using data quality indicators. *Journal of Cleaner Production,* 4(3-4): 167-174.

[24] Frischnecht, R. & Jungbluth, N. 2007. *Overview and Methodology. Ecoinvent.* Dubendorf: Ecoinvent Centre.

Table 5. Pedigree Matrix used to Evaluate Inventory Data Quality

Indicator Score	**1**	**2**	**3**	**4**	**5**
Reliability	Verified data based on measurements.	Verified data partly based on assumptions or non-verified data based on measurements.	Non-verified data partly based on qualified estimates.	Qualified estimate (e.g., by industrial expert).	Non-qualified estimate.
Completeness	Representative data from all sites relevant to the market considered, over an adequate period to even out normal fluctuations.	Representative data from >50% of the sites relevant for the market considered, over an adequate period to even out normal fluctuations.	Representative data from only some sites (<<50%) relevant for the market considered or >>50% of sites but from shorter periods.	Representative data from only one site relevant for the market considered or some sites but from shorter periods.	Representativeness unknown or incomplete data from a smaller number of sites and from shorter periods.
Temporal differences	Less than 3 years of difference to the time-period of the dataset.	Less than 6 years difference to the time period of the dataset.	Less than 10 years difference to the time period of the dataset.	Less than 15 years difference to the time period of the dataset.	Age of data unknown or more than 15 years of difference to the time-period of the dataset.
Geographical differences	Data from area under study.	Average data from larger area in which the area under study is included.	Data from area with similar production conditions.	Data from area with slightly similar production conditions.	Data from unknown or distinctly different area.
Further technological differences	Data from enterprises, processes and materials under study.	Data from processes and materials under study but from different enterprises.	Data from processes and materials under study but from different technology	Data on related processes or materials.	Data on related processes on laboratory scale or from different technology.

Sensitivity Analysis

The methodological decisions, data selection, assumptions and parameters chosen when modeling the product systems all influence the study results, and each come with a degree of uncertainty and variability. In order to determine whether certain choices significantly influence the study's conclusions, a sensitivity analysis can be performed on key parameters. Results in future studies will include sensitivity analyses tailored to the parameters that most impact the results from that specific study. This will most likely include, but is not limited to parameters such as:

(1) Baseline consumer waste rate and Apeel household waste reduction,
(2) Baseline retail shrink and Apeel shrink reduction, and
(3) Produce transportation distance.

Critical Review

Because the results of this study are intended to be shared publicly to communicate the environmental impacts of Apeel Produce, a critical review must be conducted to ensure that the LCA report complies with the requirements listed in the ISO 14040 and14044 standards. The critical review process should ensure that:

- The methods used to carry out the LCA are consistent with this International Standard;
- 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, and;
- The study report is transparent and consistent.

The critical review was carried out by Quantis USA in June 2020. The specific reviewer was Cristóbal Loyola. The ISO Compliance Assessment provided by the reviewers and the documented revisions and responses by the study's author are included in the Appendix.

Life Cycle Interpretation

Results

The complete results for the LCIA using the ILCD 2.0 2018 methodology are included in Appendix G for all impact categories. The results for all 18 scenarios for the primary impact categories are shown in Table 6 and Figures 7-11 below. These results will be further explored for the priority categories in the following section, and the contribution analysis will shed light on the hot spots within each product system.

In all of the impact categories relevant for food and agricultural products, the Apeel Produce had a lower environmental impact by 10% – 25% in a majority of cases. In general, produce categories with lower baseline environmental impacts will fall in the lower range due to smaller savings associated with waste reduction.

The environmental impact reductions with Apeel produce in Europe tend to be lower than those in the United States. This is due to a variety of factors. In many instances, waste rates at EU grocery stores are lower than in the US,[25,26] due to forward-thinking waste reduction efforts and goals set by EU retail grocers[27] and stricter food waste regulations,[28] among other factors. When baseline retail waste rates are already <5% for many produce categories in the EU, there is less room for improvement with Apeel relative to the US where retail waste often exceeds 10%.[29] Waste rates are also lower in consumer households in Europe (19% vs. 25%)[30] which also contributes to generally lower environmental impact reductions for EU produce.

In addition, little to no food waste is sent to landfill in the EU, with many member states enforcing strict regulations[31] that require food waste from stores to be valorized or disposed according to the food waste hierarchy[32]. In contrast, the United States still sends a significant portion of food waste to landfill; in fact, food waste accounts for the largest percent of material sent to landfill, by weight, according to the US EPA[33]. Very few consumers implement composting practices[34], and even some of the largest US retailers still send >60% of their food

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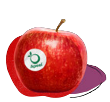
[25] European Union Food Waste Report concluded that 5% of food waste occurs at retail
[26] Buzby et al 2015 found that grocery stores accounted for 10% of US food waste
[27] https://www.eurocommerce.eu/media/120522/12_wastereport2014.pdf
[28] https://www.ecologique-solidaire.gouv.fr/gaspillage-alimentaire-0
[29] Apeel has first-hand insight into current produce waste rates in European grocery stores from data shared by EU customers; for the same produce type (e.g., avocados) baseline waste is nearly always significantly lower for EU customers compared to US customers.
[30] Porter, S.D., Reay, D.S., Higgins, P. & Bomberg, E. 2016. A half-century of production-phase greenhouse gas emissions from food loss & waste in the global food supply chain. *Science of the Total Environment,* 571: 721-729.
[31] EU Landfill directive set in 1999 obliges Member States to reduce the amount of biodegradable municipal waste that they landfill to 35% of 1995 levels https://ec.europa.eu/environment/waste/compost/index.htm
[32] https://www.euronews.com/2019/02/06/how-is-food-waste-regulated-in-europe
[33] https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials
[34] Ibid. The US EPA states that the rate of food composting in the US is only 6.3%

waste to landfill[35]. Average retail and consumer food waste treatment in the US thus results in higher methane emissions than an equal amount of food waste treatment in the EU, where most food waste is composted, incinerated, or sent to anaerobic digestion facilities. Due to these differences in waste management practices between the US and EU, greater environmental impact reductions are realized in the US through less waste sent to landfill from the retail and consumer stages.

Table 6. Results for Baseline and Apeel Produce, and % Impact Reduction with Apeel

		Climate Change Total (kg CO2-eq)	Freshwater and Terrestrial Acidification (mol H+-Eq)	Freshwater Eutrophication (kg P-eq)	Fossil Resources (MJ)	Cumulative Water Withdrawal (m3)
Avocados: EU End Market	Baseline	1.92	1.76E-02	3.70E-04	20.9	1.17
	Apeel	1.66	1.48E-02	3.30E-04	18.3	0.993
	Percent Change with Apeel	**-13.6%**	**-15.7%**	**-10.8%**	**-12.4%**	**-15.3%**
Avocados: US End Market	Baseline	3.26	1.42E-02	4.60E-04	29.4	1.30
	Apeel	2.37	1.14E-02	3.70E-04	23.9	1.05
	Percent Change with Apeel	**-27.4%**	**-19.4%**	**-19.6%**	**-18.6%**	**-19.6%**
Spanish Oranges	Baseline	1.22	9.78E-03	2.00E-04	14.7	0.208
	Apeel	1.07	8.46E-03	1.70E-04	13.0	0.183
	Percent Change with Apeel	**-12.1%**	**-13.5%**	**-15.0%**	**-11.9%**	**-12.0%**
Spanish Mandarins	Baseline	1.09	9.20E-03	1.91E-04	14.0	0.205
	Apeel	0.962	7.92E-03	1.70E-04	12.5	0.179
	Percent Change with Apeel	**-11.6%**	**-13.9%**	**-11.0%**	**-11.1%**	**-12.7%**
Mexican Limes	Baseline	1.89	1.29E-02	3.40E-04	21.8	0.854
	Apeel	1.45	1.04E-02	2.80E-04	18.2	0.686
	Percent Change with Apeel	**-23.7%**	**-19.0%**	**-17.6%**	**-16.8%**	**-19.6%**
Apples: US End Market	Baseline	2.10	9.64E-03	4.01E-04	23.5	0.300
	Apeel	1.59	7.82E-03	3.26E-04	19.4	0.242
	Percent Change with Apeel	**-24.3%**	**-18.9%**	**-18.7%**	**-17.4%**	**-19.6%**

[35] Kroger reported sending 60% of their food waste to landfill in 2018 (page 107 of their 2019 sustainability report), which represents a reduction from the 73% reported in 2017 but is still far away from their Zero Waste to Landfill goal, one the most aggressive targets set by US retailers.

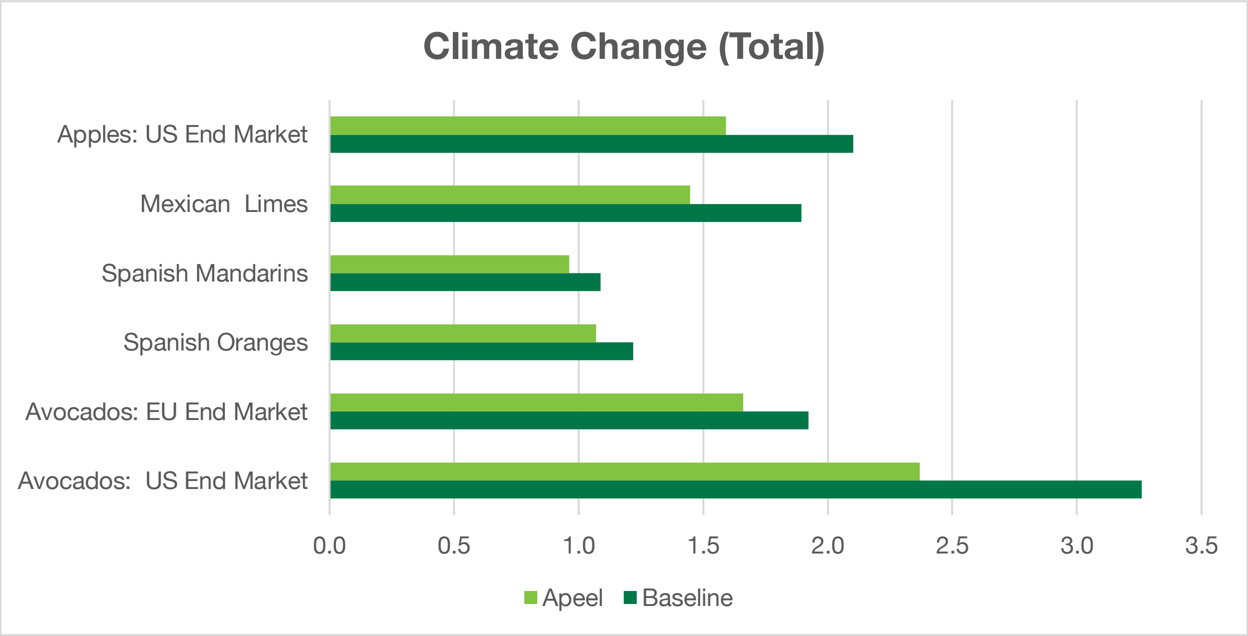


Figure 7. LCIA Results for Climate Change (Total) Impact Category – Apeel vs Baseline for All Produce Supply Chains

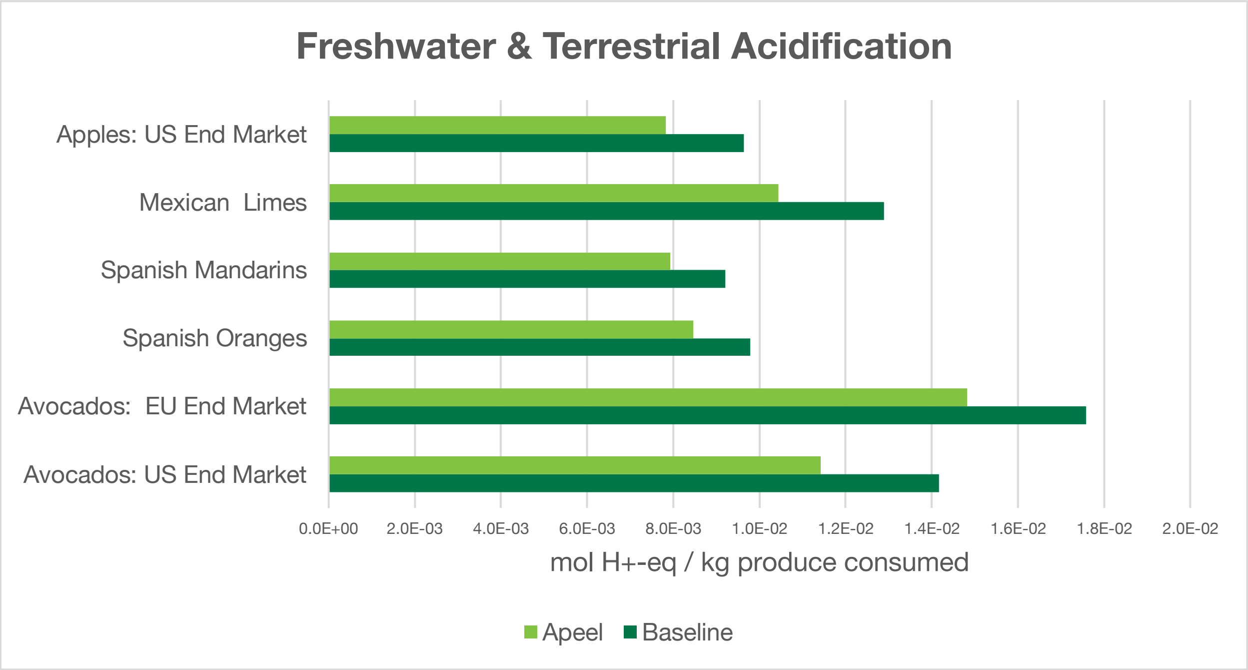


Figure 8. LCIA Results for Ecosystem Quality (Freshwater and Terrestrial Acidification) Impact Category – Apeel vs Baseline for All Produce Supply Chains

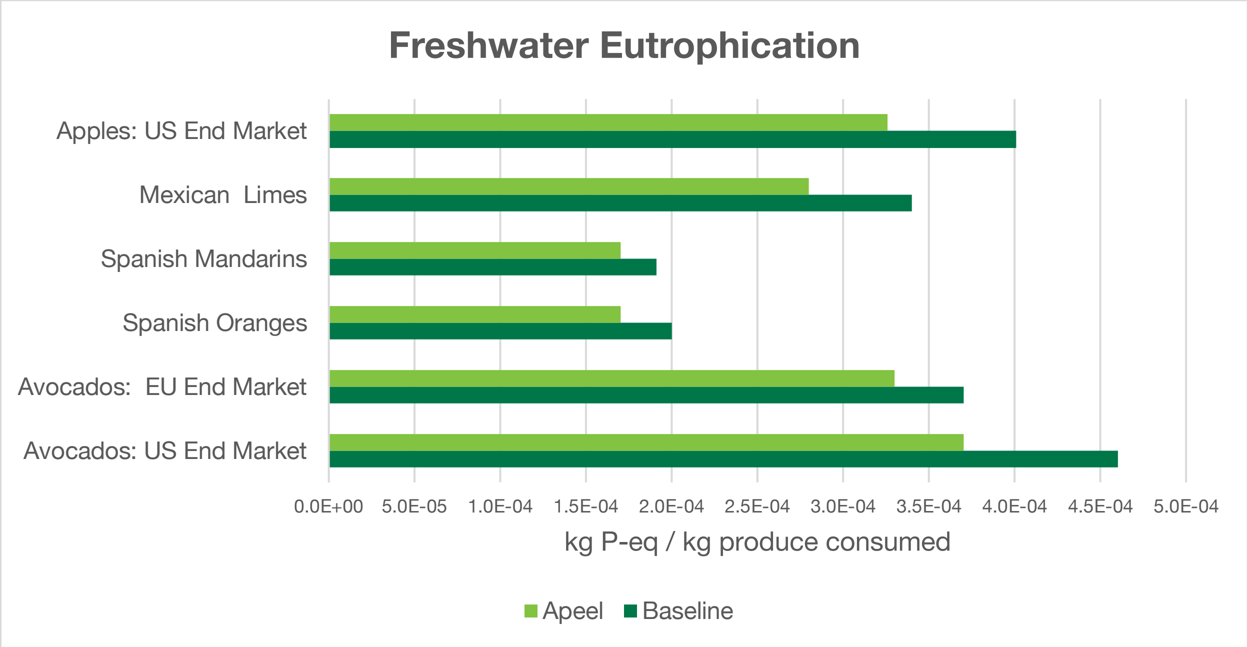


Figure 9. LCIA Results for Ecosystem Quality (Freshwater Eutrophication) Impact Category – Apeel vs Baseline for All Produce Supply Chains

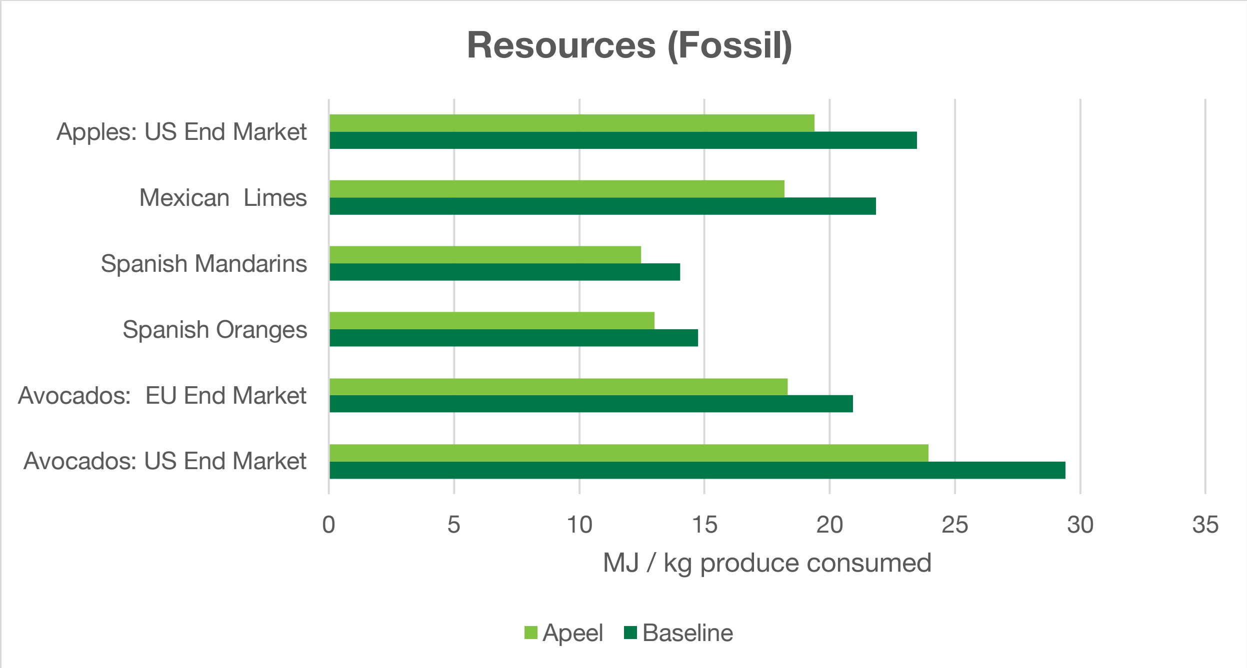


Figure 10. LCIA Results for Resources (Fossils) Impact Category – Apeel vs Baseline for All Produce Supply Chains

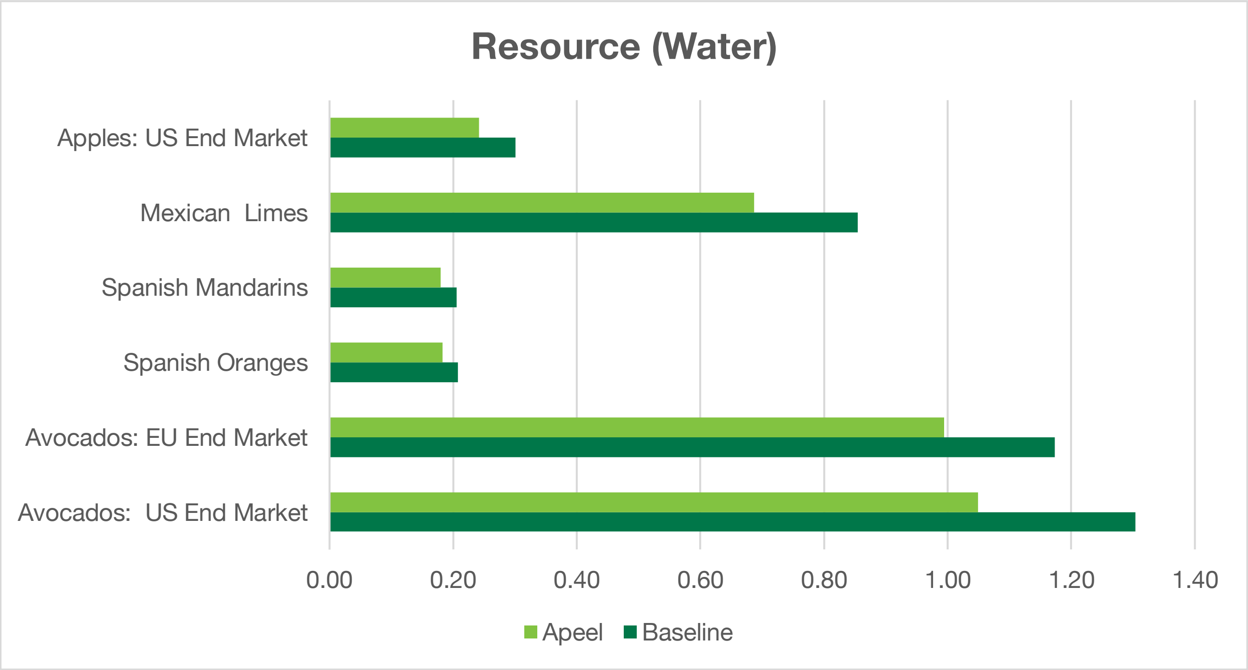


Figure 11. LCIA Results for Resource (Water) Impact Category – Apeel vs Baseline for All Produce Supply Chains

Contribution Analysis

Apeel Produce Life Cycle

To understand the contributions of the Apeel product to the overall impacts associated with the produce supply chain, a contribution analysis was conducted. At this point in time, Apeel can use this part of the assessment to identify hotspots and explore the opportunities for improvement, thus reducing the Apeel product life cycle and improving the net benefits from utilizing the Apeel product in the produce supply chain. Appendix H includes the contribution analysis for all scenarios studied in this report for the climate change (total) and resource (water) impact categories. Figures 12 – 15 below display the contribution analyses for the five major impact categories.

Generally speaking, the *Produce Production* stage is a hotspot in many impacts for all produce categories. Resource (water) is the most extreme example, with greater than 90% of water use occurring during *Produce Production* for all produce types; this is due to the significant use of water to irrigate crops. The *Produce Production* stage accounts for 10%-50% of the climate change (total) environmental, ecosystem quality (freshwater and terrestrial acidification) and ecosystem quality (freshwater eutrophication) impacts, due to the use of electricity for irrigation pumping as well as fossil fuels for farm equipment operation. Production and application of agrochemicals, such as fertilizer, pesticides, and herbicides, are also meaningful contributors to climate change and ecosystem quality impact categories.

Transportation of the produce is another common hotspot, but the location in the supply chain of the Apeel treatment is a significant factor in whether the *Pre-Treatment Transport & Processing* or *Transport to Retail* ends up being a large contributor to the overall impacts. In cases where produce production results in fewer environmental impacts, such as orchard crops like citrus and apples, the transportation step(s) tend to contribute the most to climate change (total) and ecosystem quality (freshwater and terrestrial acidification). These steps are also the hotspots for the resource (fossils) impact category due to the use of fossil fuels in transportation.

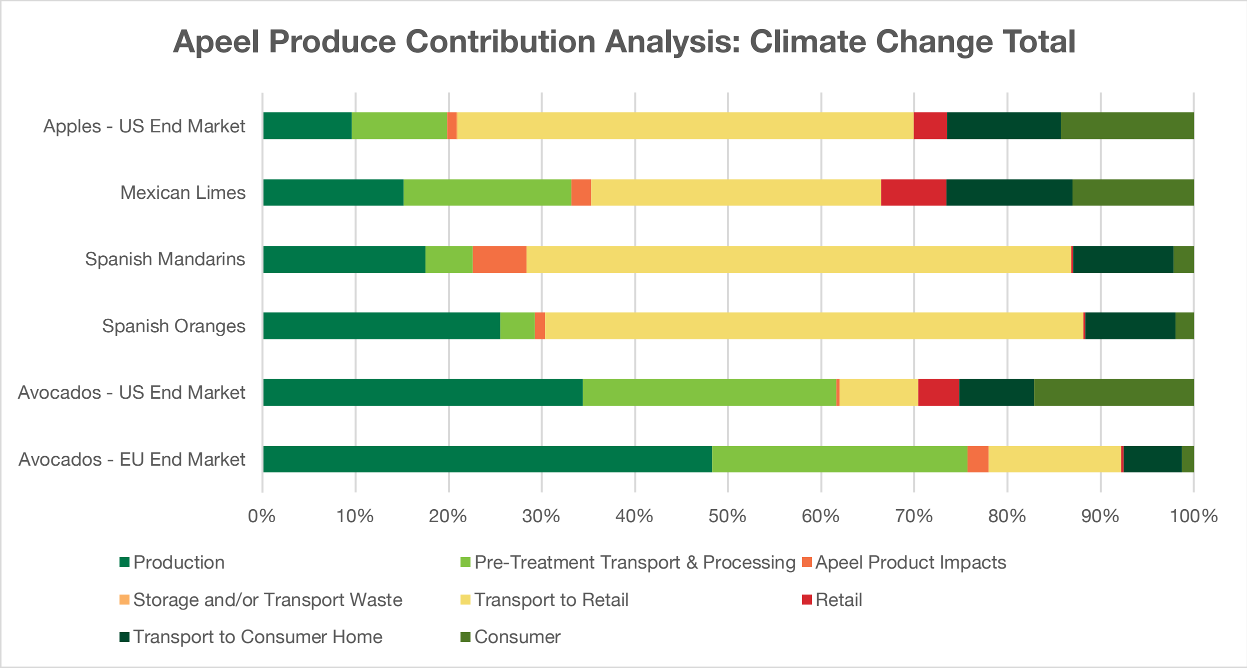


Figure 12. Contribution Analysis for Climate Change (Total) Impact Category – All Produce Supply Chains with Apeel

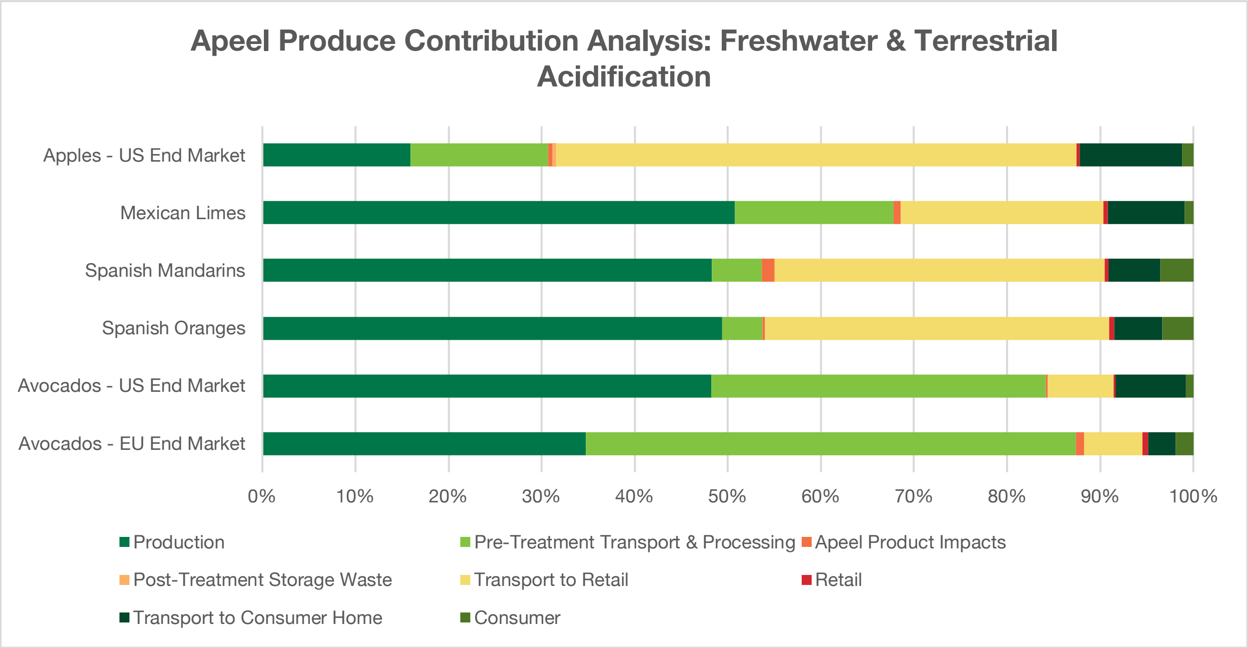


Figure 13. Contribution Analysis for Ecosystem Quality (Freshwater & Terrestrial Acidification) Impact Category – All Produce Supply Chains with Apeel

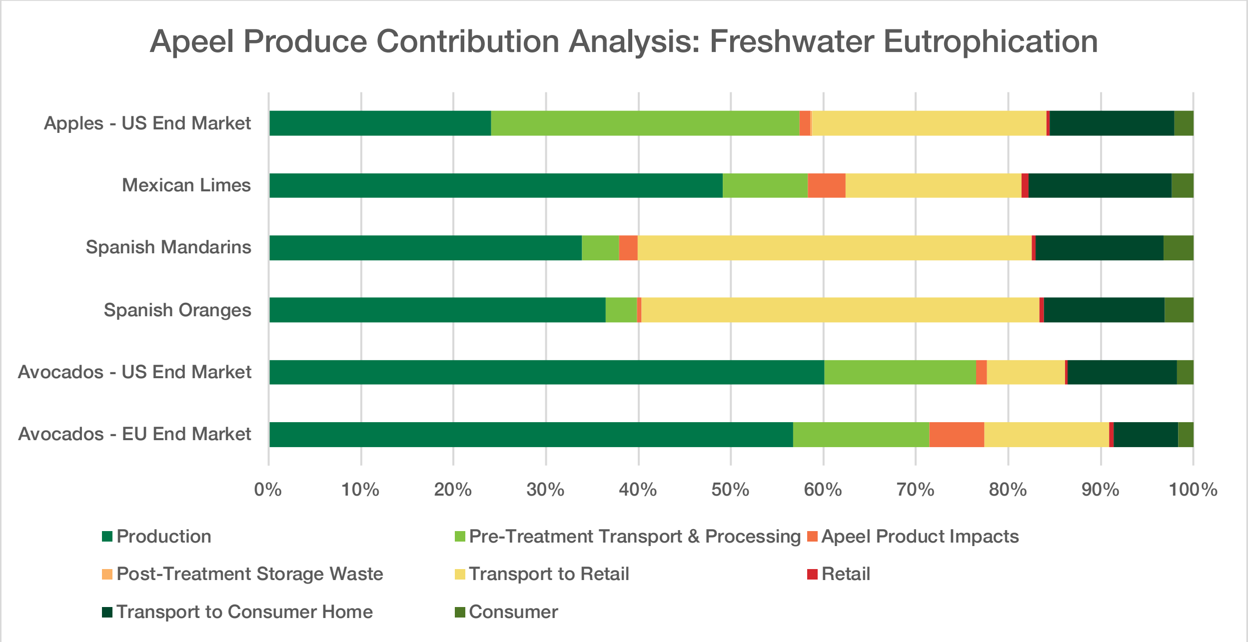


Figure 14. Contribution Analysis for Ecosystem Quality (Freshwater Eutrophication) Impact Category – All Produce Supply Chains with Apeel

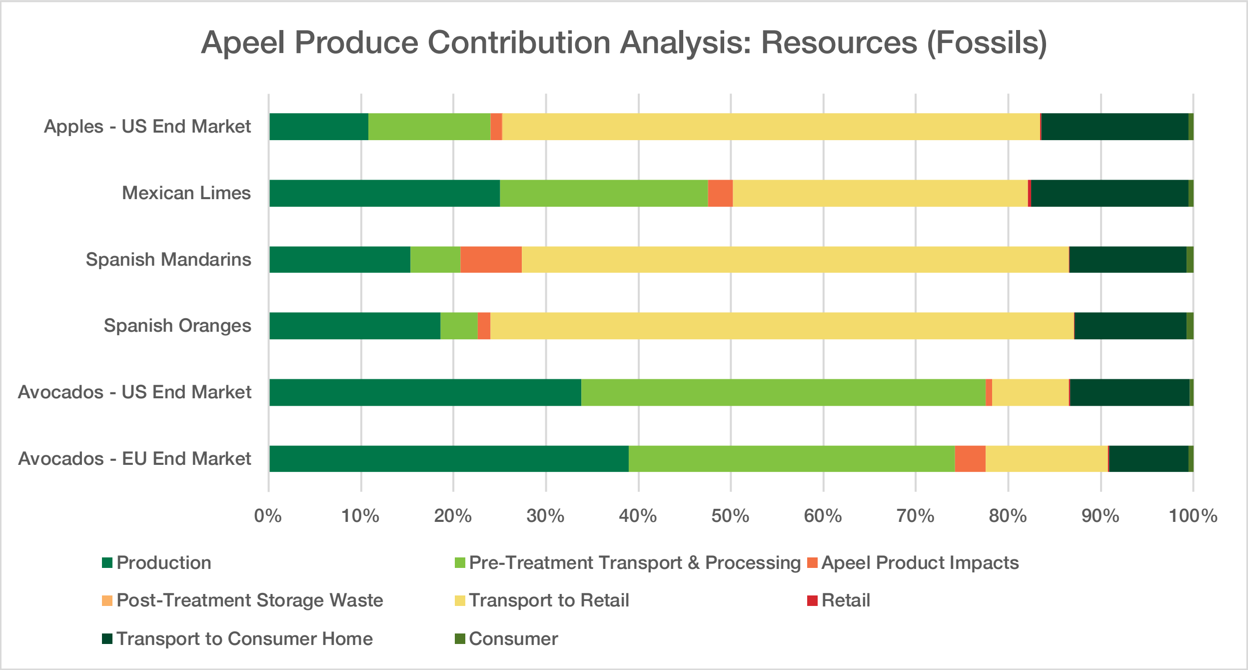


Figure 15. Contribution Analysis Resource (Fossil) Impact Category – All Produce Supply Chains with Apeel

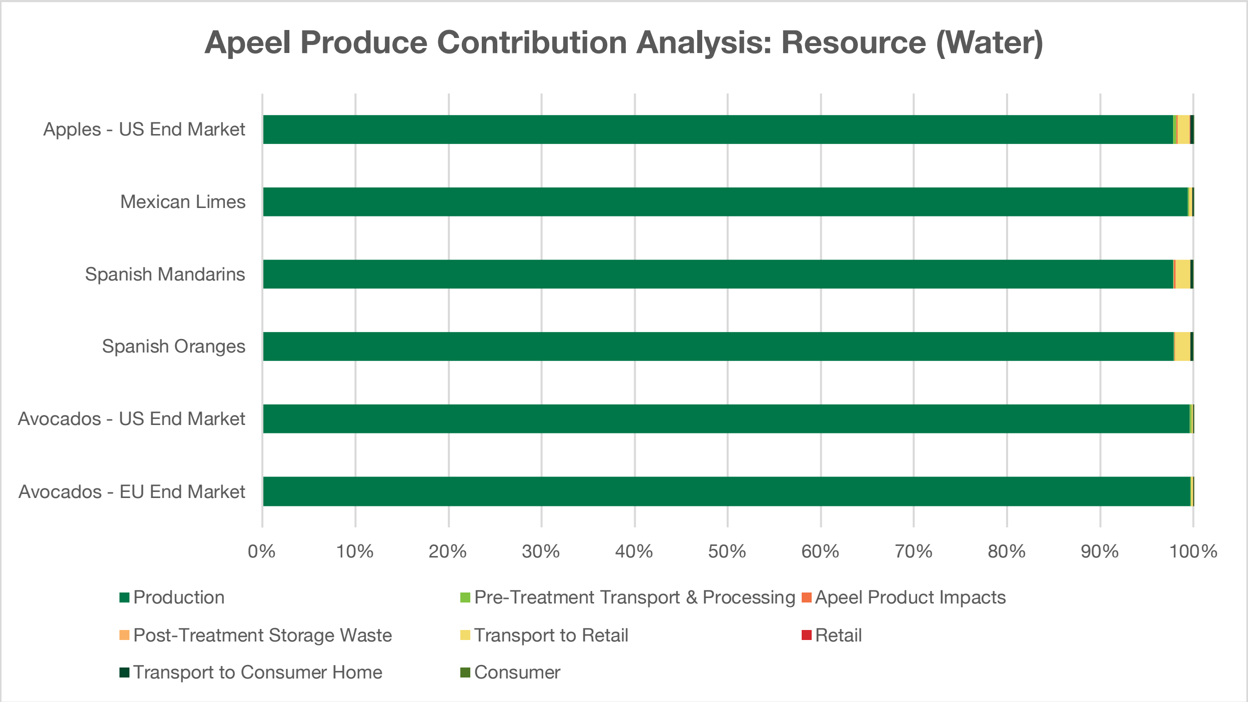


Figure 16. Contribution Analysis Resource (Water) Impact Category – All Produce Supply Chains with Apeel

Apeel-specific Processes Only

This study also includes the contribution analyses for the impacts from the Apeel-specific processes only. The following graphs (Figures 17 – 20) display examples of the contribution analyses for the Apeel-specific processes. In a majority of instances, the *Application* and *Production* processes both contribute significant impacts, with packaging and distribution having a relatively small contribution.

A majority of the energy consumption for the Apeel product (electricity and/or natural gas) occurs during product application, as it is used to heat the Apeel solution, power fans and conveyer belts, and heat air in a drying tunnel to dry the product onto produce. This explains why the *Application* process is the hotspot for the climate change (total) category. In addition, the majority countries and regions where Apeel operates still rely on fossil fuel generation sources for electricity production. This, along with the fact that Apeel uses fossil fuels natural gas and propane onsite, account for the fact that the *Application* step is also the hotspot for the resource (fossil) impact category in most produce types.

Electricity use in the upstream manufacture of inputs to the Apeel powder product are the largest contributors to the Freshwater Eutrophication and Terrestrial and Freshwater Acidification impact categories in the *Production* phase. However, the *Application* step is the hotspot due to upstream impacts from electricity generation.

Since the Apeel product is made up of agricultural inputs, the *Production* process contributed to the Cumulative Water Withdrawal since water is used to grow the crops that serve as Apeel's raw material inputs.

The *Packaging & Distribution* process contributed significantly in the Spanish Oranges example, since the Apeel product was air freighted to Spain from California at the time of the study. This is not intended to be business as usual, and therefore it is not expected for *Packaging & Distribution* to be a hotspot.

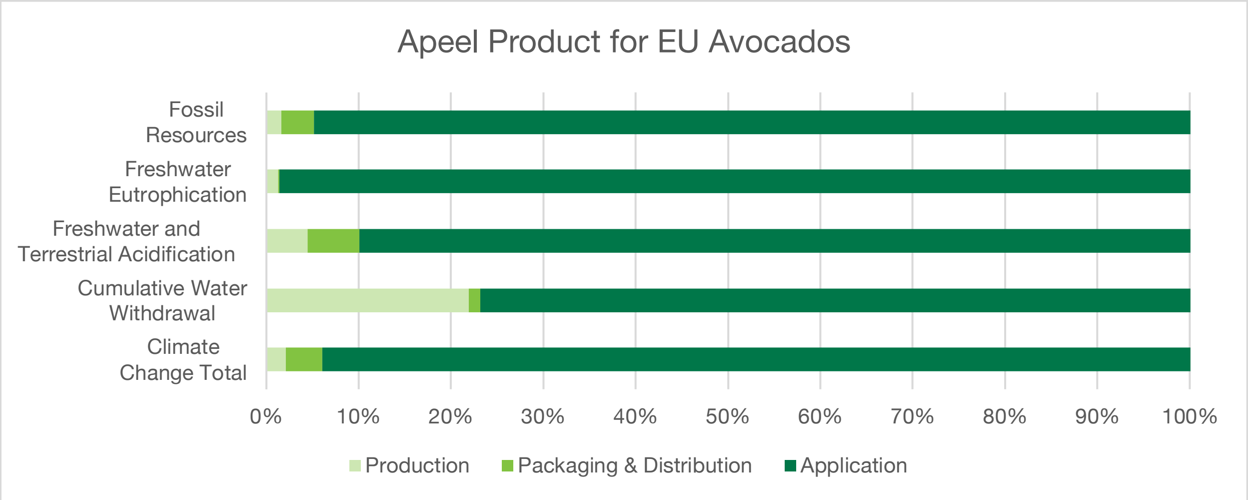


Figure 17. Apeel-specific Processes Contribution Analysis – Apeel Product for EU Avocados

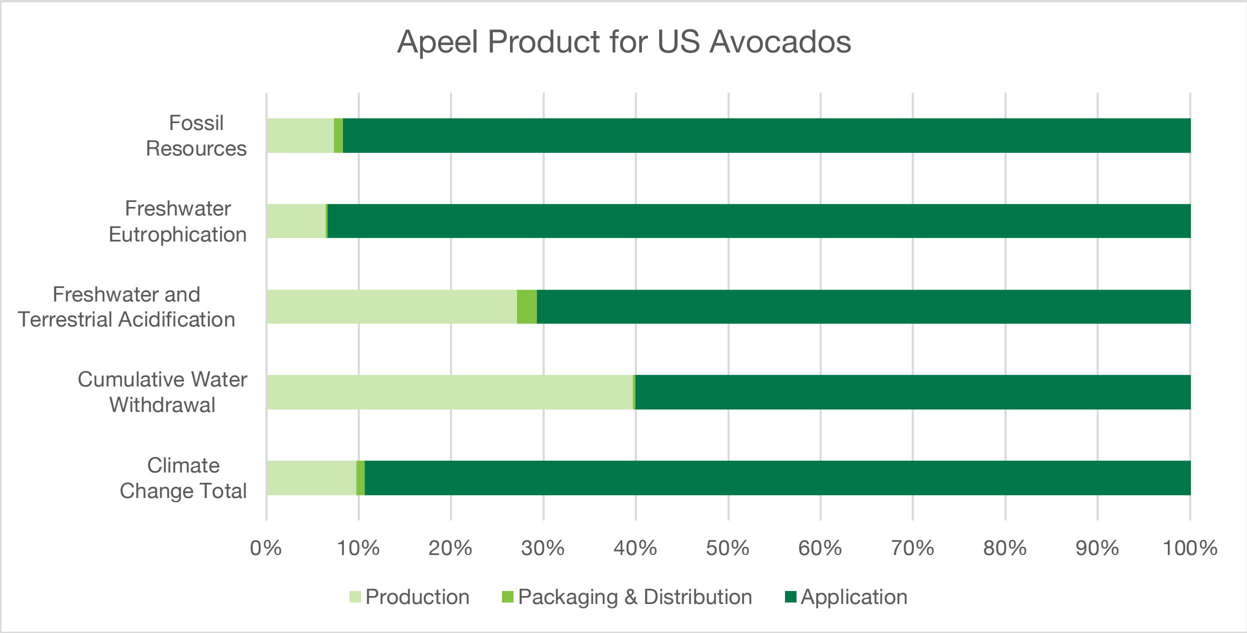


Figure 18. Apeel-specific Processes Contribution Analysis – Apeel Product for US Avocados

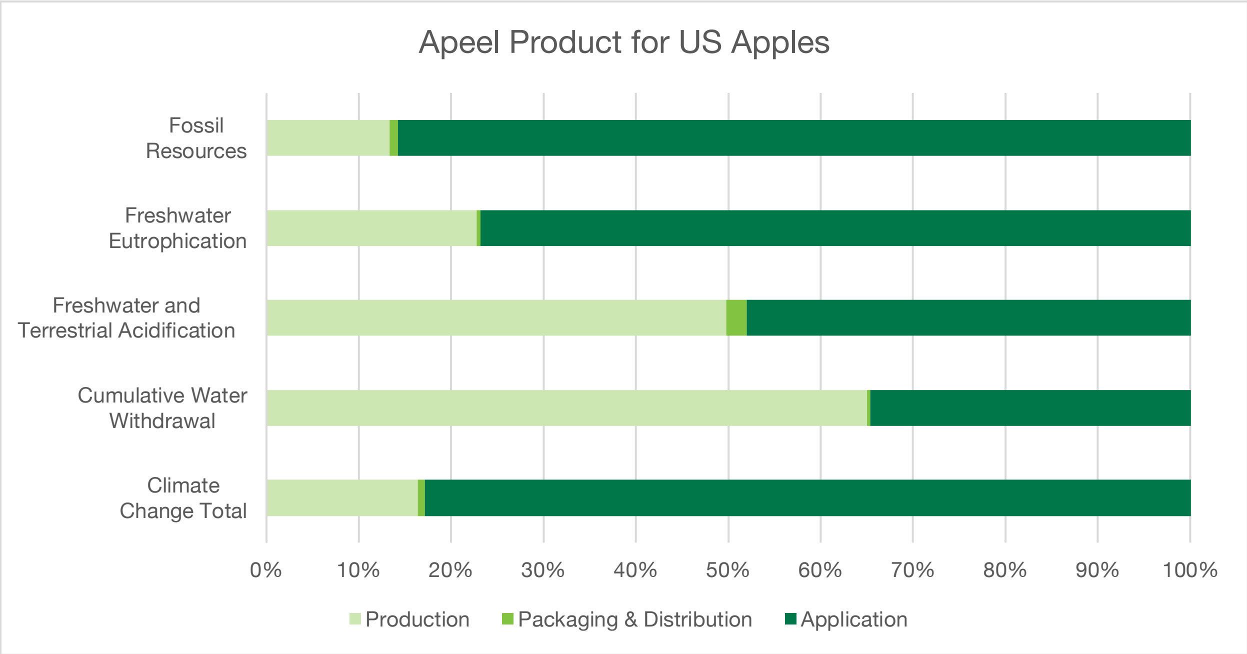


Figure 19. Apeel-specific Processes Contribution Analysis – Apeel Product for US Apples

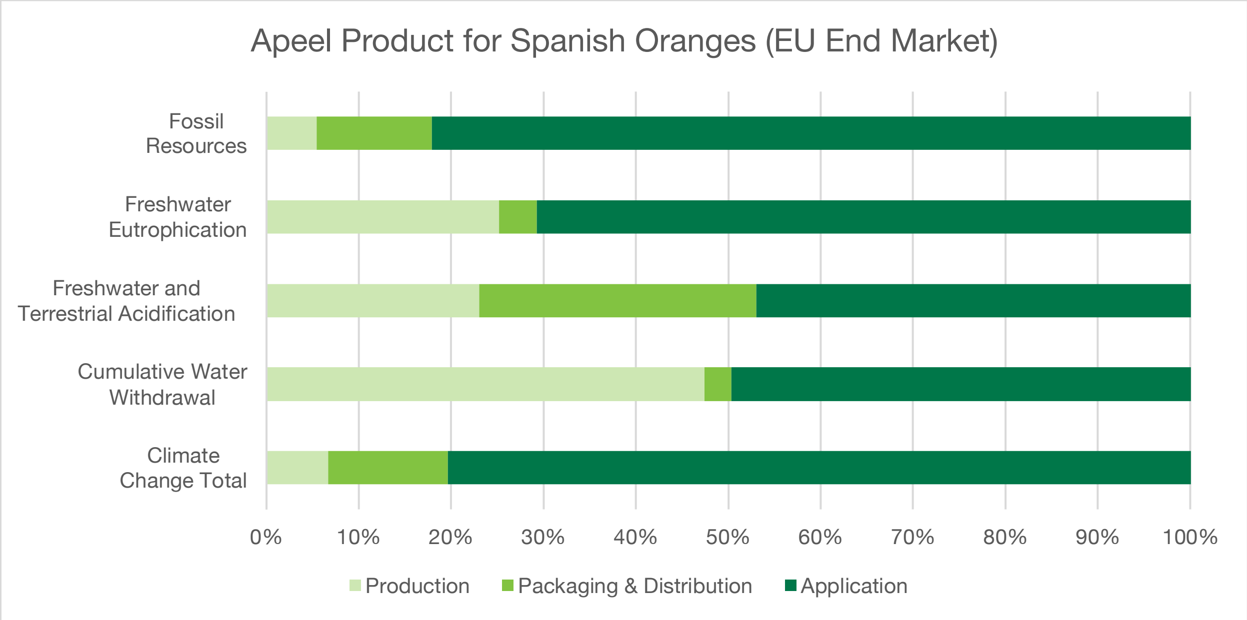


Figure 20. Apeel-specific Processes Contribution Analysis – Apeel Product for Spanish Oranges

Sensitivity Analysis

As described in the Assessment Methodology section, the sensitivity analysis will focus on three different parameters:

(1) Baseline consumer waste rate and Apeel household waste reduction,
(2) Baseline retail shrink and Apeel shrink reduction without consumer waste reduction,
(3) Produce transportation distance,

It is important for Apeel to present the results for scenario evaluated in the second sensitivity analysis listed above, where Apeel has no impact on the amount of waste occurring in consumers' homes. At this point in time, no primary data has been collected to determine how the shelf-life extension provided by Apeel will impact the rate of produce waste in the home. Future studies will examine this effect, and in the meantime, it is important to understand the product benefits without any change to household waste rates. These results, included in Appendix G with the main results and Table 15 below, show that Apeel produce still results in impact reductions of 2% - 10% across a majority of the produce types studied in this report.

Baseline Consumer Waste & Apeel Household Waste Reduction

The baseline shrink rates at both the retail and consumer stages play significant roles in the LCIA results, since they establish the total waste that the Apeel product has the potential to reduce; and therefore, the total inefficiency in produce's life cycle that can be reduced. The rate at which produce goes to waste in a consumer's home is highly variable and dependent on a number of personal factors, cultural norms, and many other elements. Baseline shrink at retail stores can differ significantly from one retailer to the next depending on the company's inventory management and sales strategy, among other factors.

Tables 7 – 10 display examples of the results of the sensitivity analysis for baseline consumer waste and amount Apeel consumer waste reduction. Examples of the results are presented here for one EU market category (oranges) and one US market category (limes) for both the climate change (total) and resource (water) impact categories. The results are expected to be relatively consistent across all impact categories, since the contributions of the later life cycle stages (i.e., retail, distribution from retail to home, and consumption) are relatively insignificant and the contributions do not vary significantly between impact categories, as shown in the contribution analyses in Appendix H.

The tables are formatted such that the % impact reduction shown in each cell correlates to the baseline consumer waste rates shown in the first column, and the percent by which Apeel reduces consumer waste shown is in the first row. For example, if the baseline consumer waste rate is 10%, and Apeel reduces consumer waste by 40%, the climate change (total) impacts would be reduced by 6%.

Table 7. Effect of Consumer Waste Rates & Apeel Reduction on Climate Change Impact Reduction for EU Oranges

Carbon Footprint Reduction, kg CO2-eq/kg oranges					
Apeel Consumer Waste Reduction					
Baseline Consumer Waste Rates		**20%**	**40%**	**60%**	**80%**
	**5.0%**	-2.3%	-3.4%	-4.4%	-5.5%
	10.0%	-3.5%	-5.7%	-7.8%	-9.8%
	15.0%	-4.8%	-8.1%	-11.2%	-14.1%
	20.0%	-6.2%	-10.7%	-14.8%	-18.5%
	25.0%	-7.7%	-13.4%	-18.5%	-23.0%
	30.0%	-9.4%	-16.3%	-22.3%	-27.6%
	35.0%	-11.2%	-19.4%	-26.3%	-32.2%
	40.0%	-13.3%	-22.8%	-30.5%	-36.9%

Table 8. Effect of Consumer Waste Rates & Apeel Reduction on Resource (Water) Impact Reduction for EU Oranges

Water Footprint Reduction, liters water/kg oranges					
Apeel Consumer Waste Reduction					
Baseline Consumer Waste Rates		20%	40%	60%	80%
	5.0%	-2.6%	-3.6%	-4.6%	-5.6%
	10.0%	-3.7%	-5.8%	-7.8%	-9.7%
	15.0%	-5.0%	-8.1%	-11.0%	-13.8%
	20.0%	-6.3%	-10.6%	-14.5%	-18.0%
	25.0%	-7.8%	-13.2%	-18.0%	-22.4%
	30.0%	-9.4%	-16.0%	-21.8%	-26.8%
	35.0%	-11.2%	-19.1%	-25.7%	-31.3%
	40.0%	-13.2%	-22.4%	-29.8%	-35.9%

Table 9. Effect of Consumer Waste Rates & Apeel Reduction on Climate Change Impact Reduction for US Limes

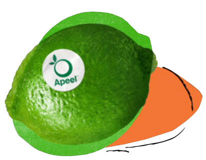
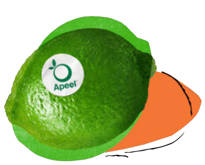
Carbon Footprint Reduction, kg CO2-eq/kg limes					
Apeel Consumer Waste Reduction					
		20%	40%	60%	80%
Baseline Consumer Waste Rates	5%	-7.0%	-8.5%	-9.9%	-11.3%
	10%	-8.4%	-11.4%	-14.2%	-16.9%
	15%	-9.9%	-14.3%	-18.4%	-22.2%
	20%	-11.5%	-17.3%	-22.6%	-27.4%
	25%	-13.2%	-20.4%	-26.8%	-32.5%
	30%	-15.0%	-23.5%	-31.0%	-37.5%
	35%	-16.9%	-26.9%	-35.2%	-42.3%
	40%	-19.0%	-30.3%	-39.5%	-47.1%

Table 10. Effect of Consumer Waste Rates & Apeel Reduction on Resource (Water) Impact Reduction for US Limes

Water Footprint Reduction, liters water/kg limes					
Apeel Consumer Waste Reduction					
		20%	40%	60%	80%
Baseline Consumer Waste Rates	5%	-7.2%	-8.1%	-9.1%	-10.0%
	10%	-8.2%	-10.2%	-12.0%	-13.8%
	15%	-9.4%	-12.4%	-15.2%	-17.8%
	20%	-10.7%	-14.7%	-18.4%	-21.8%
	25%	-12.0%	-17.2%	-21.8%	-25.9%
	30%	-13.6%	-19.9%	-25.4%	-30.1%
	35%	-15.3%	-22.8%	-29.1%	-34.4%
	40%	-17.2%	-25.9%	-33.0%	-38.8%

Baseline Retail Shrink & Apeel Shrink Reduction Without Consumer Waste Reduction

Tables 11 - 14 display the results of the sensitivity analysis for baseline retail shrink rate and Apeel reduction of retail shrink when Apeel impact to consumer waste is not included in the results. Examples of the results are presented here for one US market category (avocados) and one EU market category (mandarins) for both the climate change (total) and resource (water) impact categories. The results are expected to be relatively consistent across all impact categories; however, the baseline environmental impacts of the produce category can play a significant role in these results.

For example, with just retail waste reduction alone, the Apeel product impacts may not be justified if the baseline waste rate is very low (i.e., there are not significant savings to be had) and the impacts of producing and distributing that fruit are also small. This is evidenced in Tables 11 and 13, where for the climate change (total) impact category, there is actually an increase at the low baseline shrink rates and small improvements with Apeel, especially for mandarins which have a smaller baseline impact than avocados.

For the water withdrawal impact category, on the other hand, all Apeel produce categories have a lower impact than the baseline produce scenarios in this study, even without the inclusion of consumer waste reduction. As shown in Tables 12 and 14, even in low baseline shrink and Apeel waste reduction scenarios, Apeel enables net environmental savings rather than impacts. This is due to the fact that the impacts in the water withdrawal impact category for the Apeel product are quite small relative to the larger upstream water use for agricultural production of the produce in this study.

The tables are formatted such that the % impact reduction show in each cell correlates to the baseline retail waste rates shown in the first column, and the percent by which Apeel reduces retail waste shown in the first row. For example, if the baseline retail waste rate is 10%, and Apeel reduces retail waste by 40%, the climate change (total) impacts would be reduced by 6%. For the results in this section the baseline consumer waste is held constant at 19% for EU markets and 25% for US markets, and no Apeel reduction in waste at the household stage is included. Tables 11-14 include a box around the scenario with the baseline retail waste rates and Apeel retail waste reduction used to calculate the main report results.

Table 11. Effect of Retail Shrink Rates & Apeel Reduction on Climate Change Impacts for US Avocados

Carbon Footprint Reduction, kg CO2-eq/kg avocado									
		Apeel Retail Waste Reduction							
		10%	20%	30%	43%	50%	60%	70%	80%
	2.0%	0.11%	-0.16%	-0.42%	-0.77%	-0.95%	-1.21%	-1.48%	-1.74%
	4.0%	-0.17%	-0.71%	-1.24%	-1.93%	-2.29%	-2.81%	-3.33%	-3.84%
Baseline Retail Waste Rates	5.0%	-0.31%	-0.98%	-1.65%	-2.52%	-2.97%	-3.61%	-4.25%	-4.89%
	8.0%	-0.74%	-1.84%	-2.91%	-4.30%	-5.00%	-6.03%	-7.03%	-8.02%
	10.0%	-1.04%	-2.42%	-3.77%	-5.50%	-6.38%	-7.64%	-8.88%	-10.10%
	12.0%	-1.35%	-3.02%	-4.64%	-6.72%	-7.77%	-9.27%	-10.73%	-12.16%
	13.2%	-1.54%	-3.38%	-5.17%	-7.46%	-8.60%	-10.25%	-11.85%	-13.40%
	16.0%	-1.99%	-4.26%	-6.44%	-9.20%	-10.58%	-12.55%	-14.44%	-16.28%
	18.0%	-2.33%	-4.90%	-7.37%	-10.47%	-12.01%	-14.20%	-16.30%	-18.33%
	20.0%	-2.68%	-5.56%	-8.32%	-11.76%	-13.46%	-15.86%	-18.16%	-20.36%

Table 12. Effect of Retail Shrink Rates & Apeel Reduction on Resource (Water) Impacts for US Avocados

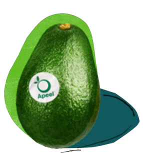
Water Footprint Reduction, liters water/kg avocado									
		Apeel Retail Waste Reduction							
		10%	20%	30%	43%	50%	60%	70%	80%
	2.0%	-0.2%	-0.4%	-0.6%	-0.9%	-1.0%	-1.2%	-1.4%	-1.6%
	4.0%	-0.4%	-0.8%	-1.2%	-1.8%	-2.0%	-2.4%	-2.8%	-3.2%
Baseline Retail Waste Rates	5.0%	-0.5%	-1.0%	-1.5%	-2.2%	-2.6%	-3.0%	-3.5%	-4.0%
	8.0%	-0.9%	-1.7%	-2.5%	-3.6%	-4.2%	-4.9%	-5.7%	-6.5%
	10.0%	-1.1%	-2.2%	-3.2%	-4.6%	-5.2%	-6.2%	-7.2%	-8.1%
	12.0%	-1.3%	-2.6%	-3.9%	-5.5%	-6.4%	-7.5%	-8.7%	-9.8%
	13.2%	-1.5%	-2.9%	-4.3%	-6.1%	-7.1%	-8.3%	-9.6%	-10.8%
	16.0%	-1.9%	-3.7%	-5.4%	-7.6%	-8.7%	-10.2%	-11.7%	-13.2%
	18.0%	-2.1%	-4.2%	-6.2%	-8.6%	-9.9%	-11.6%	-13.3%	-14.9%
	20.0%	-2.4%	-4.7%	-7.0%	-9.7%	-11.1%	-13.0%	-14.9%	-16.6%

Table 13. Effect of Retail Shrink Rates & Apeel Reduction on Climate Change Impacts for EU Mandarins

Carbon Footprint Reduction, kg CO2-eq/kg mandarin									
		Apeel Retail Waste Reduction							
		10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**
Baseline Retail Waste Rates 	**1.0%**	2.02%	1.91%	1.80%	1.69%	1.59%	1.48%	1.37%	1.26%
	2.0%	1.91%	1.69%	1.47%	1.25%	1.04%	0.82%	0.61%	0.39%
	3.0%	1.79%	1.46%	1.13%	0.81%	0.48%	0.16%	-0.16%	-0.48%
	4.0%	1.68%	1.23%	0.79%	0.36%	-0.07%	-0.50%	-0.93%	-1.35%
	5.0%	1.56%	1.00%	0.45%	-0.10%	-0.64%	-1.17%	-1.70%	-2.23%
	6.0%	1.44%	0.77%	0.10%	-0.56%	-1.21%	-1.85%	-2.48%	-3.10%
	7.0%	1.32%	0.53%	-0.25%	-1.02%	-1.78%	-2.53%	-3.26%	-3.99%
	8.0%	1.19%	0.28%	-0.61%	-1.49%	-2.36%	-3.21%	-4.05%	-4.87%
	9.0%	1.07%	0.04%	-0.98%	-1.97%	-2.94%	-3.90%	-4.84%	-5.76%
	10.0%	0.94%	-0.22%	-1.35%	-2.45%	-3.53%	-4.59%	-5.63%	-6.64%

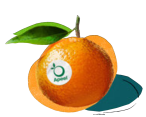
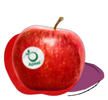
Table 14. Effect of Retail Shrink Rates & Apeel Reduction on Resource (Water) Impacts for EU Mandarins

Water Footprint Reduction, liters water/kg mandarin									
		Apeel Retail Waste Reduction							
		10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**
Baseline Retail Waste Rates 	**1.0%**	0.05%	-0.05%	-0.15%	-0.25%	-0.35%	-0.45%	-0.55%	-0.65%
	2.0%	-0.05%	-0.25%	-0.46%	-0.66%	-0.86%	-1.06%	-1.26%	-1.46%
	3.0%	-0.15%	-0.46%	-0.77%	-1.07%	-1.37%	-1.67%	-1.97%	-2.27%
	4.0%	-0.26%	-0.67%	-1.08%	-1.49%	-1.89%	-2.29%	-2.69%	-3.08%
	5.0%	-0.37%	-0.89%	-1.41%	-1.92%	-2.42%	-2.92%	-3.41%	-3.90%
	6.0%	-0.48%	-1.11%	-1.73%	-2.35%	-2.95%	-3.55%	-4.14%	-4.72%
	7.0%	-0.59%	-1.33%	-2.06%	-2.78%	-3.49%	-4.18%	-4.87%	-5.55%
	8.0%	-0.71%	-1.56%	-2.40%	-3.22%	-4.03%	-4.83%	-5.61%	-6.38%
	9.0%	-0.83%	-1.79%	-2.74%	-3.67%	-4.58%	-5.47%	-6.35%	-7.21%
	10.0%	-0.95%	-2.03%	-3.08%	-4.12%	-5.13%	-6.12%	-7.09%	-8.04%

The results are slightly more sensitive to the Apeel reduction of consumer waste since the baseline consumer waste is higher than the baseline retail shrink. A reduction at the same rate from Apeel will, therefore, have a larger impact. The scenario boxed in each table shows the baseline retail waste rates and Apeel waste reduction applied when calculating the main results in this report.

Since the Apeel product extends shelf life across the produce supply chain, Apeel produce likely lasts longer and reduces waste in consumer's homes. However, Apeel is still in the early stages of gathering data outside of in-house product testing. As a result, Apeel performs this sensitivity analysis, where consumer waste remains the same between baseline and Apeel produce, to assess the of savings enabled via retail waste reduction only since this is the part of the system where Apeel has the most data. Table 15 below shows the environmental impacts of baseline and Apeel produce across all supply chain scenarios only considering the benefits of waste reduction up through retail.

Table 15. Baseline and Apeel Environmental Impacts Without Consumer Waste Reduction

		Climate Change Total (kg CO2-eq)	Freshwater and Terrestrial Acidification (mol H+-Eq)	Freshwater Eutrophication (kg P-eq)	Fossil Resources (MJ)	Cumulative Water Withdrawal (m3)
Avocados: EU End Market 	Baseline	1.92	1.76E-02	3.70E-04	20.9	1.17
	Apeel	1.86	1.67E-02	3.70E-04	20.5	1.11
	Percent Change with Apeel	**-3.0%**	**-4.8%**	**0.0%**	**-1.8%**	**-5.4%**
Avocados: US End Market 	Baseline	3.26	1.42E-02	4.60E-04	29.4	1.30
	Apeel	3.02	1.34E-02	4.40E-04	28.0	1.22
	Percent Change with Apeel	**-7.5%**	**-5.6%**	**-4.3%**	**-4.8%**	**-6.1%**
Spanish Oranges 	Baseline	1.22	9.78E-03	2.00E-04	14.7	0.208
	Apeel	1.20	9.61E-03	2.00E-04	14.6	0.204
	Percent Change with Apeel	**-1.2%**	**-1.7%**	**0.0%**	**-1.1%**	**-1.6%**
Spanish Mandarins 	Baseline	1.09	9.20E-03	1.91E-04	14.0	0.205
	Apeel	1.08	9.01E-03	1.88E-04	14.0	0.200
	Percent Change with Apeel	**-0.6%**	**-2.1%**	**-1.6%**	**-0.3%**	**-2.4%**
Mexican Limes 	Baseline	1.89	1.29E-02	3.40E-04	21.8	0.854
	Apeel	1.80	1.22E-02	3.40E-04	21.3	0.801
	Percent Change with Apeel	**-5.0%**	**-5.1%**	**0.0%**	**-2.6%**	**-6.2%**
Apples: US End Market 	Baseline	2.10	9.64E-03	4.01E-04	23.5	0.300
	Apeel	1.99	9.18E-03	3.84E-04	22.7	0.282
	Percent Change with Apeel	**-5.2%**	**-4.8%**	**-4.2%**	**-3.4%**	**-6.2%**

Produce Transport Distance

In addition to the agricultural production stage, the transport of produce between the packing house and retail was a large contributor to the total impacts in many of the produce types and impact categories. The main results were calculated using an average transport distance, yet the exact distance can vary depending on the location of the retail store (e.g., California vs. New York in the US). A sensitivity analysis for Apeel Apples for the US market was conducted to examine how the Apeel Apple savings change for different transport distances. Apeel Apples were chosen for this analysis, because distribution of produce to retail has a high contribution to all impact categories in comparison to the other Apeel produce categories and scenarios within this study. Therefore, the effects are expected to be the greatest. Tables 16 and 17 display the environmental impact reductions with Apeel Apples across several different transport scenarios. The 100% column in both tables below shows the main results included earlier in this report for Apeel apples in the US market.

Table 16. Effect of Transport Distance on Apeel US Apple Environmental Impact Reduction (Absolute)

Apeel Savings - Absolute								
	% of study distance							
Impact Category	Unit	20%	40%	60%	80%	100%	120%	140%
Climate Change Total	kg CO2-Eq	0.383	0.415	0.448	0.480	0.512	0.544	0.576
Freshwater and Terrestrial Acidification	mol H+-Eq	1.07E-03	1.26E-03	1.45E-03	1.63E-03	1.82E-03	2.00E-03	2.19E-03
Freshwater Eutrophication	kg P-Eq	6.42E-05	6.68E-05	6.95E-05	7.22E-05	7.49E-05	7.76E-05	8.03E-05
Fossil Resources	MJ	2.165	2.647	3.129	3.611	4.093	4.575	5.057
Cumulative Water Withdrawal	m3	5.88E-02	5.88E-02	5.88E-02	5.88E-02	5.89E-02	5.89E-02	5.89E-02

Table 17. Effect of Transport Distance on Apeel US Apple Environmental Impact Reduction (%)

Apeel Savings - Percent								
	% of study distance							
Impact Category	Unit	20%	40%	60%	80%	100%	120%	140%
Climate Change Total	kg CO2-Eq	75%	81%	87%	94%	100%	106%	113%
Freshwater and Terrestrial Acidification	mol H+-Eq	59%	69%	80%	90%	100%	110%	120%
Freshwater Eutrophication	kg P-Eq	86%	89%	93%	96%	100%	104%	107%
Fossil Resources	MJ	53%	65%	76%	88%	100%	112%	124%
Cumulative Water Withdrawal	m3	100%	100%	100%	100%	100%	100%	100%

In this case, which is expected to be the most extreme examples amongst the categories considered in this study, the transport distance had a significant effect on the overall Apeel benefits. If Apeel Apples travel only 20% of the distance to retail included in the main study results, the environmental savings are only 53%-75% of those measured in the main results across the climate change (total), freshwater and terrestrial acidification, freshwater eutrophication, and fossil resources impact categories. This indicates that for categories where a majority of impacts occur during the transport step, the amount of environmental impact reduction enabled with Apeel will vary across transport distances. The Freshwater and Terrestrial Acidification and Fossil Resource impact categories are the most sensitive to transport distance, with only 59% and 53% of the original study results' environmental savings, respectively, enabled in a scenario where apples travel 20% of the study distance.

The cumulative water withdrawal is an outlier relative to the other four impact categories; 100% of the savings are still captured no matter the transport scenario since a majority of the water impacts occur during agricultural production. This will be taken into consideration in future studies as different treatment locations and supply chains are analyzed.

Inventory Data Quality Analysis

The background processes representing the highest contributions (cumulatively >95%) across the six main impact categories in the results (aquatic acidification, aquatic eutrophication, land occupation, global warming, non-renewable energy usage, and cumulative water withdrawals) were assessed for data quality using the pedigree matrix approach. Since the produce production and distribution stages make up most of the impacts, all data sources for those processes were assessed. The tables in Appendix I include lists of these processes with scores attributed to each dimension of data quality. This study does not include comparative claims against other products, and the parameters included in this list of high contributors are used as background data in both the baseline and Apeel scenario; therefore, the data quality is considered reasonable for the goals of the study.

A majority of the produce production processes analyzed have a medium data quality score (score of 3 and below). Some produce production processes that were already regionalized in the ecoinvent data (e.g., Spanish orange and mandarin production) have higher quality scores on average due to the higher reliability, geographical, and technological scores. In addition, the other processes analyzed, related to transport and packaging of produce, all received medium or high data quality scores.

For the most part, produce production processes only had scores of 4 or higher in the "temporal differences" category. This is one of the largest weaknesses from a data quality perspective; since many of the processes have been extrapolated based on datasets that were created more than 15 years ago, there is an opportunity to collect more data at the farm level to improve data quality in future studies. While this level data quality is less than ideal, Apeel is confident in the results put forth in this report for the following reasons.

First, the methods and inputs used in produce production have remained relatively consistent in recent decades. There is little room for innovation or change over time when produce requires a set of water, fertilizer, and pesticides/herbicides. Most of the areas of origin for produce included in this report have been under cultivation for many decades, with farmers following consistent agricultural practices. More recent datasets, if they were available in the ecoinvent database, may include slight changes to account for recent technological innovations. However, the major inputs that most contribute to the environmental impacts observed in this report, such as irrigation water, use of fossil fuels to pump irrigation water and operate machinery, and the manufacture and application of fertilizers, are still necessary for produce production and would still be included in updated production data. Due to this consistency over time in the inputs required for produce production, Apeel feels confident about the results included in this report that utilize processes with lower temporal data quality scores.

The second key reason Apeel remains confident in the data utilized in this report is the fact that both the baseline and Apeel scenarios rely on the same datasets and the key results presented focus on the delta between the two scenarios, rather than the absolute environmental impact of each. Apeel would be more concerned about the middling produce production data quality if the data used in only one of the scenarios received lower scores than the data utilized in the other. In addition, Apeel would set a higher data quality threshold if this report, and any external communications Apeel planned to make with this data, included statements about the absolute environmental impact of baseline and Apeel produce. Since Apeel focuses on the percentage change between the two scenarios, the level of data quality for the background data used to calculate the results in this report is adequate.

For future studies, Apeel hopes to collect and include higher quality background data in future reports. For some produce categories, Apeel works directly with produce growers and there may be future opportunities to collaborate and collect data on produce production inputs and methods. This level of direct data collection would lead to better quality produce production data and would alleviate issues with poor temporal quality scores.

One other data quality weakness was the use of a lemon production process for lime production. Ecoinvent does not include production processes for limes, however Apeel believes the lemon production processes is a valid choice as a proxy given the similarity in citrus production inputs and methods across crop types. Previous studies have shown that the water and agrochemical inputs required for citrus production vary depending on soil composition and permeability[36] rather than between specific crop types. This report was able to utilize a regionalized lemon production process as a proxy for limes in Mexico, which would account for soil type in its regionalization. As such, Apeel is confident in the use of these process as a proxy.

Lastly, while the scores from the transportation processes are of medium quality, Apeel is still confident in the results included in this report for the same reason highlighted above. Since the same transportation datasets are utilized in both the baseline and Apeel scenarios and the study does not include comparative claims against other products but rather presents the results as a % change between the two scenarios, the data quality is considered reasonable for the goals of the study. In addition, Apeel selected the “market for transport” processes in order to account for a broad range of transportation technologies in use across the various regions and supply chains presented in this study. While some regions such as the EU may utilize more recent transport infrastructure and technologies, other regions may rely on older, less efficient technologies. While data quality score would be higher if a specific truck type were selected, it may not represent the spectrum of scenarios that are possible for the produce supply chains included in this report. In future studies that more closely analyze the impact of Apeel on

[36] M.D. Goebes, R. Strader, C. Davidson. An ammonia emission inventory for fertilizer application in the United States. Atmospheric Environment, 37 (18) (2003), pp. 2539-2550

specific produce types, or for specific customers’ supply chains, Apeel will take care to select the transport modes relevant for those regions and set a higher data quality threshold. However, Apeel believes the level of data quality with the current transportation process selection is sufficient for the level and type of results presented in this study.

Limitations

This study has several limitations. First, the background data used for the produce production itself is very coarse. While this is unlikely to affect the direction of the results, future studies should consider methods to collect more location-specific and temporally-relevant agricultural production data. Second, cumulative water withdrawal only provides a sense of all the water being used but does not provide a clear indication of how impactful this water use may be. Future work should attempt to estimate cumulative water consumption, as well as take stress and scarcity indicators into account to develop a more comprehensive water footprint. Lastly, this analysis was based on either one Apeel customer, using data specific to their supply chain and in-store inventory management and consumer behaviors, or based on forecasts for in-market and supply chain parameters. While the methodology in this report should be used consistently across different supply chains for these five produce categories, the results may not be broadly generalizable to all Apeel-treated produce in the US or EU markets.

Summary & Conclusions

This LCA study evaluated the environmental impacts of avocados, limes, oranges, mandarins, and apples sold and consumed in the US and EU with and without the Apeel product. The introduction of Apeel into the produce supply chains reduced the potential impacts across all categories in the ILCD 2.0 2018 methodology by 10-25% in a majority of the produce types and impact categories; these impact reductions account for the environmental impacts of Apeel's product, which are relatively small compared to the environmental benefits of reducing food waste by extending the shelf-life of produce. The largest impact reductions were observed in the produce types with the largest environmental footprints: avocados, limes, and apples in the US market. Impact reductions tended to be higher in the US compared to the EU due to higher baseline waste rates, longer transport distances via truck, and a larger amount of produce sent to landfill from retail & consumer homes. The largest impact reductions were observed in the climate change (total) impact category, with an average 19% reduction across produce categories. The freshwater and terrestrial acidification and cumulative water withdrawal impact categories were the second largest, with an average 17% impact reduction. Lastly, both fossil resources and freshwater eutrophication impacts were still significantly reduced, at an average 15% across all produce types and supply chain scenarios.

The sensitivity analysis draws attention to the importance of the baseline retail shrink, baseline consumer waste, and Apeel reduction of both waste rates in the results. The baseline rates set the total possible improvement that can be made possible with the Apeel product in this scenario, and the Apeel product effect plays a significant role in the main results. As indicated by the results in the contribution analysis (Appendix H), the additional impacts associated with Apeel are less than 3% across a majority of scenarios and produce categories. Exceptions include produce categories with very low baseline environmental impacts (i.e., Spanish mandarins sent to the EU market). These results indicate that, the baseline shrink/waste and Apeel reduction would need to be quite low in order for the benefits to be unsubstantial.

The sensitivity analyses focused on transportation modes and distances highlight the importance of continued data collection by Apeel to understand the unique supply chain dynamics in a given scenario. Many produce categories had transportation stages as the climate change (total) and resource (fossil) hotspots; shorter transport distances may result in lower baseline environmental impacts, and lower impact reduction with Apeel. However, the sensitivity analyses did reveal that even scenarios quite different from those used to calculate the main results in this report, net environmental savings were still enabled with Apeel.

This study focused on the impacts of the Apeel product on food waste and postharvest wax for several produce categories and supply chains. Additional produce supply chain environmental efficiency gains (i.e., optimized logistics, reduced use of plastic packaging, reductions in upstream supply chain food losses, reduced reliance on the cold chain, etc.) may be possible with the Apeel product and will be investigated in future studies.

It is important to note that Apeel is continuously identifying and implementing ways to reduce the impacts generated to make, distribute and apply the Apeel product. These efforts, as well as identifying and measuring outcomes of the Apeel product on fresh product, can result in larger environmental savings into the future.

ISO Compliance Assessment

ISO 14044 LCA REVIEW

Report title	Life Cycle Assessment of Apeel Produce
Contracting organization	Apeel Sciences
Review team	Cristóbal Loyola – cristobal.loyola@quantis-intl.com
Client contacts	Jessica Vieira – Director of Sustainability Shannon Thoits – Sustainability Analyst

ISO Compliance Assessment

	ISO Requirement	Comments	APEEL RESPONSE	Second Round of comments
General reporting requirements and considerations				
☒	Are the results and conclusions of the LCA completely and accurately reported without bias to the intended audience?	The results need to include all the categories mentioned as priority, not just carbon and water. In general, the report would benefit with more interpretation of the results, as well as the conclusions.	Report now includes all five main impact categories utilized for results analysis: climate change (total), resource (water), ecosystem quality (freshwater & terrestrial acidification), ecosystem quality (freshwater eutrophication) and resources (fossils). Additional results interpretation were added in both the main discussion of results as well as the conclusions.	Requirement met
☒	Are the results, data, methods, assumptions, and limitations transparent and presented in sufficient detail to allow the reader to comprehend the complexities and trade-offs inherent in the LCA?	The report suffers of relying too much on the annexes. More tables and graphics in the report would allow an easier read, interpretation, and analysis altogether.	Additional tables and figures were added to the report.	Requirement met
☒	Does the report allow the results and interpretation to be used in a manner consistent with the goals of the study?	Only carbon and water are analyzed, when more LCIA categories are said to be of high priority. Please include an analysis of the rest of the categories.	Report now includes all five main impact categories utilized for results analysis: climate change (total), resource (water), ecosystem quality (freshwater & terrestrial acidification), ecosystem quality (freshwater eutrophication) and resources (fossils).	Requirement met
☒	LCA commissioner, LCA practitioner (internal or external)	Requirement met		
☒	Date of report	Requirement met		
☒	Statement that the study has been conducted according to the requirements of ISO 14040 and 14044	Requirement met		
☒	Reasons for carrying out the study	Requirement met		
☒	Intended applications	Requirement met		
☒	Target audiences	Requirement met		
Scope of the study				
Function				
☒	Definition	Requirement met		
☒	Statement of performance characteristics	Requirement met		
☒	Any omission of additional functions in comparisons	Requirement met		
Functional unit				

ISO Requirement		Comments	APEEL RESPONSE	Second Round of comments
☒	Definition	The functional unit only identifies the US as location of consumption, when there're products sold in the US and EU	This was a typo error on our part. Functional unit now clarified to include both US and EU.	Requirement met
☒	Consistency with goal and scope	See previous	This was a typo error on our part. Functional unit now clarified to include both US and EU.	Requirement met
☒	Result of performance measurement	It is hard to follow which waste rates were applied at each stage for each product.	More explicit reference to the appendix was added where needed.	Requirement met
System Boundaries				
☒	Definition	It seems that different products have different supply chains, which is not reflected in the process diagram included.	There are only a few unique cases where produce such as apples and mandarins had a postharvest storage period following packinghouse processing and/or Apeel product application. This optional step has been added to the process diagram. Although the exact location of supply chain "nodes" may vary across produce types, all produce follows the general flow: production, transport to packinghouse, processing, transport to retail, sale, transport to consumer, consumption. Any other unique cases are described in the System Characterization & Data Sources section.	Requirement met
☒	Omissions of life cycle stages, processes or data needs	Requirement met		
☒	Quantification of energy and material inputs and outputs	Requirement met		
☒	Assumptions about electricity production	Requirement met		
Cut-off criteria for initial inclusion of inputs and outputs				
☒	Description of cut-off criteria and assumptions	Requirement met		
☐	Effect of selection on results	Not applicable.		
☒	Inclusion of mass, energy and environmental cut-off criteria	Requirement met		
Life cycle inventory analysis				
☒	Data collection procedures	Requirement met		
☒	Qualitative and quantitative description of unit processes	Requirement met		
☒	Sources of published literature	There are still some sources missing throughout the report	Additional sources have been added where needed.	Requirement met
☒	Calculation procedures	Requirement met		

	ISO Requirement	Comments	APEEL RESPONSE	Second Round of comments
☒	Data quality analysis	Data quality analysis lacks interpretation, please include.	Additional interpretation added to data quality analysis.	Requirement met
☒	Treatment of missing data	Requirement met		
☒	Sensitivity analysis for refining the system boundary	Not applicable		
☒	Documentation and justification of allocation procedures	It is not clear how benefits of waste treatments are accounted	Benefits of waste treatments are not included per the ecoinvent cutoff by classification methodology, where only burdens from waste treatment should be included in the system boundary. This is now explicitly stated in the report. Appendix F exclusively details the burdens from various methods of food waste treatment.	Requirement met
☒	Uniform application of allocation procedures	Same as above	See comment above.	Requirement met
Life cycle impact assessment				
☒	LCIA procedures, calculations and results of the study	Not all the impact categories said to be analyzed have been analyzed. Please include all of them.	Additional categories now included.	Requirement met
☒	Limitations of the LCIA results relative to the defined goal and scope of the LCA	Requirement met		Requirement met
☒	Relationship of LCIA results to the defined goal and scope	Not all the impact categories said to be analyzed have been analyzed. Please include all of them.	Additional categories now included.	Requirement met
☒	Relationship of the LCIA results to the LCI results	There is a lack of interpretation for the different products and impact categories. Please expand.	Additional results interpretation added.	Requirement met
☒	Impact categories and category indicators considered, including a rationale for their selection and a reference to their source	Impact categories selected are ok, but they're not explored in the study.	Additional categories now included.	Requirement met
☒	Descriptions of or reference to all characterization models, characterization factors and methods used, including all assumptions and limitations	Requirement met		
☒	Descriptions of or reference to all value-choices used	Requirement met		

	ISO Requirement	Comments	APEEL RESPONSE	Second Round of comments
	in relation to impact categories, characterization models & factors, normalization, grouping, weighting and, elsewhere in the LCIA, a justification for their use and their influence on the results, conclusions and recommendations			
☒	A statement that the LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks	Missing	This is included already at the end of the *Impact Assessment* subsection at the top of page 34i n the **Assessment Methodology (LCIA)** section.	Requirement met
☒	Results	Needs more elaboration at the results level. It is hard to follow the results as the report lacks graphics to help in the process.	Additional results elaboration and graphics added.	
☒	Assumptions and limitations associated with the interpretation of results, both methodology and data related	Requirement met		
☒	Data quality analysis	Lacks interpretation	Additional interpretation added.	Requirement met
☒	Full transparency in terms of value-choices, rationales and expert judgments			
Critical Review				
☒	Critical review by external expert			Requirement met
☒	Name and affiliation of reviewers			Requirement met
☒	Critical review reports			Requirement met
☒	Responses to recommendations			Requirement met