Wrap It Up, We Won't Take It...(unless it's asparagus)

a produce packaging life cycle assessment

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Plastic has made our modern world possible. But in doing so, it has earned a pretty bad rap, especially from environmental enthusiasts. From banned bags to banished straws, and from micro to macro-plastic pollution - it's a hot topic on everyone's mind.

However, it seems that whether plastic is considered "bad" for the environment is relative. Tradeoffs are inherent when weighing the environmental cost to the benefits realized by its service. And it appears produce packaging is no different.

Almost half of produce worldwide is wasted, which means fruits and vegetables have the highest wastage rates of any food category[1]. This is because of the way our food system has developed - most people don't live right next to a farm. In fact, much of the produce you eat comes from hundreds or even thousands of kilometers away[2]. And as soon as a piece of produce is harvested, it starts to ripen. There is a short window of time at which it's edible, and if it's not eaten before the window closes, it gets tossed without living it's produce destiny!

Surprisingly, one way to increase that window of time is to wrap it in plastic. But knowing the woes of plastic pollution, we couldn't help but wonder if the benefits from extending produce's shelf life are worth the environmental risk?

Why Package Produce?

Produce continues to respire, or 'breathe', after they are harvested. This process of oxidizing and producing carbon dioxide ripens the produce until eventually it is no longer fresh. Decreasing respiration rate is the name of the game when it comes to preserving produce.

One technology that is currently being used to slow down the fruit's breathing is called modified atmosphere packaging, or MAP. And it's just what it sounds like - packaging used to alter the composition of ambient air. Plastic films, foils, and other packaging materials are used to contain an optimal blend of oxygen,

[1] SAVE FOOD: Global Initiative on Food Loss and Waste Reduction. Food and Agriculture Organization of the United Nations (UN FAO). Can be accessed at: http://www.fao.org/save-food/resources/keyfindings/en/

[2] Where does our food come from? Seedmap.org. Can be accessed at: http://seedmap.org/where-does-our-food-come-from/

carbon dioxide, and nitrogen for the produce[3]. Specifically, the packaging is flushed with nitrogen to maintain low levels of oxygen to prevent oxidizing. MAP also regulates moisture levels, which reduces spoilage caused by mold and other anaerobic organisms.

That sounds good and all, but this is plastic we are talking about; the same stuff that creates garbage patches in the ocean and kills millions of marine animals each year. So we were curious to find out, *is it ever worth covering our produce with plastic*[4]?

To figure out the environmental impacts associated with MAP, we conducted a life cycle assessment for three types of produce. We made sure that the primary function of MAP would not serve any additional purpose besides modifying the atmosphere. This meant that grapes, berries, and cherry tomatoes were nonstarters since packaging also serves as a carrying container.

But, asparagus, bell peppers, and vine-tomatoes were all available in the grocery store without packaging, so we knew that the MAP was only there to extend shelf life. Asparagus is normally air-freighted to make it to your home in time for dinner, so we thought this would be a good one to look into. Additionally, vine-tomatoes are a high priced commodity and reducing waste would help distributors and retailers reduce lost income due to food spoilage. And bell peppers last for a while, so why even add any packaging?

Environmental Impacts of MAP

Measurements and assumptions were made in order to evaluate the environmental impacts of the packaging[5]. Each produce had two types of packaging, a combination of low-density polyethylene (LDPE), high-density polyethylene (HDPE), and/or cardboard. The volume of nitrogen used to flush out the packaging was estimated by measuring the area of the package and multiplying it by 1 centimeter thick layer of gas. Also, we assumed all packaging ends up in sanitary landfills, and that there is approximately 95 kilometers between the consumer and landfill.

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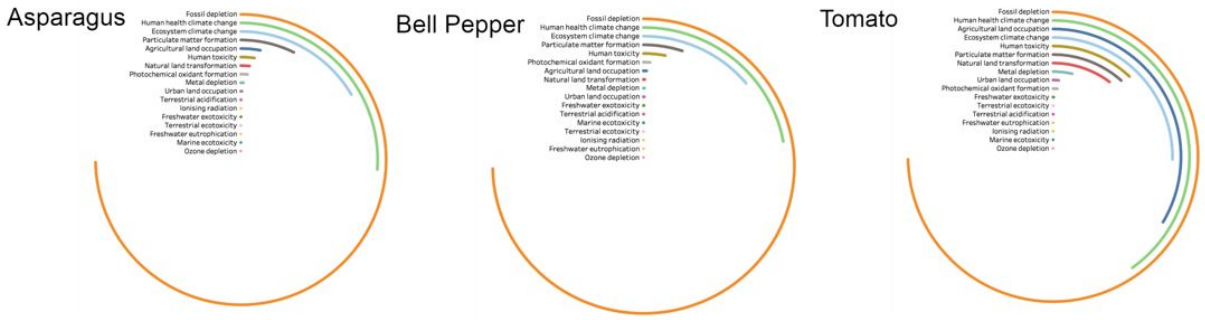
[3] What is Modified Atmosphere Packaging (MAP)? Dansensor. Can be accessed at: https://dansensor.com/solutions/modified-atmosphere-packaging-food-and-beverage-industry

[4] Parker, Laura. We Made Plastic. We Depend On It. Now We're Drowning In It. National Geographic. Can be accessed at: https://www.nationalgeographic.com/magazine/2018/06/plastic-planet-waste-pollution-trash-crisis/

[5] For those who are interested - our functional unit was kilograms of packaging per kilogram of produce (kg of packaging / kg of produce). To characterize our end points, we used the ReCiPe database. We made assumptions regarding the identification of the plastic that was used in the Trader Joe's samples that we obtained. Also, we had to use polyethylene granulate instead of polyethylene packaging film due to lack of availability of data in ecoinvent.

So what did we find? Fossil fuel depletion and climate change impacts on human health were the two largest impact categories for all three packages[6]. We assume this is because plastic comes from oil, and as we know, oil is a fossil fuel.

The third largest impact category was climate change effects on the ecosystem for asparagus and bell pepper packaging. But for vine-tomatoes, it was agricultural land occupation. This was unsurprising because the vine-tomatoes were in a cardboard box in addition to being wrapped in plastic. And since cardboard comes from wood pulp, the box is more than likely responsible for the impact on agricultural land occupation. But we should note that this doesn't consider the additional land that would be used if more vine-tomatoes are wasted, which is the case when shelf life is not extended. But we'll get into more of that a little later.



Environmental impacts of modified atmosphere packaging for asparagus, bell peppers, and tomatoes. ReCiPe characterisation model was used to translate emissions and resource extraction into impact scores.

Avoided Produce Waste Thanks to Packaging

So it's pretty clear that plastic packaging has detrimental environmental impacts. But since it also reduces food waste, it provides environmental benefits too.

And reducing produce waste is no joke. Worldwide, 45% of fruits and vegetables are wasted each year[7]. In the United States, this wasted produce uses 30 million acres of cropland each year[8] !

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[6] Again, for those who are curious- we ran a Monte Carlo simulation to see what our distribution would look like given the amount of uncertainty we had in our scale and was provided through ecoinvent for our intermediate and elementary flow matrices. From that we determined that uncertainty did not have too much of an impact on our final model - good stuff!

[7] SAVE FOOD: Global Initiative on Food Loss and Waste Reduction. "Key facts on food loss and waste you should know!" Food and Agriculture Organization of the United Nations (FAO). Can be accessed at: http://www.fao.org/save-food/resources/keyfindings/en/

[8] Conrad, Z., Niles, M. T., Neher, D. A., Roy, E. D., Tichenor, N. E., & Jahns, L. (2018). Relationship between food waste, diet quality, and environmental sustainability. *PloS one*, *13*(4), e0195405.

So then the pressing question was - do the added benefits through waste aversion outweigh the impacts of the plastic packaging?

This was a tricky question, and required some creative research. First we needed to understand the baseline emissions of asparagus, tomatoes and bell peppers. Luckily someone did the work for us. Stoessel et al. quantified the environmental impacts of 34 kinds of produce up to the retail stage in the supply chain[9]. From this we used data for green asparagus, vine-tomatoes and bell peppers.

Next, we needed to find out just how many extra days of freshness MAP provided. Through some digging online, we found that MAP extends the life-time of tomatoes by 21 days[10], 6 for asparagus[11], and 0 for bell peppers. Yep, zero days; which means packaging doesn't really serve a purpose for the bell peppers. What a waste!

Then we sought out how extended shelf life related to food waste. Fortunately, researchers looked at over 800 grocery store products to analyze the relationship between time on the shelf and the amount of goods sent back to the distributor[12]. This helped estimate the percentage of goods returned based on shelf life, which we used as a proxy for the amount of waste avoided through the use of packaging.

It's important to note that this study mainly quantified the relationship between shelf life and goods returned for dairy products, beverages and ready made meals. Most of the products considered had a normal shelf life of 30-50 days. This wasn't the perfect model for produce, as fruits and vegetables usually have a shorter life span than 30 days. Also, fruit and vegetable products may not actually be sent back to the distributor and instead just thrown out. We used this model due to lack of better data, however we recognize that it may have caused our results to underestimate the amount of produce wasted after a given number of days.

After all of that research, we were ready to evaluate the environmental impact of avoided waste. This was measured by multiplying the percentage of produce wasted and the produce's baseline

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[9] Stoessel et al. Life Cycle Inventory and Carbon and Water FoodPrint of Fruits and Vegetables: Application to a Swiss Retailer. ETH Zurich, Institute of Environmental Engineering, CH-8093 Zurich.

[10] Mangaraj, S., Goswami, T. K., & Mahajan, P. V. (2009). Applications of plastic films for modified atmosphere packaging of fruits and vegetables: a review. *Food Engineering Reviews*, *1*(2), 133

[11] Sothornvit, Rungsinee and Kiatchanapaibul, Peeriya. (2009). Quality and shelf-life of washed fresh-cut asparagus in modified atmosphere packaging. *Food Science and Technology*, 42, 1484-1490.

[12] Spada, A., Conte, A., & Del Nobile, M. A. (2018). The influence of shelf life on food waste: A model-based approach by empirical market evidence. *Journal of Cleaner Production*, *172*, 3410-3414.

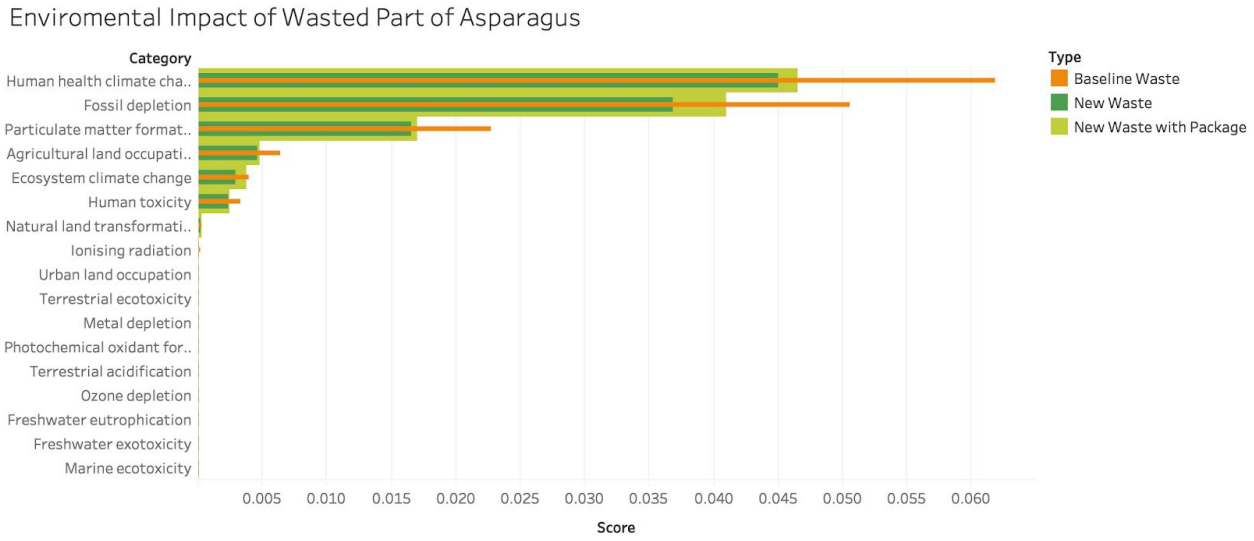
environmental impact. Because bell peppers' shelf life was not extended at all by the addition of MAP, we assumed that no waste was avoided.

Now, we have the original and the new environmental impact profile of the wasted produce. The last step was to add the impact from the MAP to the new profile, and compare it with the original. If the new impact and the MAP impact is less than the original impact, the application of MAP improves the overall environment performance for the produce.

So, Is MAP Worth It?

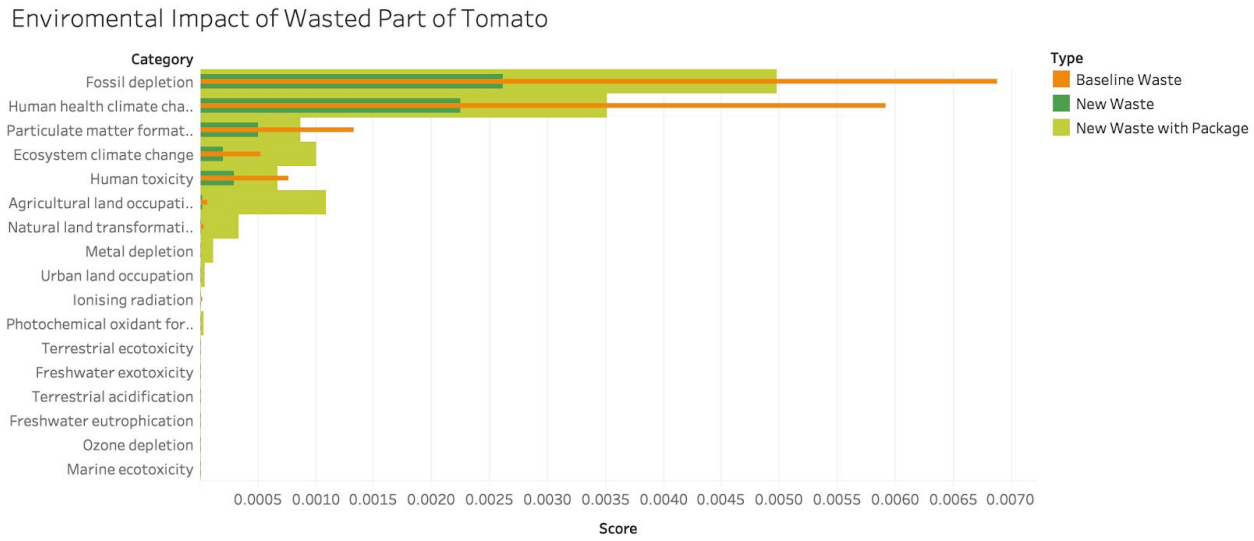
Interestingly, our results tell different stories depending on the produce.

MAP for asparagus is definitely a winner. With the extended shelf-life, asparagus with MAP has less impacts across all environmental categories. The biggest improvement is climate change's impact on human health, followed by fossil fuel depletion and particulate matter formation. It seems that if the packaging is disposed of properly, we can enjoy the benefits of extended shelf-life and be (relatively) environmentally-friendly at the same time.



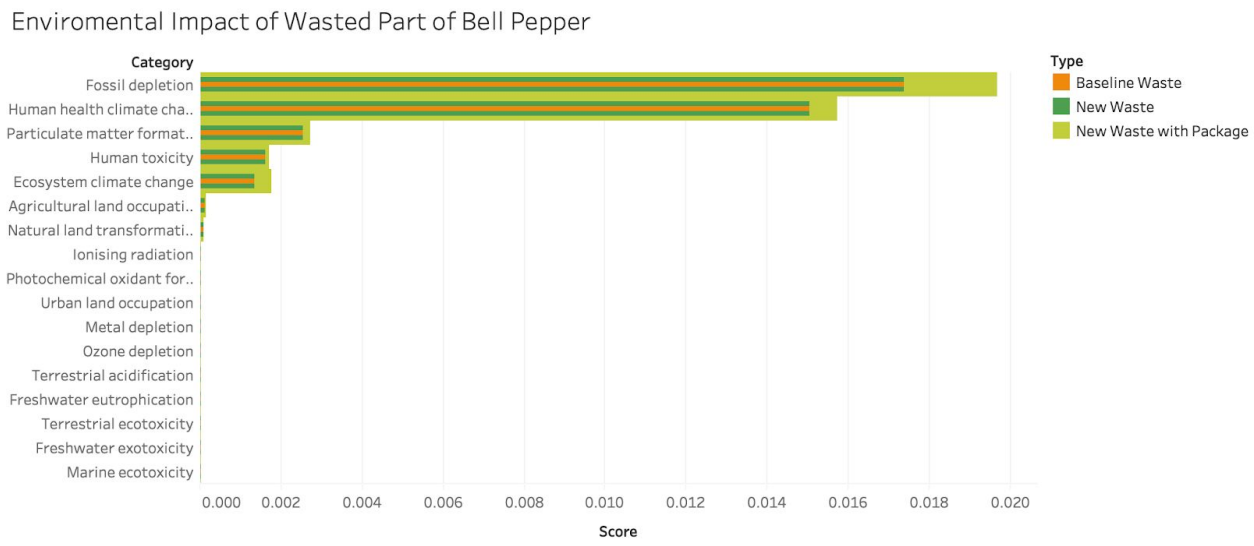
The situation is not as straightforward for vine-tomatoes, but our results suggest that MAP is the best option. Vine-tomato with MAP has a better performance in the same major categories as asparagus - climate change's impact on human health, fossil fuel depletion, and particulate matter formation. However, because of the cardboard box in the package, adding MAP to vine-tomato will use more agricultural land and accelerate natural land transformation. If you

think about it, only a simple cardboard box (which might not have any functional necessity for vine-tomato) in the bag could contribute to food insecurity and deforestation[13]. Yikes!



Now to the bell peppers. Nature gives these sweet and spicy guys superhero powers to stay fresh for a long time. Okay, that might not be a superhero power in the conventional sense, but for a piece of produce, we think it is! Therefore, packaging long-lasting produce like bell peppers is a pure waste of resources. After adding MAP, bell peppers' environmental performance decreases across all categories. Next time you're in the grocery store, remember to pick the naked ones!

[13] The State of the World's Forests 2016: Forest and Agriculture: Land Use Challenges and Opportunities. UN FAO.



There are a few limitations with our analysis, so like any preliminary analysis, these recommendations require further research. While our study assumes that waste only occurs at the retail level, impacts at other stages in the supply chain are undoubtedly important and may vary depending on whether or not MAP is used. A reduced shelf life can have effects on land use that are not necessarily considered here, and a longer shelf life can potentially reduce some pressure on agricultural land use due to changes in consumer behavior. A longer shelf life can also influence supply chain distribution and logistics, such as transporting the produce by slower but more environmentally-friendly methods, which doesn't necessarily extend the benefit to the consumer, and can lead to a different outcome in life cycle impact. Lastly, An increased shelf life can extend the market reach of the product to other parts of the world where it was not previously available, which could potentially increase the environmental impact of the produce ultimately. All of these outcomes were difficult to consider and include in our analysis, but would be worth looking at in more detail.

Tradeoffs - Such is Life

Undoubtedly there are many tradeoffs of whether or not to use MAP. MAP may reduce the aforementioned environmental impact categories when considering the offset produce waste, but there are others not considered in this life cycle assessment. For instance, not all of the packaging ends up in landfills like we assumed. Since plastic is quite light, it can easily transport by wind and end up in the ocean. What, then, are the environmental consequences to the ecosystems that endure this pollution? Similarly, what if we gave microplastic pollution a stronger weight or

influence in our model? In this case, the costs of introducing more plastic to our food system could potentially outweigh the benefits of a longer shelf life.

YUM, Alternatives are on The Menu!

Luckily we may be able to have our cake (or asparagus, or bell pepper, or vine-tomato) and eat it too! There are new ways of extending the freshness of produce through plant-derived coatings. Apeel Sciences, a food technology startup based in Goleta, California, is addressing food waste through extending the shelf life of produce with a plant-derived coating. According to Apeel, their agricultural solution is inspired by nature. This might be the solution we're looking for to reduce food waste while also reducing plastic usage in our food systems. Hooray, it's a win-win!