Five Misperceptions Surrounding the Environmental Impacts of Single-Use Plastic

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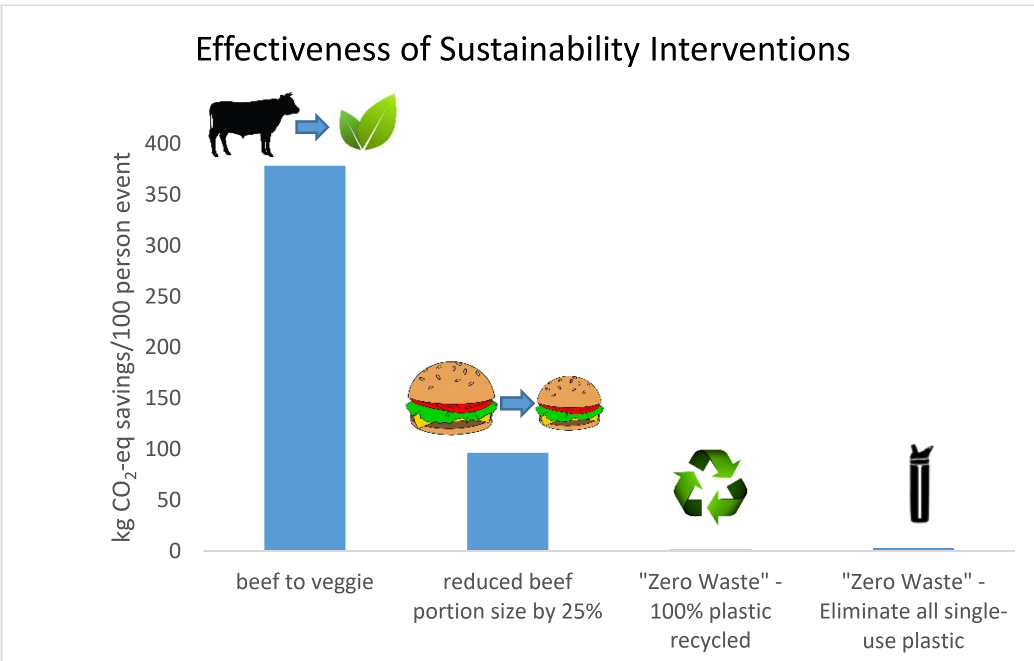

Abstract

This article explores five commonly held perceptions that do not correspond with current scientific knowledge surrounding the environmental impacts of single-use plastic. These misperceptions include: 1) plastic packaging is the largest contributor to the environmental impact of a product; 2) plastic has the most environmental impact of all packaging materials; 3) reusable products are always better than single-use plastics; 4) recycling and composting should be highest priority; 5) "zero waste" efforts that eliminate single-use plastics minimize the environmental impacts of an event. This paper highlights the need for environmental scientists and engineers to put the complex environmental challenges of plastic

waste into better context, integrating a holistic, life cycle perspective into research efforts and discussions that shape public policy.

Introduction

Major efforts across the globe are seeking to address our single-use plastics problem and resulting ecological damage. It is essential that the scientific community takes a larger, system-level view to appropriately contextualize the problems of plastic waste, combat common misperceptions, and ensure that the best scientific knowledge is represented in discussions surrounding potential initiatives to reduce the environmental impacts of plastic and plastic waste.

Focusing sustainability efforts on reducing visible impacts such as solid waste generation can detract focus from less visible, and often more damaging, environmental impacts associated with energy use, manufacturing, and resource extraction. Well-intentioned efforts that are focused primarily on plastic reduction usually demonstrate only marginal improvements in the total environmental impacts associated with consumer products. As this paper shows, efforts to reduce single-use plastic may distract from larger environmental issues, or worse, result in even greater environmental impacts due to unintended consequences. Scientists need to expand the conversation beyond its current focus on single-use plastic reduction toward a more holistic approach to minimize total environmental impacts of products throughout their supply chains.

The Plastic Waste Problem

The ability to manipulate and use natural gas distillates to create various forms of plastic has brought about one of the greatest shifts in material transitions of our society[1]. Inexpensive, versatile plastics have created a shift from durable, reuseable materials to single-use disposables. The majority of single-use plastics take the form of packaging, as well as once-through products such as plasticware for dining and single-use medical equipment.[2]

Plastics that are properly captured and disposed through municipal solid waste systems pose minimal risk to ecosystems; however, plastics that enter ecosystems through mismanagement and "leakage" can pose physical and chemical hazards to wildlife.[3] There are growing concerns about how improperly disposed plastics are degrading ecosystems, with particular concerns surrounding damage to marine ecosystems and the adverse ecological effect of microplastics.[4] It is estimated that 4.8-12.7 million MT of plastic can enter marine ecosystems in a given year.[5] Major policy efforts across the world are underway to reduce the use of single-use plastics, such as adoption of plastic bans or fees associated with the use of single-use plastics.[6] There has been some evidence that recently implemented policies to reduce single-use plastics have already had unintended consequences of environmental problem-shifting,[7,8] highlighting the importance of a holistic approach.

While some in the scientific community have argued that the health risks to ecosystems from plastics are overstated,[3,9] this article is not meant to downplay the environmental concerns associated with plastics and plastic wastes. Nevertheless, a broader suite of impacts that extend throughout the supply chain should be considered and balanced against the direct physical and chemical ecosystem hazards of plastic waste.

Life-Cycle Thinking for Evaluating Plastic Systems

Life cycle assessment (LCA) is a tool to systematically evaluate the environmental impacts that occur throughout the entire supply chain of a given product from resource extraction to ultimate disposal or reuse.[10] LCA quantifies the environmental impacts of products on the basis of multiple environmental impact categories, which can include various metrics associated with climate change, acidification, eutrophication, energy use, water and resource depletion, solid waste generation, ozone depletion, smog formation, human and ecological toxicity, land use, as well as other impact categories.[11] Due to data availability, many studies select a subset of impact categories to analyze. For the purposes of this paper, environmental impacts broadly refers to the range of impacts reported by the reviewed study of interest.

Life cycle thinking encourages a holistic perspective, taking into account multiple different environmental impacts that occur at every stage of the supply chain of a product. One of the major purposes of conducting an LCA is to avoid environmental problem shifting, or solving one environmental issue only to cause another. LCA systematically evaluates the entire supply chain in order to appropriately include environmental impacts that may be overlooked yet still have a major influence on the overall environmental profile of a product. As an example, Figure 1 depicts various environmental impacts associated with a packaged food product. The environmental impacts that are visible to the consumer include only those associated with the use or disposal phases of the product. Meanwhile, there are a wide range of environmental impacts that are largely invisible to the consumer, including those associated with intensive agricultural production, energy generation, refrigeration and transportation throughout the supply chain, and the processing and manufacturing associated with food and packaging.[12]

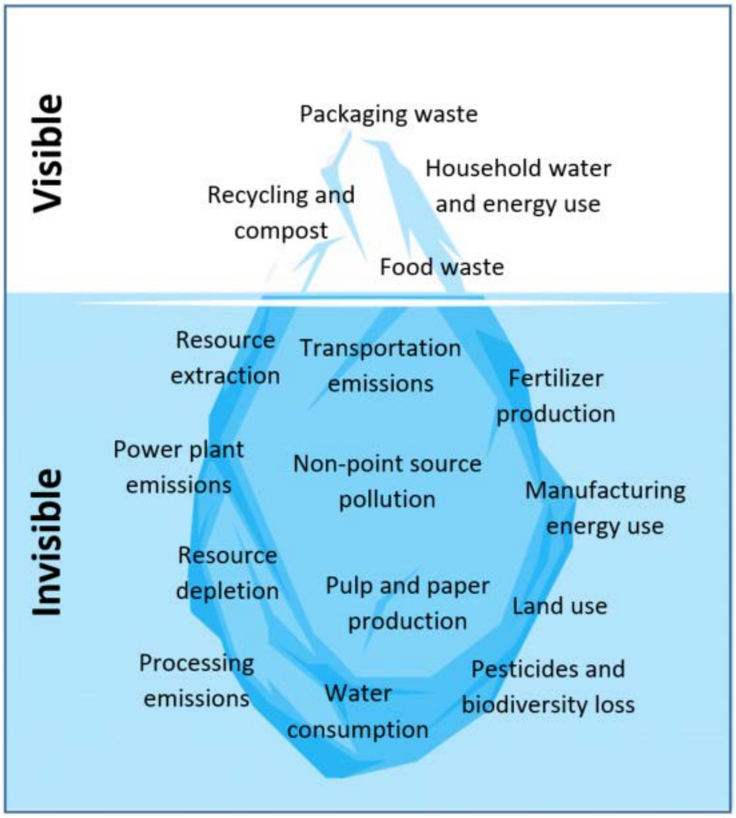

Figure 1. Examples of visible and invisible environmental impacts of a packaged food product from a life-cycle perspective.

The adage to "Reduce, Reuse, Recycle", commonly known as the 3Rs, was created to provide an easy-to-remember hierarchy of the preferable ways to reduce environmental impact.[13] Most environmental messaging does not emphasize the inherent hierarchy of the 3Rs and consumers often over-emphasizes the importance of recycling packaging instead of reduced product consumption.[14,15] At the highest priority, the 3Rs encourage reducing consumption to the extent possible. When it is not possible to reduce consumption, reuse items to extend their useful life. Finally, when neither reduction nor reuse are possible, materials should be recycled to recover valuable materials and prevent depletion of additional resources.

Although the 3Rs are one of the greatest successes in environmental education and communication, the 3Rs are rooted in a focus on solid waste reduction rather than promoting life cycle, systematic thinking about environment and sustainability issues. Given packaging's ubiquity and volume, it is not surprising that consumers and environmentalists alike have given major attention to reducing packaging and its resulting environmental damages. Focusing environmental efforts on reducing visible impacts such as solid waste generation associated with plastic waste can distract focus from the impacts of climate change, ecotoxicity, biodiversity loss, and resource depletion that occur upstream in the supply chain and are largely invisible to the consumer. This paper highlights five common misperceptions that seem to have arisen from the focus on reducing solid waste and reviews insights gained from taking a broader view of life-cycle thinking.

Misperception #1: Plastic packaging is the largest contributor to the environmental impact of a product

LCA Insight: The product inside the package is usually responsible for greater environmental impact than the packaging.

On a life cycle basis, the resource extraction, manufacturing, and use phases of a product generally dominate the environmental impacts of most products, whereas the production of packaging and packaging disposal often represent only a few percent of total life cycle impact.[12,16] Meanwhile, studies have shown that consumers' perceptions of environmental impacts do not correspond with scientific evidence, and consumers tend to focus on the impact of the packaging rather than the impact of the product itself.[17,18] Further, consumer perception regarding the environmental friendliness of packaging influences their perceptions of the environmental attributes of the product inside.[19]

Food systems are one of the dominant sectors for the use of single-use plastics. Due to the environmental intensity of agricultural production, the environmental impacts associated with food production far surpass the environmental impacts of packaging.[12,20] Counterintuitively, increasing the amount of packaging can decrease total life cycle impact of a food product by reducing food waste via improved shelf life, quality, and freshness of perishable foods.[21] This is particularly true for environmentally intensive foods such cheese, high breakage rate items such as eggs, or high spoilage items such as bread.[22] In such cases, the package's ability to protect food against loss or spoilage tends to avoid greater environmental impacts than those incurred by the production of the actual packaging material.[18,21,23,24]

A number of LCA studies show that when compared to their traditional counterparts, consumer products that reduce food waste and energy use tend to have lower aggregate greenhouse gas (GHG) emissions, despite generating a higher quantity of solid waste through single-use plastic packaging. For example, a study on coffee pods showed that the use of coffee pods could have lower environmental impacts than coffee brewed via traditional drip coffee makers.[25] Similarly, a study on direct-to-consumer meal kits showed that the meal kits had fewer greenhouse gas emissions than the same meals purchased at a grocery store, despite having greater amounts of packaging.[26]

Misperception #2: Plastic has the most environmental impact of all packaging materials

LCA Insight: Plastic is often responsible for fewer environmental impacts than many common packaging materials

Literature has shown that consumers' perceptions of the environmental impacts of packaging are largely based on intuition and do not necessarily correspond to actual environmental impact.[27] Consumers tend to rate plastic as more environmentally harmful compared to other types of packaging, regardless of the actual environmental attributes of the materials.[17,18,27] Although individual packaging systems can vary, LCA studies have shown plastic generally has lower environmental impacts than single use glass or metal in the majority of environmental impact categories measured.[17,28,29] When compared to single-use paperboard cartons, the relative environmental impacts of plastic containers are mixed and largely depend on the specific product as assumptions within the study.[30–32] The smaller emissions burdens associated with plastics are largely due to less materials needed for effective packaging performance, lower transport emissions due to lower mass, and lower energy and material associated with the production of plastic relative to other materials. The misperception of the relative environmental impacts of plastic is particularly important to recognize given potential environmental problem-shifting as consumers adopt substitutes with less favorable attributes, which has been shown to occur as a result of plastic bans.[33]

An increasing trend to substitute single-use plastic packaging with single-use glass-based packaging is particularly troublesome from a life cycle energy and GHG perspective. When comparing the relative environmental impacts of single-use glass and plastic, plastic has been shown to be significantly better in terms of energy use, greenhouse gas emissions, and multiple other environmental impact categories.[17] Glass containers are a higher energy-intensity material to produce and are significantly heavier than their plastic counterparts, increasing associated transportation emissions.[34] Recycling of glass can also be problematic, since it is logistically and energetically prohibitive to remanufacture into new glass product.[35] Reclaimed glass is increasingly used as aggregate in construction materials in order to avoid high energy recycling operations.[36] It should be noted that substituting reusable, refillable glass bottles for single-use plastic is likely to offer environmental benefits, although these results vary depending on a number of assumptions regarding the actual reuse rate of the bottles.[37]

Even though plastic outperforms glass on a wide variety of impact categories, there are tradeoffs in chemical exposure associated with plastic food packaging[38,39] that are not often taken into account within LCA studies due to lack of data. In light of concerns about chemical leaching and plastics, substitution of paperboard packaging may be a superior alternative than glass.[30–32]

Misperception #3: Reusable products are always better than single-use plastics

LCA Insight: Reusable products have lower environmental impacts only if they are actually reused a sufficient number of times to compensate for their greater materials intensity

Environmental efforts have consistently recommended reusable options over disposable items, and in the 3R hierarchy, reuse is preferable to recycling.[13] Life cycle studies have shown that the debate between reusable and disposable products is complex and depends on the specific products being evaluated.[40–42] Although reusable alternatives can have lower environmental impacts than their single-use plastic counterparts, the benefits are often contingent on the assumption that the reusable product are actually reused, and usually reused a large number of times. If the reusable product is not reused a large enough number of times to compensate for its greater materials intensity, the single-use, disposable option may be environmentally preferable.

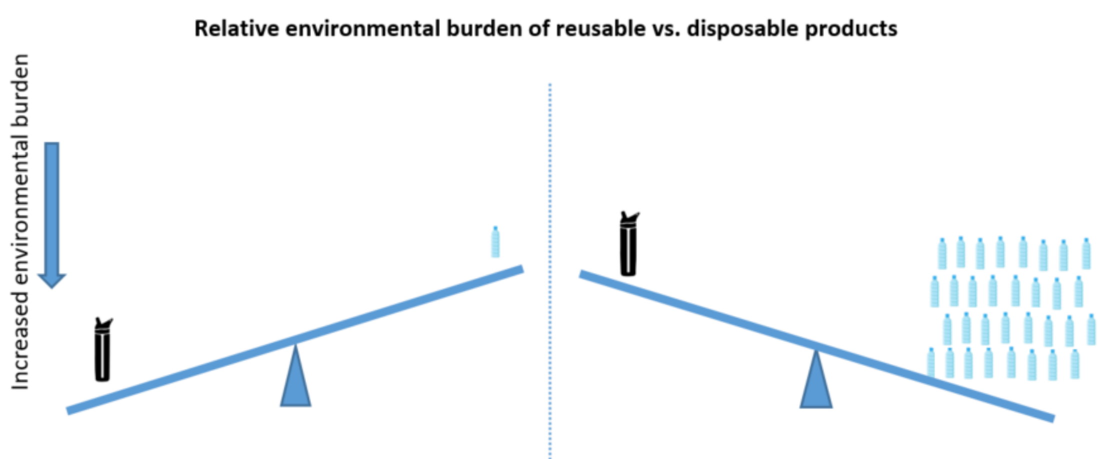

Figure 2. Conceptual diagram showing the material intensity of reusable versus single-use water bottles. Reusable bottles offer greater environmental benefits only after they have displaced a sufficient number of disposable alternatives.

Most reusable products are designed for a relatively long product lifetime compared to disposable alternatives. Because the product must last, reusable alternatives must be made of more durable materials than single use options and generally require more material overall to make. Meanwhile, single-use plastics are easy to manufacture, can often perform a required function with very little material use, and are responsible for low manufacturing and transportation emissions. At the same time, the upstream emissions for the reusable option occur once, whereas upstream emissions occur every time another disposable item is produced. The reusable option must be used a sufficient number of times to payback the costs of the additional upstream environmental impact burden. Figure 2 depicts the conceptual rationale for needing to reuse a reusable product a large number of times in order to break even. In addition to upstream emissions, some reusable products incur significant use phase emissions, such as the environmental impacts associated with washing the item. When taking into account dishwashing impacts, it can take longer for the reusable option to break even with the disposable option or potentially not break even at all.[43–45]

A study by the Dutch Environmental Protection Agency on reusable grocery shopping bags investigated the number of uses required for reusable grocery bags to break even when compared to single-use low-density polyethylene plastic alternatives.[46] Assuming a weekly shopping trip, a reusable polymer bag would need to be used by a consumer 1-8 weeks before the relative GHG emissions for the reusable bag was less than the single-use plastic alternative, and 9-21 months before it became environmentally preferable in all measured impact categories, which included resource depletion, human toxicity, and a variety of impacts associated with air and water pollution. A conventional cotton grocery bag was estimated to need to be reused for 2.9 years to payback the GHG emissions associated with the upstream impacts of cotton agriculture and processing and 137 years of weekly shopping trips (i.e. 7100 uses) for all environmental impact categories. The payback for organic cotton was even worse. This example highlights the need to pay careful attention to the material intensity of reusable products and emphasizes that the default assumption that reusable is always better can be flawed.

The environmental payback associated with reusable products should not be seen to suggest that reusable alternatives should not be promoted to displace single use plastic options. Nevertheless, it can be easy for consumers to fall into a reusability trap, perceiving reusable items to being preferable to disposable items, but not actually using the reusable product the requisite number of times to actually achieve an environmental benefit. Responsible reuse on the behalf of the consumer is necessary in order to make reusable products environmentally beneficial. A worst-case scenario option can be created when more durable and material intensive products get treated as semi-disposable after only a couple of uses. As one example, replacing reusable water bottles every few months due to consumer preference or loss is a scenario where greater environmental impacts are likely to occur, despite the perception of environmental improvement.

Misperception #4: Composting and recycling should be highest priority

LCA Insight: The environmental benefits associated with recycling and composting tend to be small compared to efforts to reduce overall consumption

When consumers are asked what makes a package sustainable, the most frequent choices are recyclability, compostability, and recycled content rather than considerations of upstream environmental impact or functional ability to protect a product.[17,27] In terms of the 3Rs, “Recycle” is the least effective strategy and should only be deployed when “Reduce” and “Reuse” options have been exhausted.[13] The environmental benefits associated with recycling are contingent upon virgin resources being displaced. Due to recycling losses and degradation of material quality during recycling, recycled material will never be able to fully offset the environmental impacts associated with production. Therefore, reduction in materials consumption is always preferable to recycling, since the need for additional production is eliminated.

The environmental benefits of recycling stem from the assumption that a recycled product can be made using fewer new materials and energy than a virgin product; however, that is not universally true due to energy use and material loss throughout the recycling process.[47] Nevertheless, recycling does usually offer the advantage or reducing the amount of virgin materials and energy required to make a new product.[48] The overall benefit of recycling is variable according to a variety of assumptions with respect to material and energy recovery.[49] One prior study has shown that the energy requirement associated with recycling plastic is 26-44% less than the energy requirement of creating virgin plastic.[50] while another found that benefit to be 40-85%, with a GWP savings of 25-75% over virgin material.[51] Meanwhile, a recent analysis suggests that the benefits of recycling are often overstated, and that actual displacement of virgin material is less than often reported.[48]

Beneficial recycling efforts can be undermined by the availability of functioning recycling markets. Without viable markets for secondary materials, plastics that are collected via recycling efforts may ultimately end up in a landfill. For example, China’s recently implemented ban on importation of plastic waste has significantly disrupted the capacity of global recycling channels. Without significant changes to recycling practices in domestic markets, much of the plastic collected for recycling is likely to be landfilled.[52]

This article does not suggest that recycling is without benefits, but highlights that recycling efforts are not the panacea that many consumers assume. Recycling definitely has a place in reducing the environmental impacts of products and helping to create a circular economy. But recycling does not erase any of the upstream impacts incurred throughout the resource extraction and manufacturing stages of the product. The benefits of recycling are confined to reduction of further material depletion and energy use, to the extent that virgin materials are displaced with recycled materials [48] .

Similar to recycling, consumers also see composting as highly beneficial. Composting provides an alternative end-of-life option to landfilling, although composting also does not eliminate any of the upstream environmental impacts associated with resource extraction and manufacturing of a product. This article focuses on examining the benefits of biodegradable plastic in the context of overall plastic waste reduction. Discussion of the merits of composting food waste and other biodegradable products is outside the scope of this article. There are logistical benefits to co-composting biodegradable plastics with food waste, the food waste is ultimately the more important driver to improved environmental impact than compostable plastic packaging.[53]

One of the major potential advantages to biodegradable plastic is the potential to reduce ecological damage due to improper disposal of plastic waste leading to physical damage of organisms. In addition, when biodegradable plastic is made from biomass, there is also a common sentiment that a renewable feedstock is inherently environmentally favorable than a fossil-based feedstock [54]. The reality of biodegradable plastic does not often live up to consumer perception of the potential benefits. There have been many studies that study the environmental impacts of bio-based plastics relative to fossil-based plastics. Although results can vary greatly on assumptions related to producing biomass and the specific products studied, a critical review indicated that there is no definitive evidence to suggest that bio-based plastics have a lower overall environmental footprint.[55] In addition, biodegradable plastics only degrade under very specialized conditions and may not help reduce physical damage associated with improper disposal of plastics leaked to the environment.[56–58] Biodegradable plastics are therefore unlikely to naturally degrade in marine environments that are of primary concern. In addition, lack of ability to differentiate between compostable and recyclable products among consumers could contaminate recycling streams with greater amounts of bioplastic, undermining recycling efforts.[54]

Finally, when comparing end-of-life options, composting plastic has a worse energy and GHG emissions profile than landfilling, incineration, recycling, or anaerobic digestion these materials.[44,59]

While this result may seem counter-intuitive, composting plastics releases carbon into the atmosphere in the form of GHG emissions. Other end-of-life mechanisms such as incineration and anaerobic digestion also release the carbon contained within the product, but are able to convert the product into usable energy while doing so. Meanwhile, landfilled and recycled biodegradable plastic allows the carbon to remain in a solid state without gaseous emissions, and recycling has the advantage of reduced materials and energy associated with displacing virgin material.

In summary, recycling and composting efforts have some value, but ultimately, mindful consumption that reduces the need for products and eliminate wastefulness, reducing the intensity of the supply chain, and trying to design products that will actually be reused by the consumer are more effective at reducing overall environmental impact. Nevertheless, it is fundamentally easier for consumers to recycle the packaging of a product rather than voluntarily reduce demand of that product,[60] which is likely one reason why recycling efforts are so popular.

Misperception #5: "Zero waste" efforts that eliminate single-use plastics minimize the environmental impacts of an event

LCA Insight: Well intended zero waste initiatives have the potential to create additional environmental impacts if not designed for holistic reduction of environmental impacts. Mindful consumption, waste reduction, and the types/amount of products consumed are larger factors dictating the environmental impact of an event, whereas the benefits of diverting waste from landfill are relatively small.

"Zero waste" events tend to focus on minimizing or eliminating the amount of material that goes to landfill at an event. These events often substitute compostable materials for single-use plastic alternatives and/or making extensive use of recycling, with clearly designated receptacles for both waste disposal methods. Despite good intentions, zero waste events may not ultimately meet intended goals of reducing environmental impact. In addition to diverting attention from overall environmental impacts associated with the event, they can run the risk of having a greater overall environmental impact than a traditional event.

Well intentioned interventions to divert waste to landfill can backfire. For example, event organizers may fall into the reusability trap (See Misperception #3), where "durable" goods are given out during the event to eliminate the disposal of single-use materials. While these giveaways may reduce landfill waste at the actual event, these reusable options only result in an environmental benefit if they are consistently used by participants post-event, at a frequency that will pay back the increased amount of materials needed to create the reusable product. Reusable giveaways that are not of sufficiently high quality to incentivize repeated use post-event are particularly troublesome, since a product that is intended for repeated use is essentially transformed into a materially-intensive single-use product. Similarly, if participants accumulate more reusable products than they can effectively use (i.e. cupboards filled with reusable water bottles), it will create additional environmental burden through manufacturing that exceeds the impact associated with single-use products. This unintended consequence at zero waste events can be avoided by encouraging participants to bring their own existing reusable alternatives to events rather than broad dissemination of reusable giveaways that may not actually be reused.

Even if a zero waste event does not increase environmental impact, zero waste events can be problematic by potentially misleading participants into believing an event is zero or low impact. In practice, diverting waste from landfill only has a marginal effect on the overall environmental impact of an event (See: Misperception #4). A prior analysis of zero-waste events in collegiate sports found that zero waste strategies that focused on composting and recycling were significantly less effective at reducing environmental impacts when compared to reduction of edible food.[61] Zero waste events that focus only on end-of-life considerations by relying on compostable/biodegradable items will yield only minimal improvements over a traditional event, unless there are simultaneous efforts dedicated to reducing overall consumption and reduced environmental intensity of the services provided at the event.

As a thought experiment to put zero waste events into perspective, some simple scenarios can be explored using a hypothetical 100 person cookout that traditionally serves 1/3 lb hamburgers and bottled water. The organizers of the event consider 4 basic options to improve environmental impact: 1) Continue to serve bottled water and recycle all bottles; 2) Eliminate single-use plastic by providing water coolers and having participants bring reusable bottles; 3) Reduce portion sizes of beef burgers to be ¼ lb burgers; 4) Substitute black bean burgers for beef burgers. Beyond the specific interventions, it is assumed that nothing else changes in each scenario. Through this simplified thought experiment, we can see the relative importance of the various interventions in Table 1 and Figure 3.

	Emission factor (kg CO2-eq/kg product)	Mass of product (kg product/person)	GHG Impact per person (kg CO2-eq/person)
beef	26.6	0.15	3.86
black beans	0.51	0.15	0.077

beef (reduced portion)	26.6	0.113	2.89
Plastic (landfilled)	2.4	0.013	0.030
Plastic (recycled)	1.2	0.013	0.016

Table 1. Emissions factors and masses of beef, black bean, and plastic used for thought experiment. Data obtained from [62]

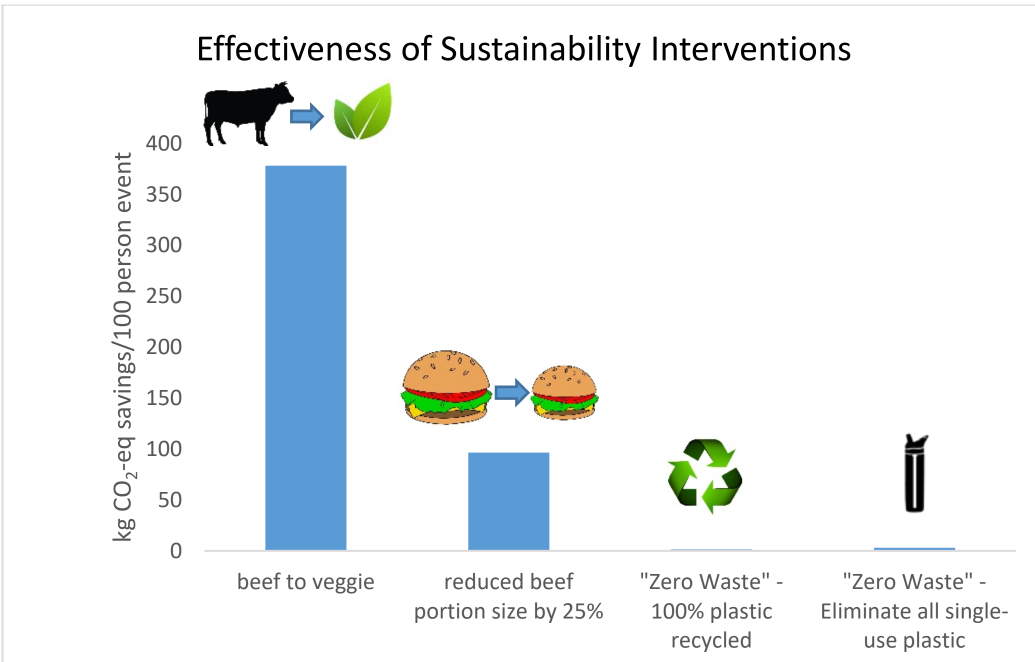

Figure 3. GHG emissions reductions associated with 4 scenarios in a hypothetical 100-person event that serves 1/3 lb beef burgers and 16 oz. bottled water, based off the data in Table 1. Beef to veggie scenario is the difference between 100 beef and 100 bean burgers. Reduced portion size scenario is 75% of 100 beef burger impacts. Recycled plastic scenario is the difference between 100 landfilled and recycled plastic bottles. Single-use plastic elimination scenario is 100% of 100 landfilled bottles.

As shown in Figure 3, the zero waste interventions of recycling or eliminating all plastic (1.4 and 3.0 kg CO_2-eq/100 person event, respectively) are orders-of-magnitude less effective at reducing GHG emissions than interventions that reduce or eliminate the consumption of environmentally-intensive foods (96 and 380 kg CO_2-eq/100 person event for 25% reduction in beef portion and substituting beans for beef, respectively). This thought experiment underscores the importance of putting environmental impacts associated with single-use plastics into perspective and taking a more holistic approach. The interventions to eliminate single-use plastic to landfill do result in improved environmental outcomes; however, a focus on reduction of landfill waste can distract from other more significant steps that event organizers can take to reduce environmental impacts. Organizers who choose to select lower intensity proteins, reducing the portion sizes of environmentally intensive foods, and taking steps to significantly reduce or eliminate food waste are all likely to result in greater environmental benefits than focusing on diverting solid waste from landfill.[21,63]

Shifting environmental impact communication toward systems-level impacts

As this paper has shown, an emphasis on the reduction of solid waste as a sustainability strategy fails to address the full spectrum of environmental issues that occur prior to consumption. Single-use plastics are a visible and tangible symbol of the larger environmental issues associated with over-consumption of resources. Although the use of single-use plastics has created a number of environmental problems that need to be addressed, there are also numerous upstream consequences of a consumption-oriented society that will not be eliminated, even if plastic waste is drastically reduced.

The five misconceptions identified in this paper emphasize the need for the environmental science and engineering communities to promote systems thinking when discussing environmental impacts. Placing plastic waste in its appropriate context is the first step toward improved scientific communication of environmental impacts. In addition, scientific communication needs to move well beyond "Reduce, Reuse, Recycle" to help the public draw connections between consumption of products, energy use, and the upstream environmental effects such as ecosystem damage and climate change that are not as obvious as the visible reminder of solid waste. In addition, policies to reduce single use plastics should be carefully thought through, using the best known evidence from environmental science, life cycle assessment, and behavioral science in order to reduce potential for environmental problem shifting.

This paper is not intended to be an argument against efforts to reduce the impacts of single-use plastics. Improved recycling, circular economy, and zero waste events are necessary steps toward sustainability. If sustainability efforts are intended to be truly impactful, organizations need to think systematically about overall energy and materials consumption.

While misperceptions about single-use plastic are real, it will be important for the environmental community to harness the enthusiasm associated with single use plastic reduction to take a more holistic viewpoint. The impacts of plastic waste pollution are able to be captured through visceral images of damages to wildlife and voluminous piles of material, capturing public attention and support for actions to reduce plastic waste.[64] Plastic waste reduction has a variety of fairly straightforward potential solutions that are feasible and reasonable that do not necessarily require wholesale changes to human behavior.[65]

Efforts to reduce plastic waste should not be an endpoint, but rather, help initiate broader conversations to create a more informed public and leverage public interest in single-use plastic reduction for greater environmental improvement.

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