American Chemistry Council

TRUCOST

Plastics and Sustainability:

A Valuation of Environmental Benefits, Costs and Opportunities for Continuous Improvement

Prepared By Trucost
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Credits

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About Trucost

Trucost helps companies and investors to achieve success by understanding environmental issues in business terms. Our data-driven insights enable organizations to manage risks and identify opportunities for growth.

We are the world's leading experts in quantifying and valuing the environmental impacts of operations, supply chains, products and financial assets. By putting a monetary value on pollution and resource use, we integrate natural capital into business and investment decisions.

With offices in Europe, the US and Asia, Trucost works with businesses worldwide to increase revenues, improve communications, meet marketplace expectations and comply with regulatory requirements.

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The work was performed by Trucost as an independent contractor. The findings and conclusions are strictly those of Trucost. Trucost makes no statements nor supports any conclusions other than those presented in this report.

Legal Statement

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Executive Summary

Objectives

Global production of plastics has grown 20 fold from 15 million metric tons (Mt) in 1964 to 311 Mt in 2014 (Plastics Europe, 2015), with plastics becoming ubiquitous across almost all facets of the economy. With its ever-expanding applications, plastics have delivered many benefits for society. Plastic packaged food lasts longer, reducing wastage. Use of plastic in pipes facilitates clean drinking water supplies, while plastic enables life-saving medical devices such as surgical equipment and drips. Due to its light weight, plastic use in vehicles has reduced carbon dioxide emissions from transport (Andrady & Neal, 2009).

However, as the use of plastic in modern society has increased, so too have the environmental impacts associated with its production and disposal. Trucost research for UNEP in 2014 highlighted the environmental costs of plastic use in consumer products, including emissions of greenhouse gases, air, land and water pollutants, depletion of water and the production of marine debris in the global oceans (UNEP, 2014). These environmental costs have prompted some to argue that plastics should be replaced with alternative materials, which may present fewer environmental challenges. However, recent studies by Franklin Associates (2013) and Denkstatt (2011), which modeled the substitution of plastic with alternative materials (such as paper, steel, aluminum and glass), suggest that a move away from plastics may come at an even higher net environmental cost.

This study seeks to build upon this research using Trucost's natural capital valuation framework to value the environmental costs of plastic and its alternatives, and consider how more sustainable practices could help reduce the environmental costs of plastic use in the consumer products sector.

Specifically, this study aims to:

- Quantify the environmental cost of plastic used in the consumer goods sector and compare this with a hypothetical scenario in which most plastic used in consumer products and packaging is replaced with a mix of alternative materials that serve the same purpose.
- Map the environmental costs of plastic and alternative material use across the value chain, geographic regions and consumer goods sub-sectors, to help target interventions to improve sustainability at key points where the greatest benefits can be achieved.
- Identify those sectors exposed to the greatest environmental risks if plastic were replaced with alternatives.
- Quantify the potential environmental benefits of strategies to further improve the sustainability of plastic use, such as more efficient packaging design, improved waste collection and material and energy recovery systems, and increasing low-carbon energy use in the plastics manufacturing sector.
- Provide recommendations for the plastic manufacturing sector on ways to reduce the environmental costs of plastics.

Methodology

The production, use and final disposal of most materials, including plastic and alternative materials, has a range of environmental and social costs that in most cases are not reflected in the market prices of goods and services. In order to enhance the sustainability of material use in the consumer goods sector it is essential that both the costs and benefits of different material options are considered. Applying environmental or 'natural capital' valuation techniques enables the measurement and communication of these environmental impacts in monetary terms. These costs can also be factored into business and investment decision making, policy setting and in considering tradeoffs between the implied costs and benefits of economic activity. In order to quantify the environmental costs associated with the use of plastic and alternative materials, a modeling methodology was designed which follows seven steps: 1) sector selection, 2) plastic use quantification, 3) substitution modeling, 4) scope and boundary selection, 5) impact quantification, 6) environmental valuation and 7) sensitivity analysis.

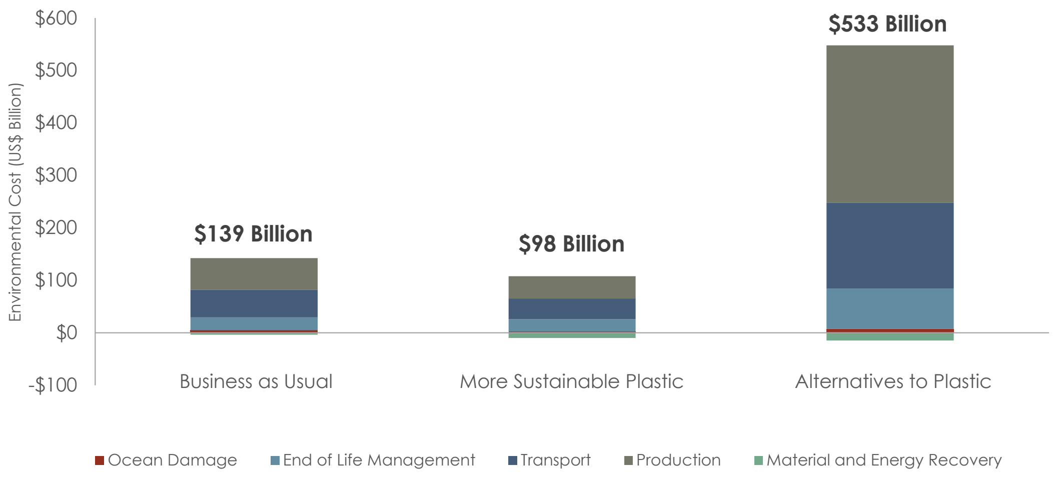
As with any innovative research, there are some limitations and not all aspects of the plastic and alternative material life cycle could be captured within the study. However, the methodology was designed to make use of the best available data and capture the most material impacts of plastic and alternative material use in consumer products.

Key Findings

The environmental cost of plastic in consumer goods is 3.8 times less than the alternatives materials that would be needed to replace plastic.

Although alternative materials such as glass, tin, aluminum and paper are viable alternatives to plastic in many consumer goods applications, they have higher environmental costs in the quantities needed to replace plastic. Trucost estimates that substituting plastic in consumer products and packaging with alternatives that perform the same function would increase environmental costs from $139 billion to a total of $533 billion. In most cases the environmental cost per kilogram of alternative material is less than that of plastic. However, on average over four times more alternative material is needed (by weight) to perform the same function. For example, a typical plastic soft drink bottle contains 30 grams of plastic. But if replaced by a weighted average mix of alternative materials currently used in the market, an equivalent capacity bottle would require 141 grams of alternative materials such as glass, tin or aluminum in the USA.[1] Extrapolating to the entire consumer goods sector, over 342 Mt of alternative material would be needed to replace the 84 Mt of plastic used in consumer products and packaging in 2015.

Figure 1: The Environmental Cost of Business as Usual Plastic, Alternatives to Plastic and a More Sustainable Plastic in Consumer Goods



Source: Trucost

The environmental cost to society of consumer plastic products and packaging was over $139 billion in 2015, equivalent to almost 20% of plastic manufacturing sector revenue, and is expected to grow (to $209 billion by 2025) if current trends persist.

This includes the costs imposed on society due to the impacts from greenhouse gas emissions; air pollution; land and water pollution; water depletion; ocean impacts and other costs created throughout the plastics value chain. These externality costs are equivalent to 20% of the plastic industry's total revenue in 2015 (IBIS World, 2015), and represent a serious risk to the future profitability of the plastics industry if internalized as business costs through increased regulation (for example, on carbon emissions) or through pressure from customers and communities concerned with the

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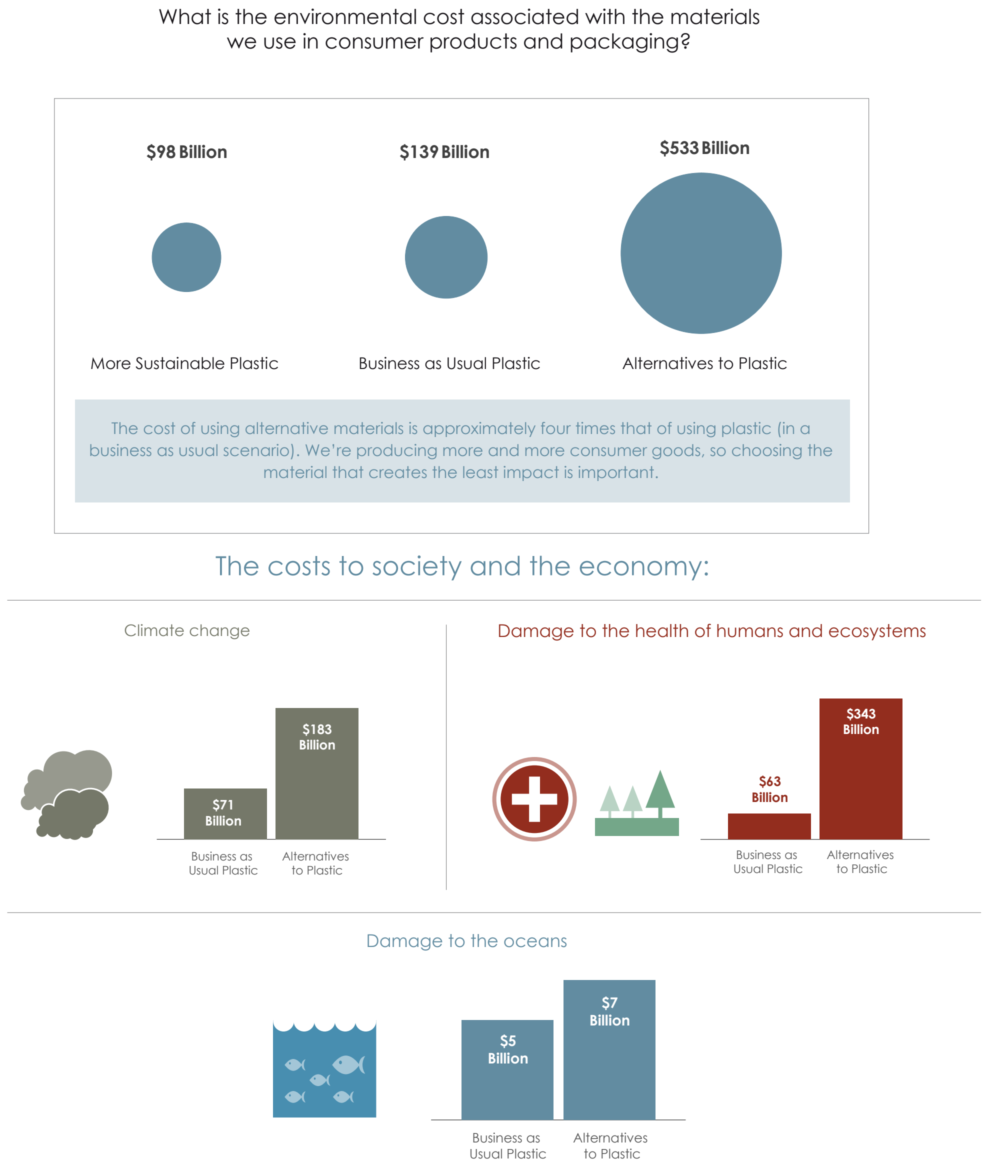
[1] Different quantities of each alternative material will be needed to replace plastic in each application. To simplify the presentation of this example, a weighted average of the substitution weights was calculated based on the current market shares of alternative materials in the beverage container market.

impact of plastic. Realization of external environmental costs as business costs threatens the profitability of the consumer goods sector, particularly in small margin and highly plastic dependent segments. Enhanced action by the plastics industry and consumer goods industry, along with governments, NGOs and consumers, is needed to address the environmental cost of plastics.

Will Replacing Plastic with Alternative Materials Reduce the Environmental Cost of Consumer Goods?



The cost of using alternative materials is approximately four times that of using plastic (in a business as usual scenario). We're producing more and more consumer goods, so choosing the material that creates the least impact is important.

All dollar values are in USD

Source: Trucost

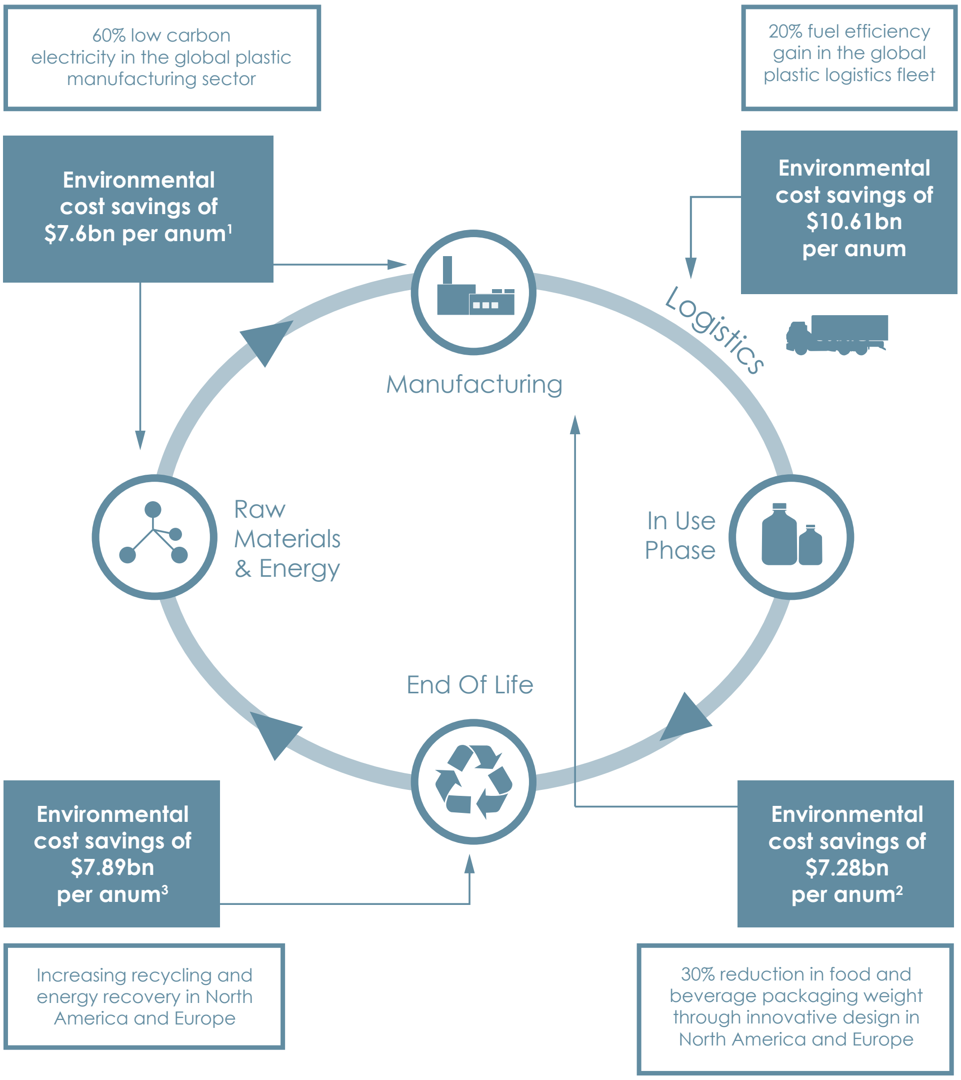
Production of plastic materials and their transport are the largest sources of environmental costs.

The total environmental cost of producing plastic materials for the consumer goods sector was over $60 billion in 2015, and the transport of these materials to market added a further $53 billion in environmental costs (totaling over $113 billion per annum). This suggests that the plastics manufacturing industry has significant opportunity to reduce the environmental costs of plastics through its operations and supply chains. For example, Trucost estimates over $33 billion in environmental cost savings could be achieved under the following intervention scenarios for the plastic manufacturing sector:

- $7.6 billion in environmental costs could be saved if the global plastics industry doubled its use of electricity from low-carbon sources such as wind, solar, and hydro power, or $15.2 billion with a switch to 100% low-carbon electricity.
- $7.3 billion in environmental cost savings could be made through if more efficient packaging designs could be developed in the food and soft drinks and ice sector that deliver the same packaging functions but require 30% less plastic.
- $10.6 billion in environmental cost savings could be achieved through a 20% improvement in the fuel efficiency of the vehicle fleet used to transport plastics, through technological change or modal shift toward lower emission transport modes such as rail. While not directly within the control of the plastics industry, changes to procurement policies with a preference for more efficient transport could aid in facilitating such improvements.

Additional interventions modeled in this study targeting improved waste management and recovery could increase these environmental cost savings to $41 billion, or 30% of the overall environmental cost of consumer goods sector plastic use (Figure 1).

How Can the Lifecycle Impacts of Plastic Use Be Further Reduced?



Notes/Assumptions
1. Low carbon electricity sources include wind, solar, hydro and nuclear power.
2. Assumes weight per package can be reduced by 30% without compromising packaging functionality.
3. Recycling or plastic packaging and products increased to 55% and landfilling limited to 10%.

All dollar values are in USD

Source: Trucost

Moving to a more circular economy can reduce the environmental costs of plastics.

The circular economy is an alternative to the traditional linear make-use-dispose economic model, which prioritizes the extension of product life cycles, extracting maximum value from resources in use, and then recovering materials at the end of their service life. An important principle of the circular economy is increasing the capture and recovery of materials in waste streams so that they can be recycled and reused in new products. Increasing the recycling of post-consumer plastics (to 55%) and minimizing landfilling (to a maximum of 10%) could deliver significant environmental benefits. If these targets were implemented across Europe and North America, the environmental cost of plastics could be reduced by over $7.9 billion in net terms, accounting for the increased environmental impacts associated with waste collection and management, and in addition to the direct economic gains associated with the recovered value of recycled plastics and recovered energy. Recycling delivers a social and environmental return on investment, on top of the economic value of recovered materials, with the environmental benefits of increasing recycling in this scenario outweighing the costs of pollution emissions and external waste management costs by at least 3.9 times.

Capturing plastic waste before it reaches the ocean could cut ocean costs by over $2.1 billion.

Improving waste collection and management is key to reducing the quantity of plastics entering the ocean each year, along with the resulting environmental costs. Asia, with its large and growing consumer goods market and comparably low municipal waste collection rates, is estimated to contribute over 70% of the total quantity of plastic reaching the ocean from the consumer goods sector each year. Trucost estimates that by increasing the municipal waste collection rate in Asia to a GDP weighted average of 80%, the annual global plastic input to the oceans could be cut by over 45% (1.1 Mt) and save $2.1 billion in environmental costs. Looking ahead, similar investments in waste management infrastructure will be critical in Africa where incomes are rising and waste management systems remain poor. As incomes rise, waste generation rates (including plastic waste) are expected to increase with significant implications for the world's oceans. However, it is important to note that without commensurate improvements in material and energy recovery, the ocean cost benefits of better waste collection could be offset by increased environmental, disamenity[2] and public costs of waste management.

Plastics can enable significant environmental benefits in the use phase.

Some key examples include the lightweighting of automobiles and in the use of specialized packaging designs to minimize food waste. Trucost estimates that substitution of plastic components with alternative materials in passenger vehicles sold in the North America in 2015 would lead to an increase in lifetime fuel demand for those vehicles of over 336 million liters of gasoline and diesel, and at an environmental cost of $2.3 billion. This equates to an environmental cost increase of $169 per gasoline or diesel passenger car sold in North America in 2015. Similarly, improved skin-type plastic packaging for sirloin steak can cut food waste by almost half compared to conventional plastic packaging (34% waste to 18% waste) with environmental savings of $606 per metric ton of beef sirloin sold. This equates to environmental savings of over $2.2 million for every additional 1% of sirloin steak sold in improved packaging in the USA. This case study illustrates the significant environmental net benefits that plastic food packaging can deliver where it helps to avoid the waste of resource intensive food products.

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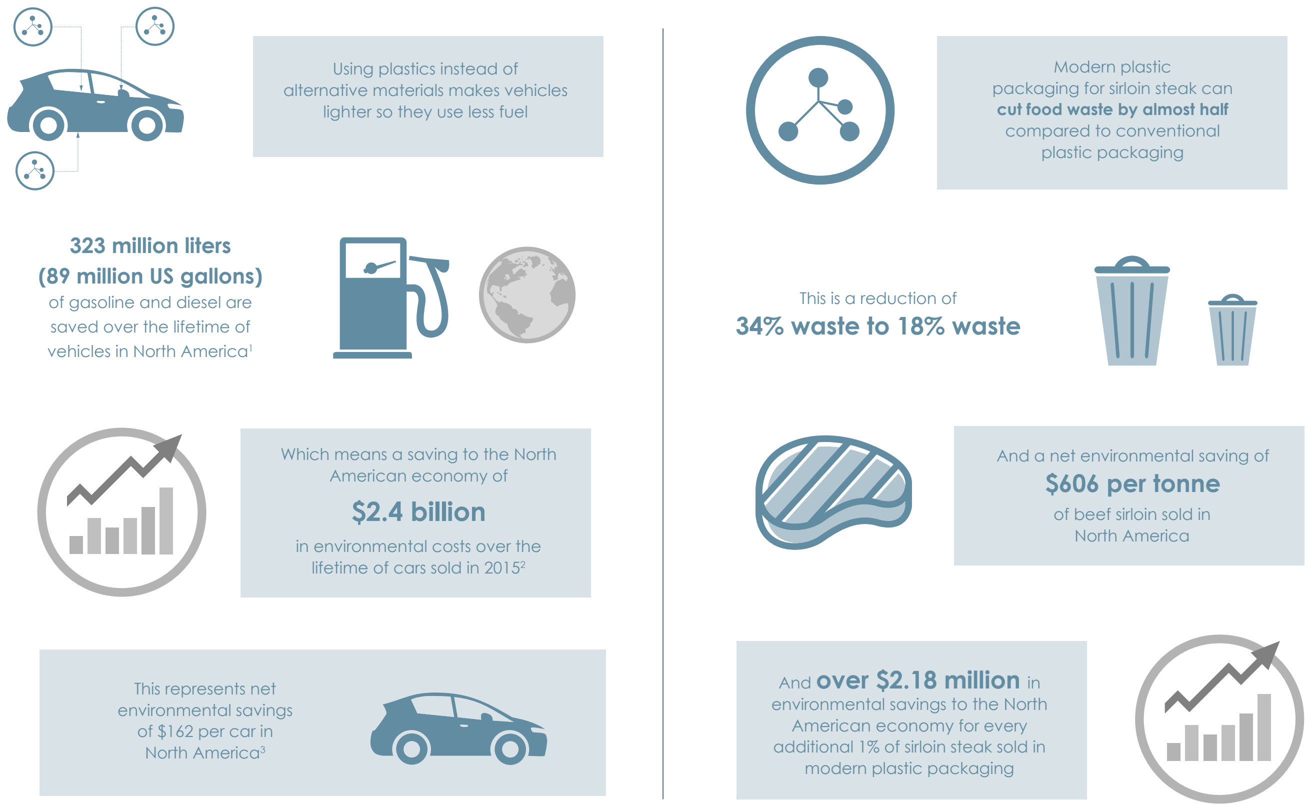
[2] Disamenity is a descriptor for the localised impacts of landfill and other waste management activities that generate negative reactions from communities located in the immediate vicinity of the waste management site (DEFRA, 2003). This could include noise, dust, odor, nuisance, visual intrusion or the presence of vermin (ibid).

Examples of How Plastics Are Helping Reduce the Environmental Footprint of Consumer Goods



Using plastics instead of alternative materials makes vehicles lighter so they use less fuel

323 million liters (89 million US gallons) of gasoline and diesel are saved over the lifetime of vehicles in North America[1]

Which means a saving to the North American economy of **$2.4 billion** in environmental costs over the lifetime of cars sold in 2015[2]

This represents net environmental savings of $162 per car in North America[3]

Modern plastic packaging for sirloin steak can **cut food waste by almost half** compared to conventional plastic packaging

This is a reduction of **34% waste to 18% waste**

And a net environmental saving of **$606 per tonne** of beef sirloin sold in North America

And **over $2.18 million** in environmental savings to the North American economy for every additional 1% of sirloin steak sold in modern plastic packaging

Notes/Assumptions
1. Fuel savings over 13 year operating life of gasoline and diesel passenger vehicles sold in North America in 2015.
2. Environmental cost savings include avoided life cycle water consumption, greenhouse gas and air, land and water pollutant emissions associated with fuel production, distribution and combustion.
3. Assumes 13.8 million vehicles sold in North America in 2015.

All dollar values are in USD

Source: Trucost

The environmental advantages of plastics are not equal across consumer product sectors.

Due to the different types plastics used, and the different functions they perform, in different consumer goods sectors, the relative advantages of plastic over alternatives can vary widely. While environmental costs are estimated to increase across all sectors with the replacement of plastics with alternatives, the magnitude of this change ranges from a factor of 2 to 3 in the furniture, automobiles, and clothing and accessories sectors, to a factor of more than 4.5 in the soft drinks and ice, consumer electronics, household durables and non-durables, and toys sectors. The Toys sector is the most plastic intensive sector modeled in this study and the environmental costs associated with this sector would increase by a factor of 6.3 if plastics were replaced with alternatives.

Sectors in which the relative advantages of plastics over alternatives are smallest could represent targets for innovation to further improve the environmental performance of plastic throughout the life cycle. The change in environmental costs is greatest for packaging applications, increasing by a factor of 4.2 across all sectors when plastics are replaced, compared to 3.4 for plastic used in products. This highlights the greater material efficiency of plastic in a broad range of packaging applications compared to alternatives – with less material needed to achieve the same outcome.

Recommendations on the Pathway to a More Sustainable Plastics Economy

The pioneering Valuing Plastic study (UNEP, 2014) established plastic use in the consumer goods sector as an important natural capital risk, creating significant costs to society, which if internalized through regulation, consumer pressure and other mechanisms, could threaten future revenues and profitability across the sector. This study sought to extend the research presented in Valuing Plastic with an explicit focus on examining how plastic use in consumer products could be made more sustainable, by comparing the relative environmental performance of plastic and its alternatives, and by examining possible strategic interventions at key leverage points in the plastics value chain that can deliver net environmental benefits. Based on this research, Trucost recommends the following key actions to aid in creating a pathway to more sustainable plastic use in the future.

- The plastic manufacturing industry has direct influence, or indirect influence via its supply chain management practices, over a significant share of the environmental costs of plastic use in consumer goods sector, and other sectors. The industry is thus ideally positioned to lead in driving further improvements in the environmental performance of the plastic supply chain. Increasing sourcing of low carbon energy and improvements in the fuel efficiency of the logistics fleet represent key potential opportunities to reduce the environmental costs of the sector in the short and medium term.

- In the longer term, innovations in plastic manufacturing technology that enable a shift toward a mix of more environmentally sustainable alternative energy feedstocks, design for recycling strategies and ever increasing material efficiency in product and packaging applications hold potential to reduce the environmental costs of plastic across the life cycle.

- Investment in more efficient packaging technologies that use less plastic to meet customer needs can help to reduce not only the plastic industry's direct and supply chain environmental footprint, but also enable environmental gains in the logistics and waste management phases of the value chain by light weighting consumer products. Furthermore, where innovative packaging designs better protect and extend the shelf life of food products, the environmental benefits of avoided food waste can be many times greater than the costs of producing the packaging. Similarly, the development of novel plastic components that can displace metal components in automobiles offers significant potential environmental benefits through improved fuel efficiency over the life of the vehicle.

- Investments in extending municipal waste collection services and improving waste management practices in developing economies are critical to addressing the challenge of plastic debris in the oceans. The impact of plastic on the global oceans could be further reduced through strategies to better capture littered and mismanaged waste on land before it reaches the ocean, expanding markets for recycled materials to increase the economic incentive to prevent waste leakage, and by limiting the use of harmful plastic additives that can be leached into the ocean over time.

- Step change increases in the recycling of post-consumer plastic waste, along with energy recovery, can have a major impact on the environmental costs of consumer plastics use. Such interventions would also help to capture some of the $80-$120 billion in lost economic value estimated by the Ellen MacArthur Foundation (2016) due to the single use of plastic packaging materials. The plastics manufacturing industry can play a role in driving this transition to a more circular economy by engaging with recyclers to optimize the efficiency and yields from plastic recovery processes, through for example, greater standardization of materials and packaging format types that enable more effective post-consumer sorting and separation.

- Adoption of natural capital accounting in the plastic manufacturing sector can help companies to understand their environmental impacts and potential exposure to increased costs or increased competitiveness due to advantages compared to alternative materials due to tightening environmental regulation and consumer pressure to improve environmental performance. Furthermore, these techniques enable companies to evaluate and communicate the environmental benefits created by investments in process efficiency and product innovation that improve the environmental performance of the sector.

Assumptions and Limitations

This study utilizes a hybrid of two common approaches to assess the environmental impacts of products and processes, Environmentally Extended Input-Output (EEI-O) modeling and Life Cycle Assessment (LCA) modeling, to provide a sector level and global scale assessment of the environmental trade-offs between plastic and alternatives in consumer goods. The intention of this research is to help inform more sustainable material use in the consumer goods sector by identifying key hotspots of environmental impact across the life cycle, between sectors and in the choice between plastic and alternative materials. The adoption of assumptions and simplifications are essential to achieve this scale and coverage and thus the results represent an average across sectors, technologies and products, based on the best available data. Individual companies, or specific technologies or products, may over or under perform the results of this study and thus detailed assessment of specific scenarios or interventions is recommended to inform decisions at the company level. Full details of the methodology and assumptions underlying this study are provided in Appendix 1 and a summary of key limitations is provided in the introduction section.

Introduction

Global production of plastics has grown 20 fold from 15 Mt in 1964 to 311 Mt in 2014 (Plastics Europe, 2015). China is the world's biggest producer, accounting for almost a quarter of all plastic production (Plastics Europe, 2013). The use of plastic has delivered many benefits for consumers and society. Plastic packaged food lasts longer, reducing wastage. Plastic pipes enable clean drinking water supplies. Plastic is used in medical applications such as surgical equipment, drips and blister packs for pills. Due to its light weight, plastic use in vehicles has reduced the carbon dioxide emissions emitted through vehicle use (Andrady & Neal, 2009). Plastic is one of the most useful and important materials in modern society, yet its environmental impacts cannot be ignored.

Valuing Plastic 2014 identified $75 billion[3] in annual natural capital, or environmental, costs associated with plastic use by the consumer goods sector alone (UNEP, 2014). One of the greatest environmental impacts of plastic is greenhouse gas emissions associated with the use of as energy for manufacturing resin and processing. Around 4-6% of oil production is used as feedstock to make plastics, and a similar amount is used as energy in the manufacturing process (Thompson et al, 2009, Ellen MacArthur Foundation, 2016). However, in parts of the world such as the United States, natural gas and natural gas liquids are the predominant plastic resin feedstock and energy source (EIA, 2016). In addition, additives used in certain product categories – for example, plasticizers used in non-durable household goods, stabilizers and flame retardants used in consumer electronics (OECD, 2009).

Upon disposal, plastic waste can create additional social costs, creating health and environmental harms, imposing costs on governments in managing waste, and when leaked into the ocean, causing impacts on marine life and the ocean economy.

In light of these social and environmental costs, some argue that plastics should be replaced with alternative materials, which may present fewer environmental challenges. However, recent studies by Franklin Associates (2013) and Denkstatt (2011), which model the substitution of plastic with alternative materials (such as paper, steel, aluminum and glass), suggest that a move away from plastics may come at a net environmental cost.

This study seeks to build upon this research using Trucost's model for valuing the environmental costs of plastics to investigate how the environmental costs of the consumer goods sector may change if plastic were replaced with alternatives, and the potential environmental impact of practical changes in the way plastics are produced, used and managed. The original Valuing Plastic (2014) report did not compare the environmental cost of plastic with that of the alternatives needed to replace it, nor did consider the potential benefits of plastic in the use phase. This report addresses these gaps to provide additional information needed to make informed decisions about the use of plastics.

Substituting Plastics with Alternatives

Plastic could theoretically be substituted with alternatives in many of its applications in the consumer goods sector. However, in most cases the substitution of plastics is not one for one – the different physical properties of plastic compared to its alternatives mean that a larger mass of alternative materials is typically needed to achieve the same function as plastic. A good example is the plastic beverage container. Packaging a 500ml carbonated beverage in a typical polyethylene terephthalate (PET) plastic bottle requires just under 30 grams of plastic. However, an equivalent bottle manufactured from a weighted average mix of alternative materials used in this market (tin, aluminum, glass and paper) would weigh 141 grams in the USA (mass ratio of 4.7 to 1). This logic of functional equivalence is applied to all plastic applications modeled in the consumer goods sector to estimate the total quantities of a mix of alternatives needed to replace plastic.

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[3] The environmental cost of plastic use in the consumer goods sector was re-estimated in this study with a broader and more comprehensive scope. As such, the estimated environmental costs of plastic use have increased. The drivers of this change are described in Appendix 3.

Prior studies suggest that approximately 3.5 times more alternative material would be needed to replace plastic in common packaging applications in North America (Franklin Associates, 2013) and 3.7 times more for a selection of product and packaging applications in Europe (Denkstatt, 2011).

Objectives

The 2014 Valuing Plastic report prepared for UNEP established that the environmental (or natural capital) costs of plastic use in the consumer goods sector is significant and largely unaccounted for in the market prices of consumer goods. This is also true for plastic alternative materials and many other products and services traded in the market. Natural capital encompasses natural resources such as clean air and water, and environmental services such as food and climate regulating services. Economic activity depends on these resources and services; however, they are not often factored into corporate accounting. By measuring and valuing these environmental impacts in monetary terms, the magnitude of the social cost of environmental impacts can be made visible and integrated into the design of solutions that will deliver genuine improvements in the sustainability of the consumer goods sector.

This report is intended as an extension to Valuing Plastic (UNEP, 2014), examining the sustainability implications of replacing plastics with alternatives and seeking to quantify the potential environmental benefits of broad scale, but realistic, changes in the way plastics are used in consumer goods.

Specifically, this study aims to:

- Quantify the environmental cost of plastic used in the consumer goods sector and compare this with a hypothetical scenario in which most plastic used in consumer products and packaging is replaced with a mix of alternative materials that serve the same purpose.
- Map the environmental costs of plastic and alternative material use across the value chain, geographic regions and consumer goods sub-sectors, to help target interventions to improve sustainability at key points where the greatest benefits can be achieved.
- Identify those sectors exposed to the greatest environmental risks if plastic were replaced with alternatives.
- Quantify the potential environmental benefits of strategies to improve the sustainability of plastic use, such as more efficient packaging design, improved waste collection and material and energy recovery systems, and increasing low-carbon energy use in the plastics manufacturing sector.
- Provide recommendations for the plastic manufacturing sector on ways to reduce the environmental costs of plastics.

This study does not seek to comprehensively model the functional substitution of plastic with alternative materials in specific product applications. This has been addressed partially in prior studies and cannot be achieved within the scope of this study. Instead the study seeks to model and contrast the environmental footprint of plastic with a realistic mix of alternative materials that could be used to replace plastic in common categories of applications in the consumer goods sectors.

This study does seeks to provide a materiality assessment and heat map of important environmental trade-offs between plastics and alternatives in the consumer goods sectors. Optimizing solutions and interventions that target these hotspots will require more detailed assessment of each specific application.

This study has a sector-wide focus and a global scale and thus seeks to model the hypothetical substitution of plastic with alternatives across broad application categories, such as beverage containers or rigid protective packaging, from a top-down perspective. The broad scope of this study necessitates a range of simplifying assumptions and relies on the extrapolation of previously published plastic substitution analyses to achieve complete sectoral and geographic coverage.

High Level Methodology

This section briefly summarizes the seven key methodology steps adopted in this study. This methodology represents an extension of that developed in the 2014 report Valuing Plastic prepared by Trucost for UNEP (2014). A detailed description of the methodology and key assumptions is presented in the Appendix 1.

Step 1: Consumer Goods Sector Selection

Trucost focused its research on the same 16 consumer goods sectors that were included in the Valuing Plastic report (2014). These sectors, shown below, were selected as they are significant consumers of plastic in products and packaging. As the focus is on consumer goods, other large plastic consuming sectors such as agriculture were excluded from the study. For a full description of each sector, please refer to in Appendix 1.

Food
Soft Drinks and Ice
Tobacco
Furniture
Clothing and Accessories
Footwear
Non-Durable Household Goods
Medical and Pharmaceutical Products
Personal Products
Durable Household Goods
Consumer Electronics
Automobiles
Athletic Goods
Toys
Retail
Restaurants and Bars

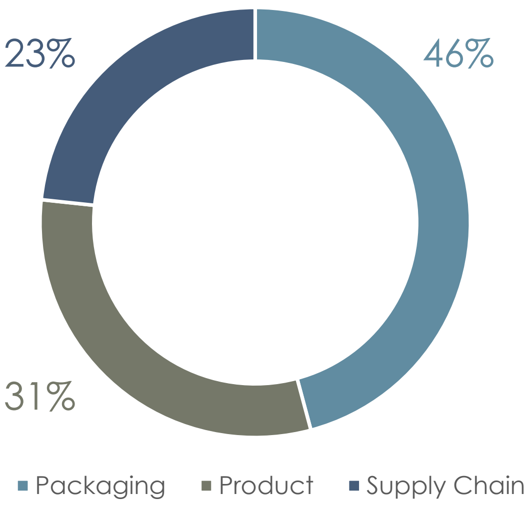
Step 2: Quantifying Plastic Demand in Each Consumer Goods Sector

Trucost estimated the total quantity of plastic demanded in each consumer goods sector using an Input-Output modeling approach to determine the expenditure of each consumer goods sector in 14 key plastic manufacturing sectors and 115 plastic commodity sub-sectors (US BEA, 2007). Importantly, each of these 115 sub-sectors was used to represent a specific plastic function or application, such as rigid bulk packaging or beverage containers, enabling Trucost to quantify not only the total amount of plastic used, but the amount used for each function. This approach enabled Trucost to estimate plastic demand per million of consumer goods sector revenue, and when combined with estimates of sector revenue (MarketLine, 2014), enabled the estimation of total global plastic demand for each sector. Plastic consumption was categorized into three types:

- **Plastic-in-product** including plastic used in products such as a child’s plastic toy or a polyester T-shirt.
- **Plastic-in-packaging** including plastic used as packaging such as carrier bags and shampoo bottles.
- **Plastic-in-supply-chain** including plastic used by suppliers such as bags containing fertilizer used by farmers supplying the food sector.

This study includes only plastic and alternatives that form part of the final consumer product or its packaging (plastic-in-product and plastic-in-packaging). Other plastic and alternative material used earlier in the supply chain was excluded from this analysis due to a lack of data on plastic substitution ratios and end-of-life management practices.
As shown in Figure 2, the majority of plastic use in the consumer goods sectors is used in products (31%) and consumer packaging (46%).

Figure 2 Plastic Demand for All Consumer Goods Sectors for Products, Packaging and Supply Chain (% Total Mass)



Source: Trucost

Step 3: Modeling Plastic Substitution With Alternatives

This study models a realistic scenario in which plastic used in the consumer goods sector is replaced with a mix of alternative materials that can provide the same function. Modeling a one-for-one substitution of plastics with alternatives is not realistic because:

Plastics and alternative materials have different physical and chemical properties and thus different weights will be required of each material for a given application or function.

Some plastic applications cannot be fulfilled with alternative materials, and in many cases not all alternative materials can substitute for plastic.

In order to model the functionally equivalent mix of alternative materials required to replace plastic in each sector, this study builds on the detailed work of Denkstatt (2011) and Franklin Associates (2013) which investigated the substitution of plastic with alternatives in specific product and packaging applications. The methodology adopted to define plastic substitution ratios in different applications is described in detail in the citations above. Trucost integrated the findings of Denkstatt (2011) and Franklin Associates (2013) to produce the plastic substitution model used in this study.

This substitution model includes the following alternative materials:

- Steel, iron and tin plate
- Aluminum
- Glass
- Paper and Paperboard
- Textile
- Wood
- Mineral Wool
- Leather
- Residual non-substitutable plastic resin and rubber

Table 1 shows the estimated quantities of plastic and alternative materials demanded in each consumer goods sector per million of revenue.

Table 1 Plastic and Alternative Material Demand per Million of Revenue (Metric Tons per Million US$)

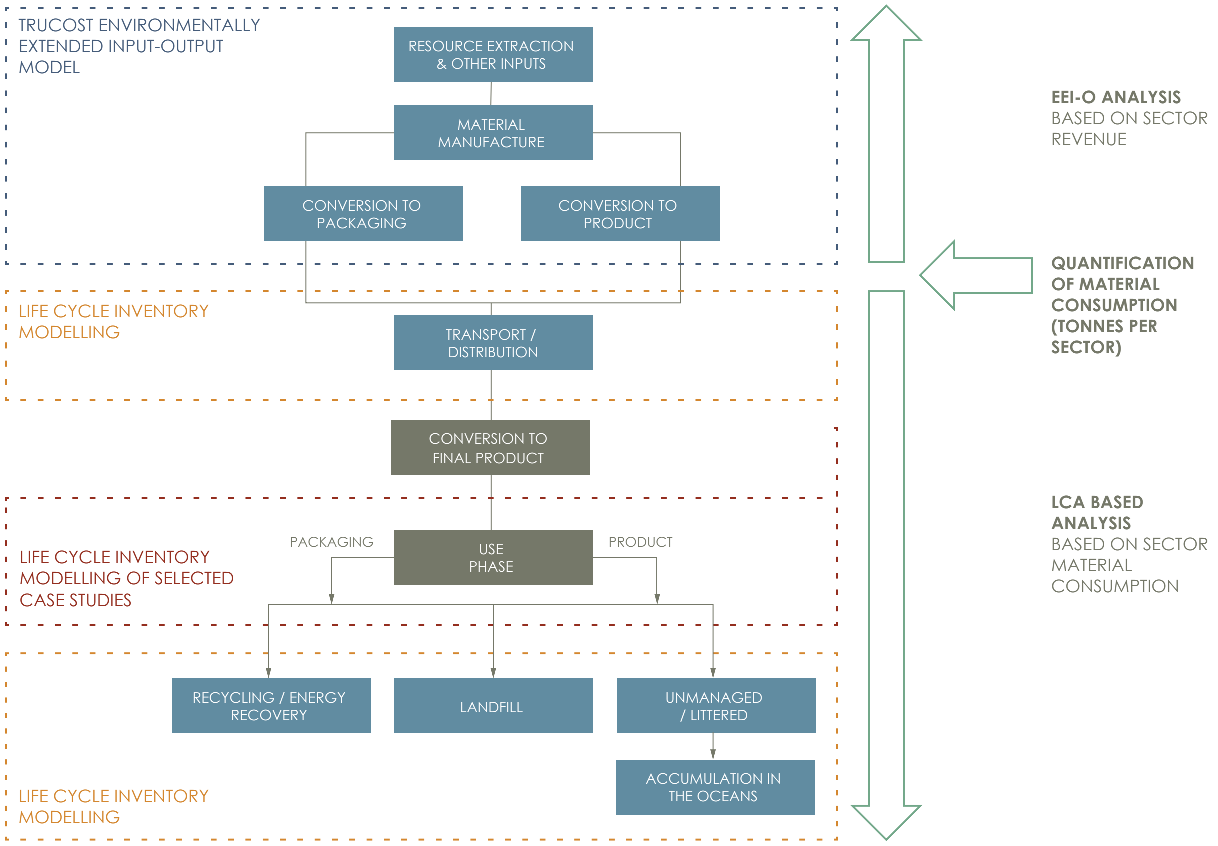
CONSUMER GOODS SECTOR	BUSINESS AS USUAL (TONNES/$ MILLION)			PLASTIC ALTERNATIVES (TONNES/$ MILLION)		
	PLASTIC IN PRODUCT	PLASTIC IN PACKAGING	TOTAL PLASTIC*	ALTERNATIVES IN PRODUCT	ALTERNATIVES IN PACKAGING	TOTAL ALTERNATIVES
Automobiles	3.5	0.1	3.6	8	0.2	8.2
Soft drinks and ice	0	15.4	15.4	0	112	112
Clothing and accessories	3.2	0.3	3.5	4.6	0.9	5.4
Consumer electronics	3.4	0.8	4.2	10.4	1.9	12.3
Durable household goods	10.8	4.2	15	41.4	10.9	52.3
Food	0	3.1	3.1	0	14.4	14.4
Personal products	4	4.5	8.5	12.2	32	44.1
Athletic goods	10.6	3.6	14.2	35.8	9.1	44.9
Toys	21.8	11.9	33.7	102.6	30.2	132.8
Tobacco	0.5	0	0.6	0.8	0.1	0.9
Furniture	12.3	1.5	13.8	27.6	3.6	31.2
Non-durable household goods	4.9	2.9	7.8	19.3	12.1	31.4
Footwear	9.8	3.2	13	34.6	7.4	42
Medical and pharmaceutical products	0	2.9	2.9	0	12.1	12.1
Retail	0	0.5	0.5	0	1.7	1.7
Restaurants and bars	0	1.1	1.1	0	3.3	3.3

Source: Trucost

Step 4: Scope and Boundary Selection

After modeling plastic and alternative material demand in each sector, the next step was to calculate the associated environmental impacts. Trucost set boundaries on both the included lifecycle stages and the included environmental impacts in recognition of the availability of robust data and models to input into the analysis. Impacts across the lifecycle of plastic and alternatives were considered including the extraction and processing of raw materials, conversion to manufactured commodities (such as bottles, boxes and sheets), transport to market, and the end-of-life fate of wastes. Some lifecycle stages were excluded due to practical reasons, such the conversion of manufactured commodities into final consumer goods and impacts in the use-phase, beyond those considered in the use-phase case studies.

Figure 3: High Level Methodology Overview



Source: Trucost

Step 5: Impact Quantification

Trucost quantified the environmental impacts of plastic and alternative material use in the consumer goods sector using a hybrid approach drawing on Environmentally Extended Input-Output modeling and Life Cycle Analysis techniques and datasets (as shown in Figure 3). These approaches draw upon numerous authoritative sources such as the US Toxic Release Inventory (EPA, 2016b), US Manufacturing Energy Consumption Survey (EIA, 2014), Ecoinvent Database (Weidema et al, 2013) and the US Life Cycle Inventory Database (NREL, 2013).

This study includes impacts associated with greenhouse gas emissions; water abstraction; and air, water and land pollutant emissions occurring throughout the value chain. However, the study does not include the future opportunity cost to society of depletion of non-renewable resources that may not be available to future generations.

Environmental impacts occurring at the end of life were quantified based on the waste management route used, including landfill, recycling, littering, and incineration with and without energy recovery. Key assumptions underpinning this analysis are described in Appendix 1, and were derived from authoritative sources such as the US Environmental Protection Agency (EPA, 2014), Eurostat (Eurostat, 2016) and the World Bank (Hoornweg and Bhada-Tata, 2012). In addition to the environmental impacts detailed above, the end of life impacts of chemical additives leaching into the environment, disamenity associated with landfill and incineration sites, and the release of litter into the ocean, were also included in the analysis. Other impacts, such as the opportunity cost of wasted materials and the effects of microplastic particles, were excluded due to a lack of sufficiently robust data and modeling methodologies. The study scope inclusions and exclusions are described in detail in Appendix 1.

An output oriented approach, also known as substitution or avoided burden approach, was adopted to account for the avoided environmental impacts associated with the recovery of materials and energy that displace production of virgin materials and energy from other sources (Ligthart and Toon, 2012). This approach is commonly applied in semi-closed loop recycling, which is common in consumer goods waste management.

Step 6: Valuing the Social Cost of Environmental Impacts

Consumption of natural resources and the emission of hazardous air, land and water pollutants impacts upon the Earth's stock of resources (such as clean air and water) and services (such as climate regulation and food provision) commonly referred to as natural capital. Businesses depend on natural capital to be able to operate and provide goods and services to society. Yet this is rarely accounted for in a company's financial accounts. Natural capital or environmental valuation provides a way to quantify natural capital risks and dependencies in monetary terms.

Natural capital valuation has many benefits. For instance, using a common monetary unit enables companies to compare the significance of different impacts. It can also be used to measure the success of program to reduce impacts, such as diverting waste from landfill to recycling. It also enables a company to create an environmental profit and loss account for its business, which can be integrated into its mainstream financial account. By comparing a business's annual natural capital cost to its annual revenue, a company's management can understand the risks it faces if tighter regulation or consumer demand forces it to pay these costs. This knowledge can encourage companies to take early action to reduce these risks by cutting environmental impacts.

Trucost calculated the natural capital or environmental cost of material use by converting the physical quantities of different types of environmental impacts, such as metric tons of particulate matter, into a monetary cost and adding them together. The environmental cost intensity is the sum of all the environmental impacts expressed in monetary terms per $1m revenue.

Step 7: Sensitivity Analysis

Complex modeling studies such as that presented in the report are dependent on a large number of data sources and assumptions, and are thus sensitive to the choice of assumptions and uncertainties in the underlying datasets. Trucost undertook sensitivity analyses to test the robustness of the results by modifying the following key parameters in the model:

- The material prices used to convert between financial flows and physical quantities.
- The substitution ratios used to estimate the quantity of alternative materials needed to replace plastics in each consumer goods sector.

The results of the sensitivity analysis are presented in Appendix 1.

Limitations

The scope of this study necessitates a range of simplifying assumptions and methodological choices which present some limitations that must be considered when interpreting the results.

Limitations relating to this study specifically

- The quantification of plastic and alternative material consumption undertaken in this study is sensitive to A) the assumed price of different plastic and alternative materials, and B) the mapping of sub-sectors within the input-output model to plastic functional categories. A sensitivity analysis is presented in Appendix 1 which assesses the sensitivity of the results to high and low estimates of the price for each resin considered in the study. Sensitivity to the mapping decisions made by the authors is minimized by undertaking the mapping process at the finest level of disaggregation available, enabling the model to better reflect demand for different plastic functions across the consumer goods sectors.
- Limitations on available waste management statistics and recovery rates outside Europe and North America require the adoption of simplified waste management assumptions for other countries and regions.
- It was not possible to reflect variations in the efficiency and environmental performance of waste management and recycling processes between countries due to limitations on available country specific data.
- This study does not consider impacts associated with the modification and incorporation of plastic and alternative material commodities into the final products sold by the consumer goods sector. Furthermore, the study does not comprehensively assess impacts occurring in the use phase of the life cycle, beyond the two case studies presented in

this report. However, as the modeling of the substitution of plastic with alternatives was undertaken on the basis of functional equivalence, differences between the use phase impacts of plastics and alternatives are likely to be limited in most sectors.

- Transport impacts were modeled based on material specific global average transport distances and a global average mix of transport modes, and are thus subject to uncertainty.
- This study did not capture some emerging impacts of plastics (such as microplastics) and alternative materials where sufficiently robust data and models were unavailable.
- Additional limitations associated with the quantification and the valuation of environmental impacts, are discussed in Appendix 2.

Limitations relating to Environmentally Extended Input-Output Modeling

- Input-Output models are based upon static and infrequently updated data which is sensitive to price fluctuations. This sensitivity can be mitigated by matching the price years of the input-output tables and any price data used in modeling analysis, as was done in this study.
- Although EEI-O modeling yields a more complete upstream impact assessment than life cycle analysis, downstream impacts cannot be analyzed using EEI-O and thus EEI-O must be augmented with traditional life cycle analysis techniques to model the full product life cycle.
- Input-Output modeling assumes that each sector produces a generic good or service that carries with it the same environmental impact. As such, variation in the environmental impacts associated with different resin types or grades of alternative material will not be represented in the modeling. Instead, the model represents the average impacts of producing the mix of commodities produced in each sector.
- Input-Output modeling assumes a constant set of inputs is used to produce outputs and thus does not account for improvements in efficiency for instance.
- The Trucost EEI-O model is based upon inter-sector financial transactions in the USA and thus its application globally assumes that this is representative of linkages between sectors in other economies.

Note on Valuing the Impacts of Litter in the Ocean

This study presents an evolution of the ocean impact valuation approach first presented in Valuing Plastic (UNEP, 2014), drawing on important studies published in the interim including, most importantly, the seminal study by Jambeck et al (2015). The valuation approach is discussed in further detail in the results section and Appendix 2, and seeks to model the transfer of land based unmanaged litter into marine environments and then to value the physical, chemical and biological impacts of this litter on wildlife, fisheries, aquaculture and tourism. Due to data limitations this valuation may not capture the complete social cost of the environmental damages caused by plastic and other litter in the ocean, but represents a best estimate based on current knowledge and available data.

Results

This section provides an overview of the results of this study and is organized in two parts:

Part A: The Environmental Cost of Plastics and Alternatives in the Consumer Goods Sector: This first section outlines the estimated cost of plastic use in the consumer goods sectors, and the costs of the alternative materials needed to replace plastic. This section explores the following key questions:

- What is the global environmental cost of consumer goods sector plastic use and how would this change if plastic were replaced with alternatives?
- What is the cost of plastic litter from consumer goods in the ocean?
- How do environmental costs vary between consumer goods sub-sectors, and what is the risk to revenue and profitability if those costs were internalized?
- What are the most costly environmental impacts of plastic and alternatives?
- How are the environmental costs distributed across the value chain?
- Which regions have the greatest environmental costs?
- What are the potential environmental benefits of plastic in light weighting automobiles and food waste prevention?

Part B: The Environmental Benefits of More Sustainable Plastic Use: The second section evaluates the potential impact of a series of interventions in business-as-usual plastic production and use on the environmental cost of consumer goods sector plastics use. This section explores the following key questions:

- What is the potential impact of improved waste collection on the cost of plastics to the world's oceans?
- What is the potential impact of more efficient food and drink packaging designs that uses less plastic?
- What can the plastic sector do to reduce the environmental cost of plastic production?
- What is the potential impact of shifting to a circular economy model of recycling and energy recovery in North America and Europe?
- What other interventions could improve the sustainability of plastics use?

Part A: The Environmental Cost of Plastics and Alternatives in the Consumer Goods Sector

Part A details the best estimate of the social cost of environmental costs of plastic use in the consumer goods sectors and compares this with a scenario in which the majority of this plastic is replaced with a mix of alternatives that perform the same functions.

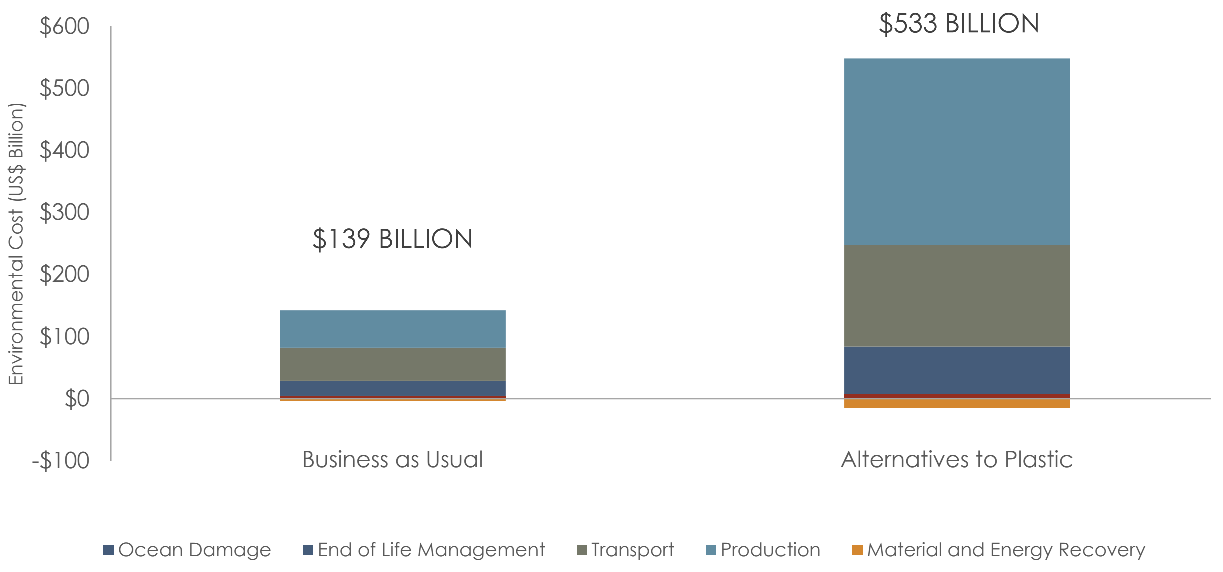
Plastic vs Alternatives: Global environmental costs

The total environmental cost of plastic use in the consumer goods sector is estimated at US$139 billion in 2015. This represents an increase from the $75 billion estimated in Valuing Plastic (UNEP, 2014) due to:

- Expansion of the analysis to include transport of plastic and alternative materials to consumer goods sector markets.
- Improvements in the valuation methodologies used to place a monetary value of environmental impacts.
- Growth in the consumer goods sector leading to higher estimated plastic demand.
- Enhancements in the modeling of the ocean impacts of plastic waste based on more recent research on this topic.

This suggests that on average across the consumer goods sector, US$4,886 in environmental costs are created from the use of plastic per million dollars of revenue in the consumer goods sectors. These environmental costs are concentrated in the production of resin, conversion to manufactured plastic commodities and the transport of these commodities to market, accounting for over 80% of the total environmental cost. An estimated $4 billion in environmental costs are avoided annually through the recycling of plastic to displace virgin production, and the recovery of energy from waste plastics through incineration.

Figure 4: Environmental Costs of Plastics vs Alternatives in the Consumer Goods Sector ($US Billion)



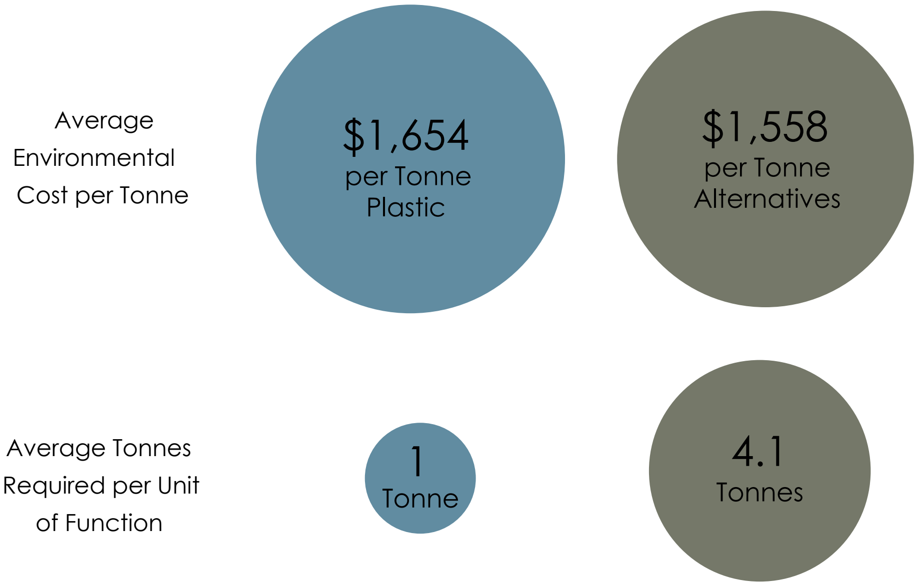
Source: Trucost

Substituting the majority of plastic used in the consumer goods sector with a mix of alternative materials that provide the same function, would increase environmental costs by a factor of four to over US$533 billion in 2015. This equates to an additional $13,887 in environmental costs created per million dollars of consumer goods sector revenue (total $18,773 per million) compared to business as usual plastic use. The environmental costs are overwhelmingly concentrated in the upstream production and transport phases of the value chain at approximately 87% of total costs.

While the environmental cost per metric ton of plastic is marginally greater on average than the mix of alternatives – $1,654 per metric ton for plastic compared to $1,558 per metric ton for alternatives – four metric tons of alternative materials are required on average to achieve the same function as one metric ton of plastic. Thus plastics are more damaging per metric ton, but due to their physical and chemical properties, can be used far more efficiently than alternative materials to achieve the same function.

While environmental costs from the production of some materials (such as aluminum and steel) are comparable or greater than that of plastic, on a weighted average basis, the cost of alternatives is lower per metric ton but greater in aggregate due to the larger quantities of material needed to fulfill the same purpose.

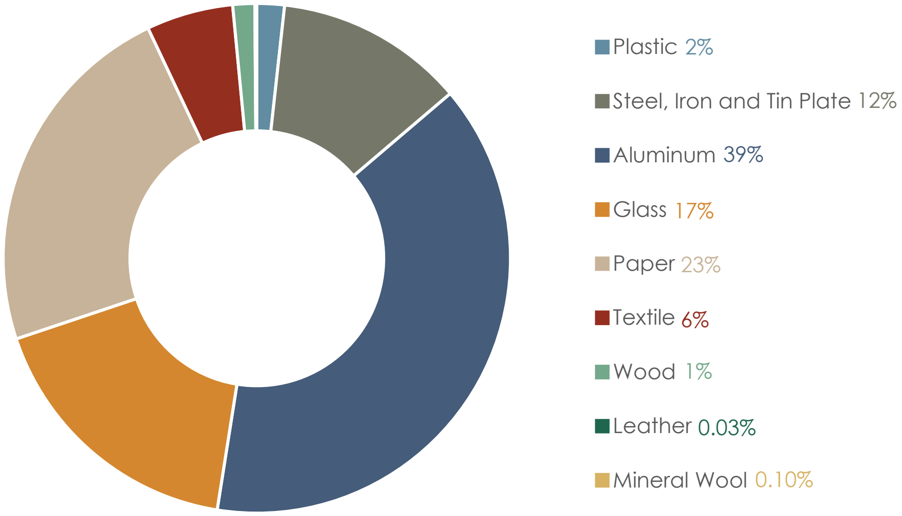
Figure 5: Environmental Costs and Substitution Quantities for Plastic and Alternatives (US$ and Metric Tons)



Source: Trucost

The largest share of environmental costs is associated with aluminum (39%), paper (23%), glass (17%) and steel and tin plate (12%), with negligible contributions from the other alternative materials studied. It is notable that while glass accounts for almost 50% of the total mass of plastic substitute materials, glass contributes just 17% of the total environmental costs. This is due to the comparatively low environmental cost of glass per metric ton compared to other plastic alternative materials.

Figure 6: Share of Total Environmental Cost by Plastic Alternative Material

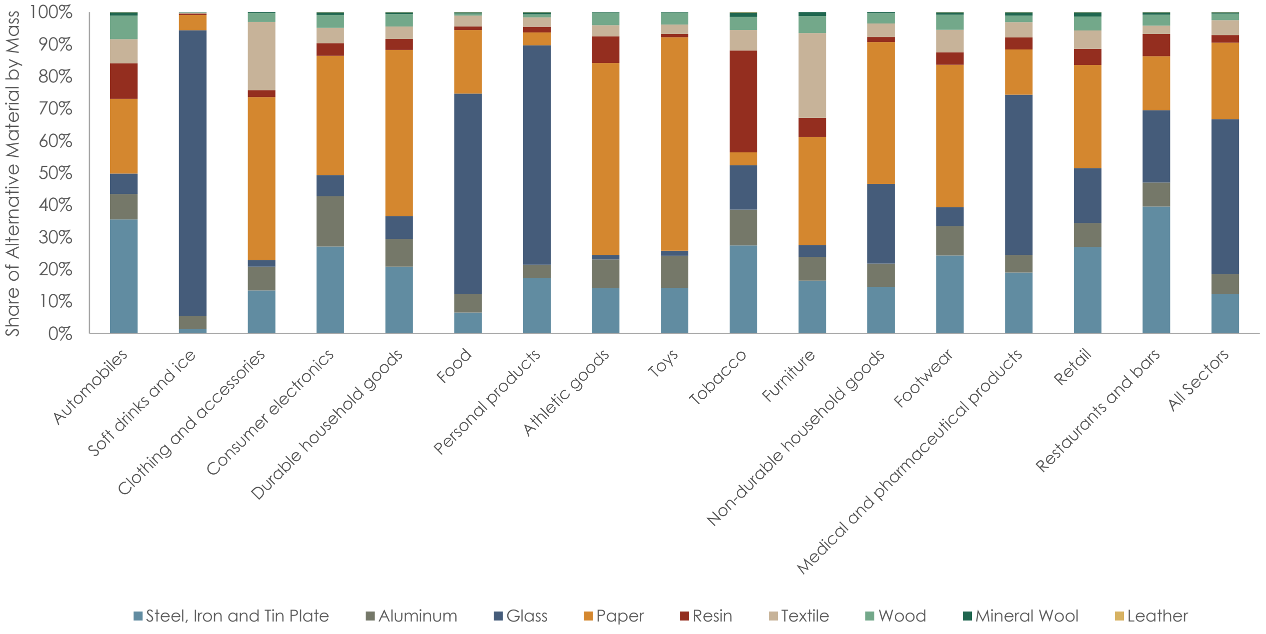


Source: Trucost

The contribution of aluminum to the environmental cost of alternatives to plastic is disproportionately high relative to its use (6% of alternative material mass but 39% of environmental costs), due to the energy intensive nature of the aluminum production process.

The modeled use of alternatives to plastic varies widely between consumer goods sectors. Glass is the most common plastic alternative due to its extensive use in the packaging of food, drinks, personal products and medication. Steel, iron and tin plate are commonly used across all sectors, as is paper and textile in some sectors. Residual non-substitutable plastic use is most common in the automobile and tobacco sectors.

Figure 7: Share of Plastic Alternative Materials per Consumer Goods Sector



Source: Trucost

Impacts on the Ocean

The global oceans are critical to sustaining the Earth's natural life support systems. They contribute to the livelihoods, culture and well-being of communities around the world, and play a vital role in the global economy, providing food and a source of income for millions of people. Yet, with a fast-growing world population, the production of waste continues to increase faster than the efforts mitigate its impact on the oceans. More mismanaged waste means more marine litter, and it has been estimated that 80% of marine debris originates from land-based sources (Jambeck et al, 2015) with the remaining 20% originating from ocean-based sources (Allsopp et al, n.d.). Land-based sources include storm water discharges, combined sewer overflows, littering, industrial activities, and solid waste disposal and landfills. Debris from such sources are often washed, blown, or discharged into waterways from rainfall, snowmelt, and wind (Sheavly and Register, 2007). In the case of both land and ocean based sources, poor waste handling practices, both legal and illegal, contribute to marine debris (ibid).

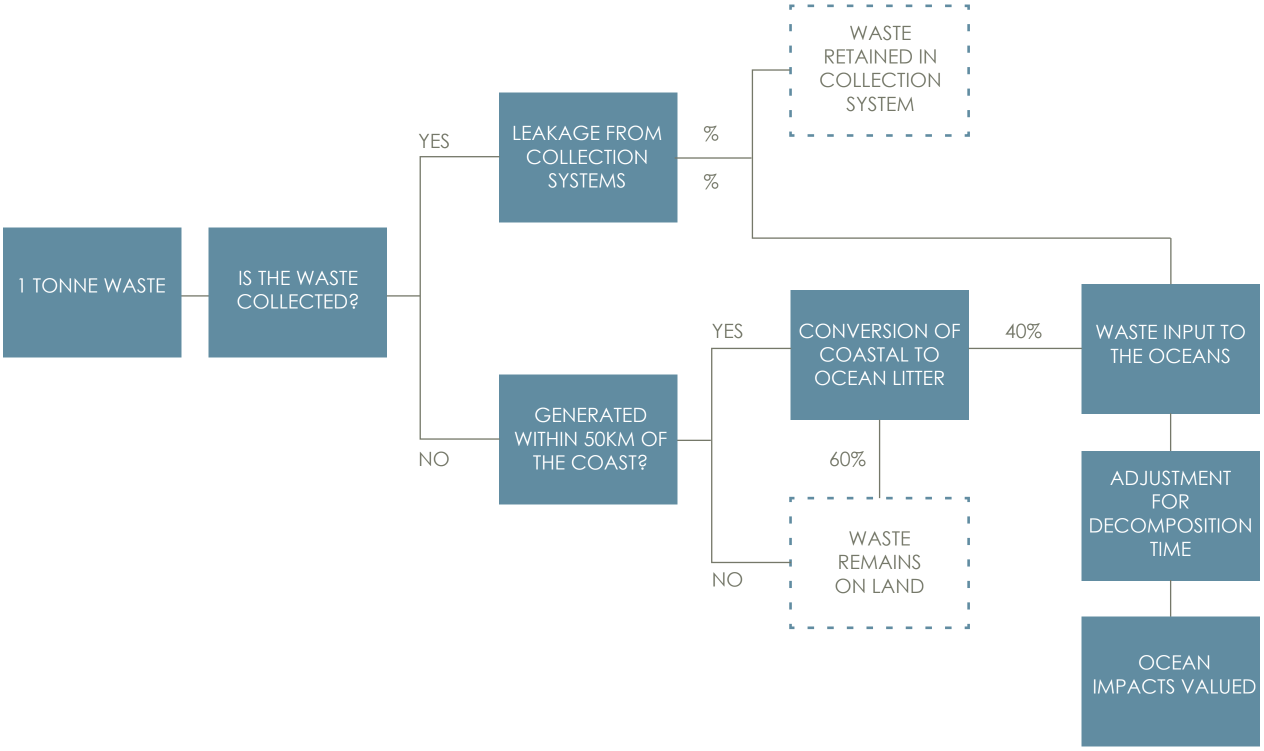
Plastic is the most common form of marine debris. Estimates have put the average proportion of plastic marine debris between 60 to 80% of all marine debris (Moore, 2008). In some places, the proportion can be as high as 90-95% of all marine debris (ibid). Plastic is frequently used in single use packaging application which are rapidly disposed and at risk of entering the marine environment if improperly managed (Jambeck et al, 2015). Plastics in the marine environment can also persist longer than some other materials due to their durability and resistance to natural biodegradation processes. Plastics can potentially persist for years to decades, or even longer in the ocean (Law et al, 2010). However, the true lifespan of plastics has been difficult estimate. In many instances, plastics will not fully degrade and instead break down into smaller and smaller pieces, eventually becoming "microplastics" or plastics that measure less than 5mm.

Marine debris can cause a variety of problems, posing environmental, economic, and health risks. Environmental risks include entanglement of marine animals, ingestion by marine animals, and the spread of invasive species. Ingested debris can block the digestive tract or fill the stomach of wildlife, resulting in malnutrition, starvation, reduced reproductive capacity, general reduction in quality of life, or death (Gregory, 2016). Floating debris can travel great distances, potentially carrying invasive species with it, introducing them to new ecosystems where they have the potential to compete with native species (Sheavly and Register, 2007). Marine debris on beaches reduces tourism and recreational use of these areas, thus decreasing their economic value (ibid). In addition, the clean-up of marine debris is costly to governments and businesses, and presents an economic opportunity cost where volunteers engage in clean-up activities, and larger debris pieces can damage vessels resulting in costly repairs and loss of time (ibid). Fish and invertebrates can ingest microplastics, potentially leading to the bioaccumulation of plastic additives and hazardous organic chemicals absorbed from the environment, within the food chain presenting potential risks for human health (Rochman et al, 2013). More recent research however suggests that the bioaccumulation of hazardous organic chemicals due to plastic ingested by marine life is small compared to bioaccumulation in prey species in most habitats. This suggests that microplastic ingestion may not increase exposure to hazardous organic chemicals in the marine environment (Koelmans et al, 2016). Nevertheless, quantifying the amount of marine debris entering the ocean is important for understanding its full economic and environmental cost and impacts.

Interest and research efforts into the issue of ocean plastic has increased significantly in recent years. In 2015, a seminal paper by Jambeck et al (2015) was published in the journal Science that described a methodology for quantifying the input of plastic into the oceans from land-based sources. This model considered the quantities of unmanaged waste generated by coastal populations (within 50km of the coast) and developed a model describing the conversion rate for land-based litter into marine debris. This paper culminated in the best estimate to date of the annual inflow of plastic waste into the ocean at between 4.8 and 12.7 Mt globally.

Building on this research, and other recent developments in marine debris research, Trucost refined its methodology for quantifying and valuing the impacts of marine litter (originally published in Valuing Plastic (UNEP, 2014)), developing the model described in Figure 8.

Figure 8: Modeling the Transfer of Land Based Waste to the Oceans



Source: Trucost

The model first estimates the quantity of mismanaged (not collected via municipal waste systems) waste generated within 50km of the coast and then applies a conversion rate derived by Jambeck et al (2015) to estimate the quantity of mismanaged coastal waste that becomes marine debris. The model also considers the additional escape of litter from waste collection and management systems (such as landfills located nearby to the coast) drawing on a recent report by the Ocean Conservancy (2015).

Trucost estimates that over 2.5 Mt of plastic marine debris was created in the consumer goods sector in 2015, from a total pool of mismanaged consumer goods plastic waste of 21 Mt. **This equates to between 20% and 50% of the total annual plastic inflow to the oceans estimated by Jambeck et al (2015) for all sectors in the global economy – not just consumer goods.** Trucost then valued this marine debris in terms the following categories of impacts:

Economic Impacts	Economic losses to fisheries, aquaculture and marine tourism. Opportunity costs for volunteers participating in beach clean-up activities.
Chemical Impacts	Damage to human and ecosystem health.
Physical Impacts	Wildlife entrapment and entanglement due to litter, valued in terms of community willingness to pay to prevent these impacts on species.

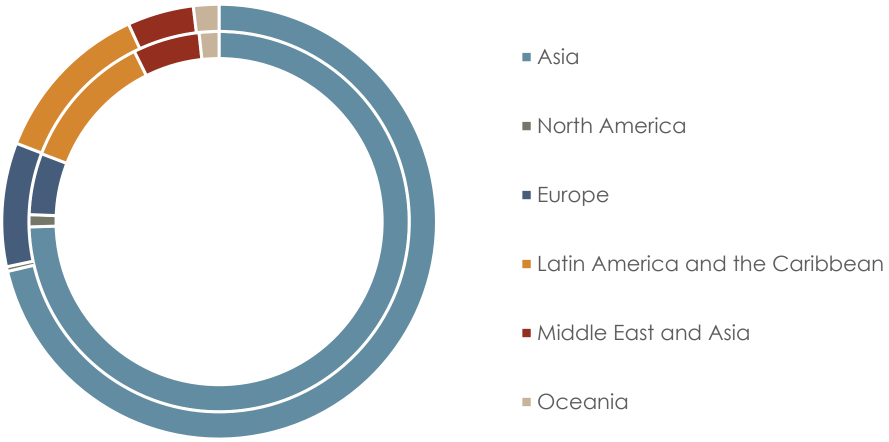
As the mechanisms modeled to estimate the transfer of plastic waste to the ocean also apply to other materials, and to allow for comparability between the business as usual and alternatives to plastic scenarios, the same model has been applied to estimate the transfer of plastic alternative materials to the ocean. The economic and physical impacts of plastic marine debris are potentially similar to that of the alternative materials – for example, an aluminum can has potential to be washed up on beaches or to entrap marine wildlife in a similar way to a plastic bottle. However, the physical and economic impacts of marine debris are likely to be a function of the time taken for the debris to decompose – the longer the decomposition time, the more likely the debris is to impact upon the economy and the environment. Many alternatives to plastic, such as paper and textiles, have more rapid decomposition rates than plastic and thus the valuation of their impact has been adjusted for the decomposition time of each material relative to that of plastic (Ocean Conservancy, 2010).

Synthesizing the models and assumptions described above (and in more detail in Appendix 1), Trucost estimates the cost of plastic marine debris created in the consumer goods sector under business as usual at **$4.7 billion per annum.** Replacing plastic with alternatives would increase the marine debris production in the consumer goods sector by 3.4 times compared to business as usual to 8.6 Mt per annum at a cost of **$7.3 billion** (1.5 times business as usual).

While the aggregate cost of ocean impacts is greater for the alternatives to plastic, this is purely a function of the larger quantities of waste materials produced in the alternatives to plastic scenario, with the ocean cost of plastics more than 2.6 times greater than that of alternatives – at **$56 per metric ton of plastic compared to $21 for alternatives.**

As highlighted in Figure 9, the overwhelming majority of marine debris is estimated to originate in Asia, where the consumer goods sector is growing rapidly and waste management systems are under developed relative to North America and Europe. This finding is consistent with a recent study by the Ocean Conservancy (2015) which suggests that around 60% of plastic waste entering the ocean originates from five countries in Asia: China, Indonesia, the Philippines, Thailand, and Vietnam. Improving waste collection systems in these countries could have a significant impact on ocean health, as considered in further detail in Part B.

Figure 9: Contribution to Ocean Cost of Consumer Goods Sector Marine Debris - Business as Usual (Inner) vs Alternatives to Plastic (Outer)



Source: Trucost

Which Sectors have the Greatest Environmental Costs?

The environmental costs of plastic and alternative material use vary widely across the 16 consumer goods sectors analyzed in this study. The environmental cost of any sector is a function of its size and relative intensity of demand for plastics, and by extension, alternative materials that serve as substitutes. The food, automobile, soft drinks and ice, and furniture sectors contribute the largest share of the environmental cost of plastic use, together accounting for almost 53% of the total natural capital costs. This is due to the high plastic demand and environmental costs per million of revenue in the soft drinks and ice and furniture sectors, and the higher turnover of the retail and food sectors.

When plastic is substituted with alternative materials, the durable household goods sector replaces the furniture sector in the top four highest environmental cost sectors. These sectors account for over 52% of the total estimated environmental costs in the alternatives to plastic scenario.

Table 2 presents estimates of the cost to each sector if the full social costs of plastic and alternative material use were internalized as private business costs, as a proportion of the total sector revenue. Such costs could be internalized within a business through:

- **Increased regulation** such as a price on greenhouse gas emissions or increased restrictions on air, land and water pollutant emissions requiring increased investment in emissions abatement. Such costs can be internalized directly and indirectly as suppliers pass on increased compliance costs down the value chain.
- **Disruption of operations** through restricted access to essential business inputs, such as water rationing in times of drought, or restricted operations due to storm damage, flood or constraints on essential processes such as wastewater or flue gas discharge.
- **Reputational damage** associated with increased customer and stakeholder awareness of the environmental costs associated with business practices. Reputational damage could be internalized through a range of routes such as reduced market share and revenue, decreased company valuation or increased financing costs.

The likelihood, timeline and the magnitude at which external costs may be internalized is likely to vary greatly between sectors and between companies within sectors due to variation in environmental impacts and dependencies. To illustrate the potential significance of external environmental risks to sector profitability, Table 2 presents the estimated change in average profit margins for each sector if the full environmental cost of plastic or alternative material use in that sector were internalized. The change in profitability is based on sector averages published by Damodaran (2016) and should therefore be taken as indicative.

The revenue at risk analysis shows that for most consumer goods sectors, external environmental costs represent between zero and three percent of total sector revenue under business as usual plastics use. Only one sector, toys, is estimated to become unprofitable under a full environmental cost internalization scenario, with revenue and all other business costs held constant.

Switching to plastic alternative materials would increase the proportion of revenue at risk on average across all sectors by a factor of four, with significant variation between sectors due to the diverse mix of alternative materials demanded in each sector. Profitability is at greatest risk in the soft drinks and ice, durable household goods, personal products, athletic goods, toys, furniture, non-durable household goods, and footwear sectors, with post internalization profit margins becoming negative in the alternatives to plastic scenario, with revenue and all other business held constant. As illustrated in Figure 10, consumer goods sector profitability is potentially at greatest risk in heavily plastic dependent segments with narrow profit margins. While hypothetical, this analysis does serve to illustrate that the scale of environmental costs created by plastic use or more environmentally costly alternatives in the consumer goods sector is significant compared to total sector revenue, and represents a potential material risk to profitability in the context of increasing regulatory and market forces that tend toward the internalization of environmental costs as private business costs.

Case Example: Soft Drinks and Ice Sector

The soft drinks and ice sector has an estimated global revenue of US$676 billion and consumes an estimated 13 Mt of plastic packaging, almost 98% of which is used in beverage containers. For every tonne of plastic used in the sector, an estimated 7.3 metric tons of alternative materials would be required, including:

- 0.1 metric tons of tin plate, steel or iron
- 0.3 metric tons of aluminum
- 6.5 metric tons of glass
- 0.3 metric tons of paper and paperboard

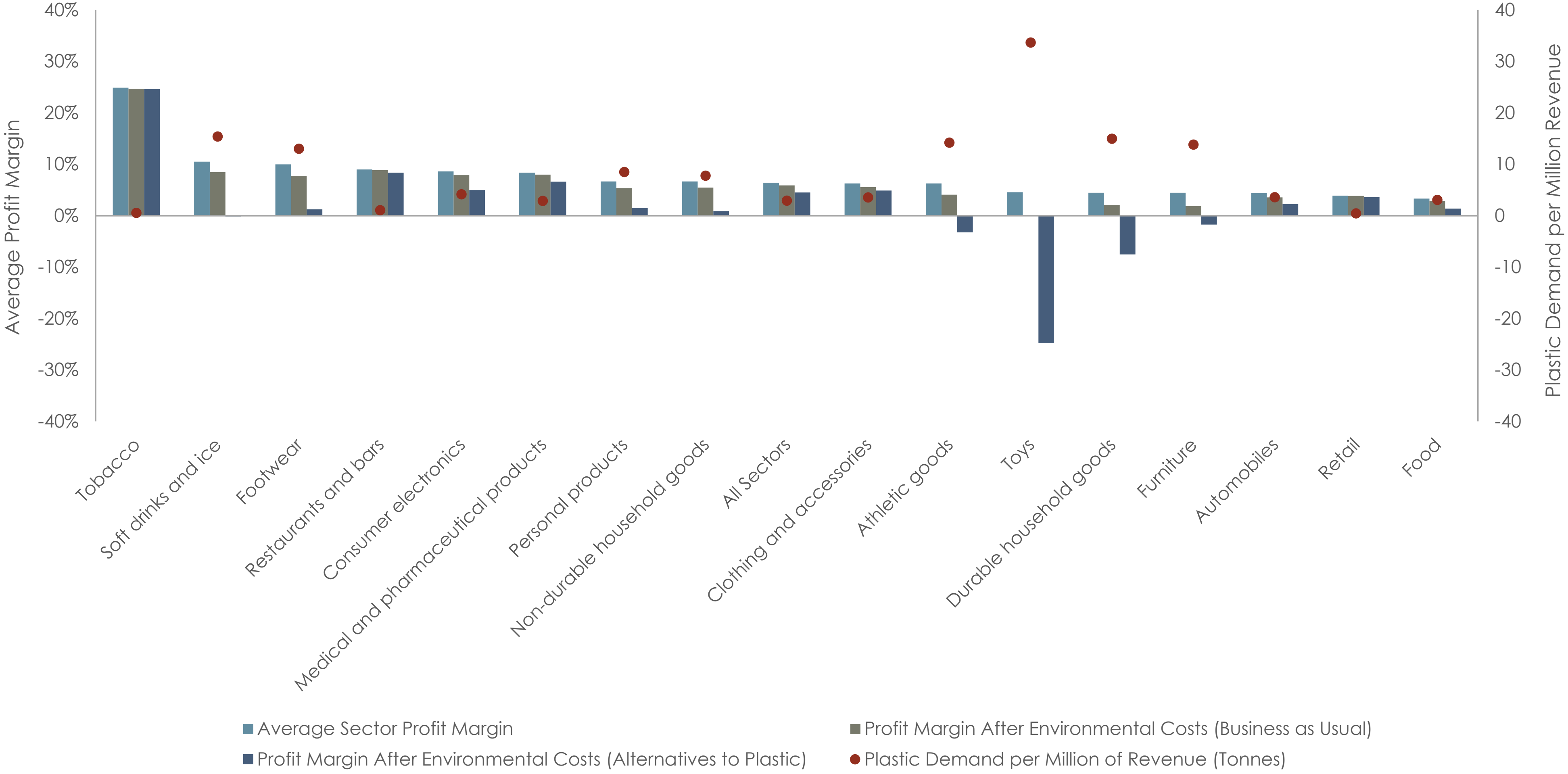
This substitution reduces the sector average cost per metric ton of material from $1,323 for plastics to $951 for alternatives, but increases the quantity of materials required by 7.3 times and the environmental cost by 5.2 times. This highlights the efficiency of plastics for use in bottling applications compared to glass, the leading market alternative.

Table 2: Environmental Costs, Intensity per Million of Sector Revenue and Sector Share of Total Environmental Costs

		BUSINESS AS USUAL				PLASTIC ALTERNATIVES			
CONSUMER GOODS SECTOR	AVERAGE SECTOR PROFIT MARGIN (%)	COST PER MILLION REVENUE (US$)	% TOTAL COSTS	% REVENUE AT RISK DUE TO ENVIRONMENTAL COSTS	% PROFIT MARGIN AFTER ENVIRONMENTAL COSTS	COST PER MILLION REVENUE (US$)	% TOTAL COSTS	% REVENUE AT RISK DUE TO ENVIRONMENTAL COSTS	% PROFIT MARGIN AFTER ENVIRONMENTAL COSTS
Automobiles	4.4%	$7,873	10.4%	0.8%	3.6%	$20,698	7.1%	2.1%	2.3%
Soft drinks and ice	10.5%	$20,392	9.9%	2.0%	8.5%	$106,527	13.5%	10.7%	-0.2%
Clothing and accessories	6.3%	$7,099	6.9%	0.7%	5.6%	$13,838	3.5%	1.4%	4.9%
Consumer electronics	8.6%	$7,362	1.7%	0.7%	7.9%	$36,288	2.2%	3.6%	5.0%
Durable household goods	4.5%	$24,422	5.5%	2.4%	2.0%	$120,174	7.1%	12.0%	-7.5%
Food	3.3%	$4,617	23.7%	0.5%	2.9%	$19,281	25.8%	1.9%	1.4%
Personal products	6.7%	$13,278	5.7%	1.3%	5.3%	$51,893	5.8%	5.2%	1.5%
Athletic goods	6.3%	$22,074	1.2%	2.2%	4.1%	$95,044	1.3%	9.5%	-3.2%
Toys	4.6%	$46,477	3.2%	4.6%	-0.1%	$293,613	5.3%	29.4%	-24.8%
Tobacco	24.9%	$2,241	1.5%	0.2%	24.7%	$2,695	0.5%	0.3%	24.6%
Furniture	4.5%	$25,699	8.9%	2.6%	1.9%	$62,180	5.6%	6.2%	-1.7%
Non-durable household goods	6.7%	$12,233	7.1%	1.2%	5.4%	$57,606	8.7%	5.8%	0.9%
Footwear	10.0%	$22,417	4.6%	2.2%	7.7%	$87,442	4.7%	8.7%	1.2%
Medical and pharmaceutical products	8.4%	$4,013	0.4%	0.4%	8.0%	$17,733	0.5%	1.8%	6.6%
Retail	3.9%	$894	8.0%	0.1%	3.8%	$3,144	7.3%	0.3%	3.6%
Restaurants and bars	9.0%	$1,707	1.2%	0.2%	8.8%	$6,436	1.2%	0.6%	8.3%
All Sectors	**6.4%**	**$4,886**	**100.0%**	**0.5%**	**5.9%**	**$18,773**	**100.0%**	**1.9%**	**4.5%**

Source: Trucost, Damodaran (2016)

Figure 10: Profit Margins after Environmental Costs of Plastic and Alternative Material Use by Sector



Source: Trucost, Damodaran (2016)

Case Example: Toys Sector

The global toys sector, with annual revenues of US$96 billion, is highly dependent on plastics for use both in products and packaging with an estimated plastic demand of 33.7 metric tons of plastic per million of revenue. This makes the toys sector more plastic intensive than any other sector. Total plastic consumption in the toys sector is estimated at 3.2 Mt in 2015, 65% of which is used in packaging. For every metric ton of plastic used in the toys sector, an estimated 3.9 metric tons of alternative materials would be required, including:

0.6 metric tons of steel, iron or tin plate

0.4 metric tons of aluminum

0.1 metric tons of glass

2.6 metric tons of paper and paperboard

0.1 metric tons of textile

0.1 metric tons of wood

In contrast to the soft drinks and ice sector, substitution of plastics with alternatives in the toys sector increases the environmental cost per metric ton from $1,379 to $2,211, due to the increased use of metals and paper. This increase combined with the greater mass of alternative materials required leads the greatest increase in environmental costs of all consumer goods sectors due to plastic substitution.

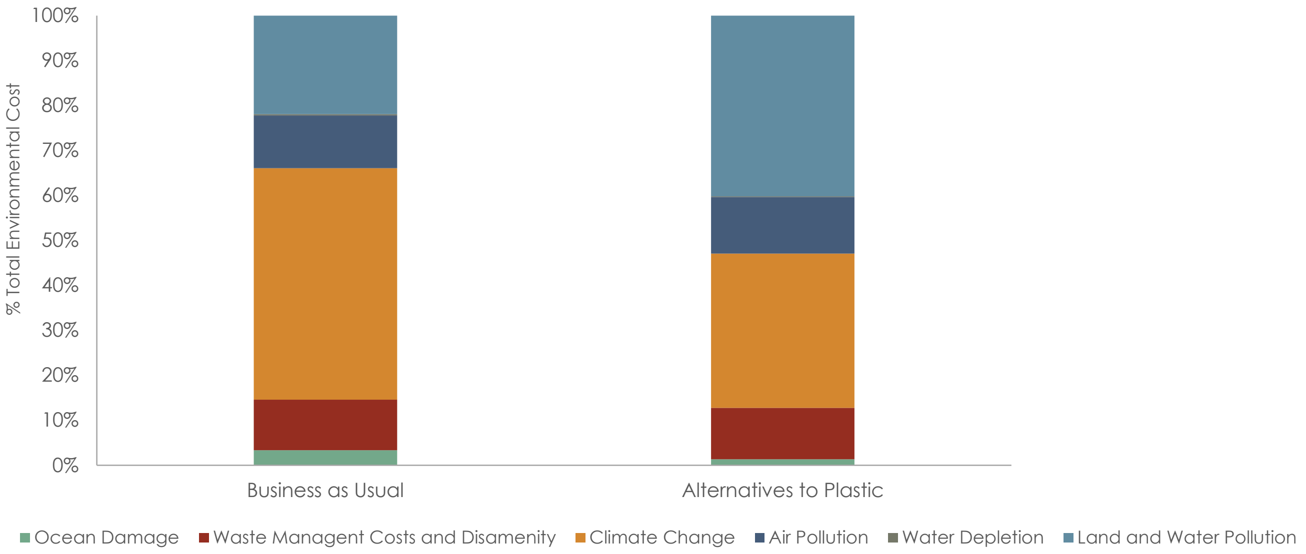
Due to the different types plastics used, and the different functions they perform, in different consumer goods sectors, the relative advantages of plastic over alternatives can vary widely. While environmental costs are estimated to increase across all sectors with the replacement of plastics with alternatives, the magnitude of this change ranges from a factor of 2 to 3 in the furniture, automobiles, and clothing and accessories sectors, to a factor of more than 4.5 in the soft drinks and ice, consumer electronics, household durables and non-durables, and toys sectors. The toys sector is the most plastic intensive sector modeled in this study and the environmental costs associated with this sector would increase by a factor of 6.3 if plastics were replaced with alternatives.

Sectors in which the relative advantages of plastics over alternatives are smallest could represent targets for innovation to further improve the environmental performance of plastic throughout the life cycle. The change in environmental costs is greatest for packaging applications, increasing by a factor of 4.2 across all sectors when plastics are replaced, compared to 3.4 for plastic used in products. This highlights the greater material efficiency of plastic in a broad range of packaging applications compared to alternatives – with less material needed to achieve the same outcome.

What are the Most Important Environmental Costs?

The production, transport and disposal of plastics and alternative materials create a range of environmental impacts which impose costs borne by society, the most material of which are captured within this study. The environmental cost of plastics under the business as usual scenario are dominated by greenhouse gas emissions (51%) and land and water pollutants (22%), with small contributions from air pollutants (12%), external waste management costs (11%) and damage to the oceans (3%). Water depletion costs in the plastics sector are negligible in the context of the broader social cost of the sector.

Figure 11: Share of Total Environmental Costs per Impact (%)



Source: Trucost

Land and water pollutant emissions dominate the environmental costs of alternatives at 40% of total costs, followed by greenhouse gas emissions (34%), air pollution (13%), and waste management costs (11%).

Greenhouse gas emissions from consumer goods sector plastic use are estimated at over 565 Mt of CO_2 equivalent, or 6.7 metric tons CO_2e per metric ton of plastic used. This compares favorably with alternatives to plastic in aggregate at 1,446 Mt CO_2e. However, the higher greenhouse gas emissions from alternatives are purely a function of the increased quantities of alternative materials required, with emissions per metric ton of material estimated at 4.2 metric tons CO_2e per metric ton on average.

The cost of land and water pollutants per metric ton of plastic is lower on average than that of alternative materials at $362 and $626 per metric ton respectively. While this may seem counterintuitive at face value, the high cost of land and water pollutants associated with alternatives to plastic is due primarily to the replacement of plastic with steel and aluminum, which also have high land and water pollutant costs.

Where are the Environmental Costs Concentrated in the Value Chain?

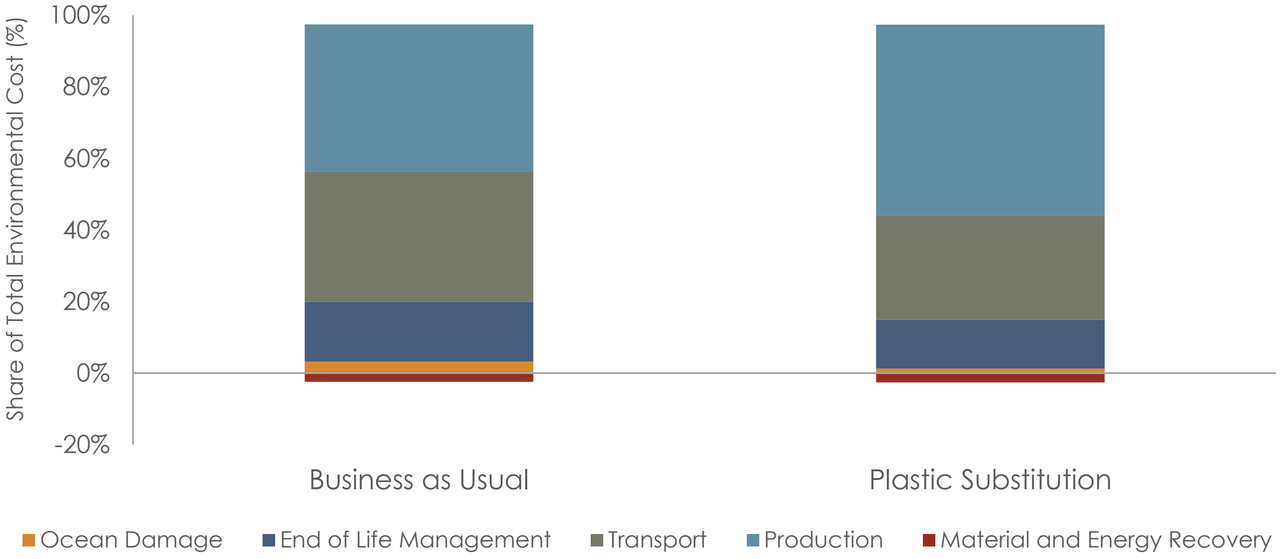
As shown in Figure 12, the greatest share of environmental costs are created in the upstream material production and transport to market phases of the value chain, in both the business as usual and alternatives to plastic scenarios. Approximately 82% of businesses as usual costs occur upstream, while in the alternatives to plastic scenario a slightly greater proportion (87%) occur upstream.

The operations and supply chain of the plastic manufacturing sector account for approximately 43% of the environmental costs under business as usual, highlighting that sustainability strategies implemented by the sector could have a significant impact on total environmental costs. These opportunities are explored further in Part B.

Avoided environmental costs due to the recovery of materials through recycling or energy recovery through incineration, are small relative to the overall costs of material use in both scenarios. At $4 billion and $15 billion in the business as usual and alternatives to plastic scenarios respectively, the avoided burdens represent just 3% of the total environmental cost of material use. This low environmental return on material and energy recovery systems is due primarily to low recovery rates globally, and even in developed economies in North America and Europe. While recovery rates are higher on average for the alternatives to plastic, some of the included materials are not commonly recyclable under typical municipal waste systems, reducing the overall recovery rate for the alternatives.

This suggests that while recycling and energy recovery can contribute to reducing environmental costs, in the case of consumer goods sector plastic and alternatives use, the greatest environmental return on investment is likely to arise from more efficient product and packaging design, and processing technologies that use less material per unit of function (greater material efficiency).

Figure 12: Share of Environmental Costs by Value Chain Stage (%)



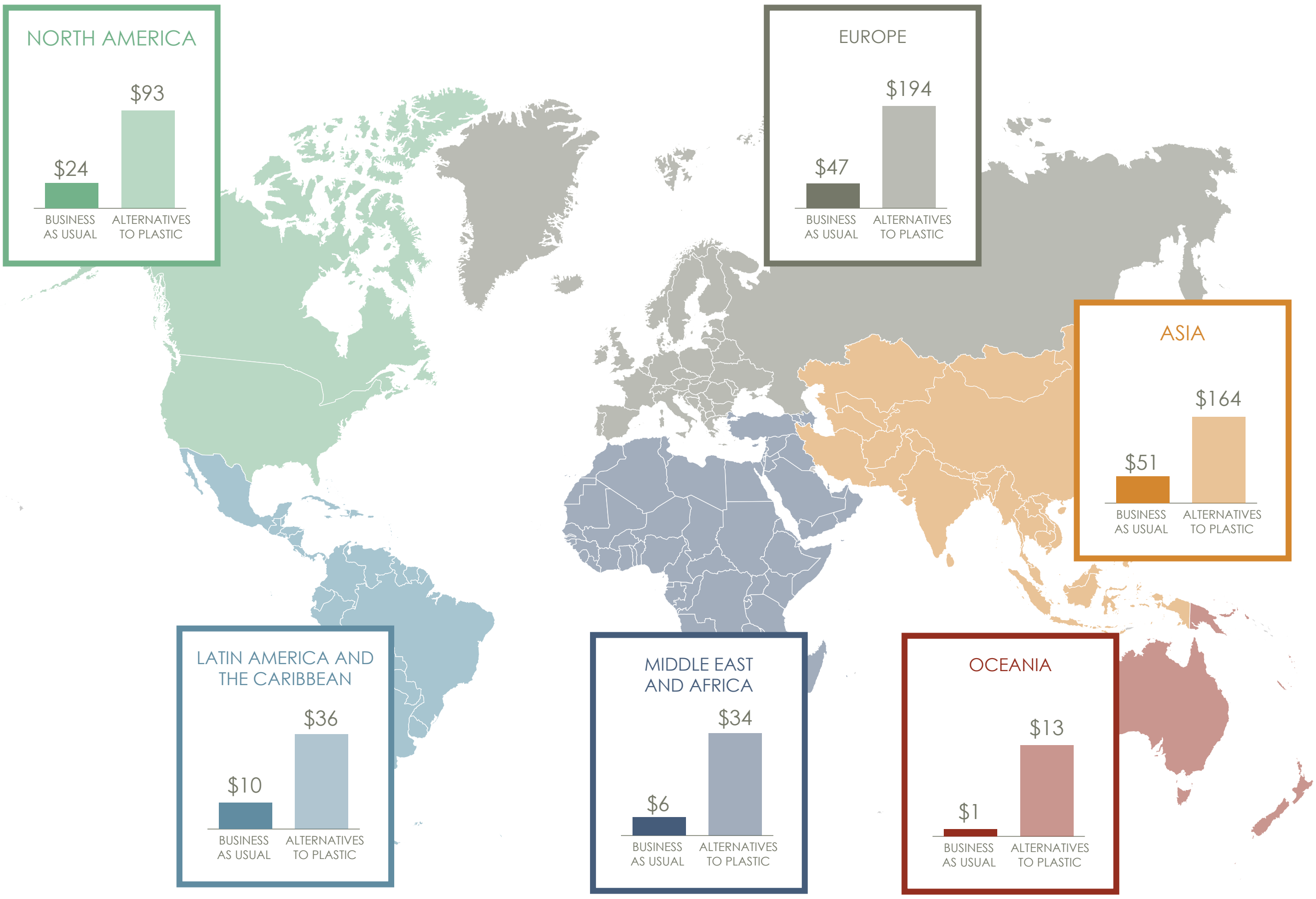
Source: Trucost

Which Regions have the Greatest Environmental Costs?

Figure 13 presents the distribution of environmental costs in the business as usual and alternatives to plastic scenarios across the six regions included in this study: Europe, North America, Asia, Oceania, Latin America and the Caribbean and the Middle East and Africa. Each region's environmental impacts were estimated based on its share of the market in each consumer goods sub-sector, and its share of global plastics production. Environmental impacts were valued based on region-specific environmental valuation coefficients that take account of local conditions such as water scarcity, population density and the mix of natural ecosystems.

Europe and Asia shoulder the largest share of environmental costs associated with consumer goods sector plastics and alternatives use. Europe is a major consumer goods sector market, managing a large proportion of end-of-life consumer goods products, and is a major producer of plastics globally. China holds a smaller share of the global consumer goods sector, but shoulders disproportionately high environmental costs due to poor waste management systems in comparison to North America and Europe.

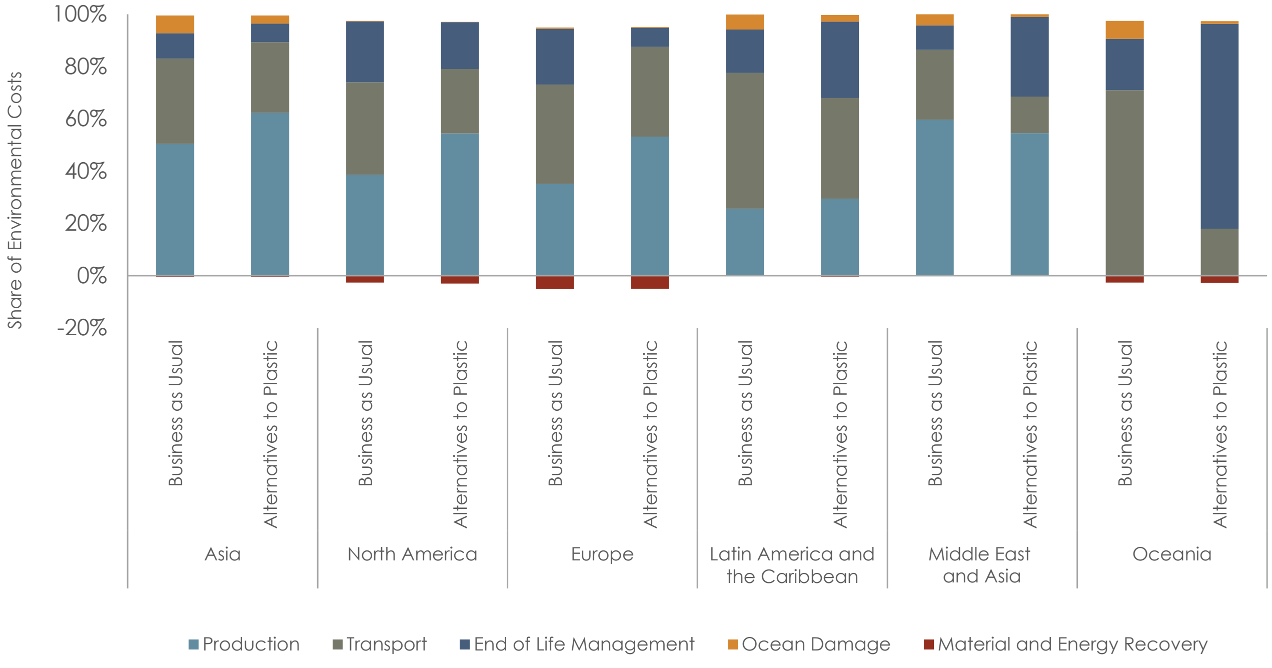
Figure 13: Environmental Costs by Region – Business as Usual vs Alternatives to Plastic



Source: Trucost

As highlighted in Figure 14 below, end-of-life management and ocean damage costs are greatest in low and middle-income regions in Asia, Latin America, the Middle East and Africa. This is due to a combination of relatively high waste mismanagement rates, low material and energy recovery rates and high landfilling rates.

Figure 14: Share of Environmental Costs by Region and Life Cycle Stage



Source: Trucost

What are the Potential Benefits of Plastics in the Use-Phase?

This study was designed to evaluate the changes in environmental costs that could be expected if plastic were replaced with a mix of alternatives that serve an equivalent function in products or packaging applications. Thus in many cases, there is no functional difference between plastics and alternatives in the use phase for consumer products. There are however some examples where plastics offer advantages over alternatives in aspects other than the primary function. Trucost has developed two case studies focusing on the food and automobile sectors to highlight the potential environmental benefits of plastics in the use phase in specific consumer goods applications.

Lightweighting in the North American Automobile Sector

The transportation sector is one of the main contributors to greenhouse gas emissions in the USA (NASA, 2009), accounting for 26% of total greenhouse gas emissions in 2014 (EPA, 2016a). Passenger cars and light-duty trucks are the most significant contributors to transport greenhouse gas emissions (EPA, 2016a). Passenger vehicles and heavy-duty trucks are also a key source of air pollution, emitting particulates, carbon monoxide, nitrogen oxides, benzene and hydrocarbons at the tail pipe. Air pollution is one of the most important environmental risks to human health and is associated with reduced life expectancy, cardiovascular disease and respiratory problems (WHO, 2014). Air pollution also presents hazards to natural ecosystems and agriculture, threatening biodiversity and crop yields (DEFRA, 2013). The social cost of air pollutant emissions is therefore high.

In light of its contribution to greenhouse gas emissions, the transport sector has been identified in the Intended Nationally Determined Contributions (INDC) outlined by several countries under the UN Framework Convention on Climate Change. The US government has committed to a 17% reduction in transport greenhouse has emission by 2025 (from a 2005 baseline) (IEA, 2015) and the European Union seeks to reduce road transport emission by 70% by 2050 (de Wilde and Kroon, 2013). Fuel economy standards, which reduce on road fuel combustion for new vehicles, are an important means of achieving these targets.

Automobile manufacturers have sought to meet increasing fuel efficiency standards through a range of strategies, including by reducing vehicle weight through the use of lightweight component materials. A study conducted by the US Department of Energy found that reducing a vehicle's weight by 10% could increase its fuel economy by 6-8% (Pyper, 2012). Manufactures like Ford and BMW have used plastic composite materials that meet durability requirements but can weigh 10-50% less than the alternative (ibid). As fuel economy standards increase, manufacturers will continue to look to materials such as plastics to help increase fuel efficiency and reduce environmental impacts.

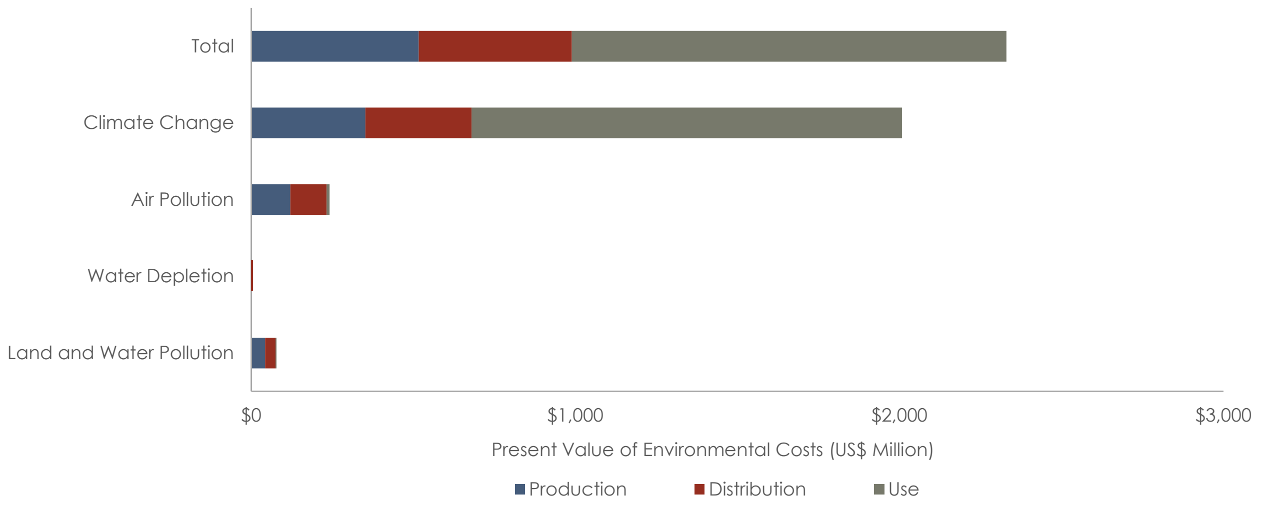
In this study, Trucost estimates that the global automobile sector consumed approximately 6.5 Mt of plastic in 2015, primarily for use in vehicle components. It is estimated that 14.8 Mt of alternative materials would be needed to functionally replace the use of plastic in this sector – an increase of more than a 230% by mass. Altering the weight of vehicles has direct implications for the fuel consumption of these vehicles, particularly in internal combustion engine vehicles where one third of the vehicle's total fuel consumption is directly dependent on weight (Koffler and Rohde-Brandenburger, 2010). Lightweight design has been recognized as one of the key measures for reducing vehicle fuel consumption, this means that replacing plastics in vehicles with the heavier alternatives leads to increased fuel consumption and as such, increased environmental impacts and cost.

In this case study, Trucost sought to estimate the total life cycle environmental costs associated with increased fuel consumption that would result if plastic in diesel and gasoline passenger vehicles were replaced with alternatives in the North American automobile sector. This case study was based on the methodologies described in PE International (2012) and Koffler & Rohde-Brandenburger (2010). This method estimates the increase or decrease in fuel consumption as compared to a business-as-usual scenario based on a change in vehicle weight – due in this case to the replacement of plastic components with alternative materials.

The North American market accounts for 15.8% of the global automobile market and gasoline and diesel driven passenger vehicles and light trucks account for 85% of this market (PE International, 2012). Vehicles were assumed to have a total lifetime mileage of 150,000 miles (PE International, 2012) and future environmental costs over the life of the vehicle were discounted to present values.

Trucost estimates that if plastic components in passenger vehicles produced in North America in 2015 were replaced with alternative materials, the vehicles would require an additional 336 million liters of gasoline and diesel to operate over their lifetimes. The environmental cost of producing, distributing, and combusting this fuel in the first year is estimated to be US$176 million and US$2.3 billion over the lifetime operating mileage of vehicles produced in 2015. This equates to an environmental cost of $169 per gasoline or diesel passenger car sold in North America in 2015. The greatest environmental cost arises from greenhouse gas emissions ($2 billion), primarily arising at the tail pipe. Environmental cost from land and water pollutants account for US$0.1 billion with the majority of the impacts split between fuel production and distribution. Together, GHGs and land and water pollutants account for 90% of the total environmental cost of substituting plastics with alternative materials in the North American automobile sector.

Figure 15: Estimated Lifetime Environmental Costs of Reduced Fuel Efficiency in Passenger Vehicles Sold in the USA in 2015 (US$ Million)



Source: Trucost

Reducing Food Waste in Packaged Meat Products

The UN Food and Agriculture Organization (FAO, 2011) estimates that around one third of all food produced is lost or wasted globally. Food loss can occur throughout the supply chain from farm and processing stage losses through to wasted food in retail outlets and households. While food loss in developing countries and industrialized countries are equally likely to occur, they tend to occur at different stages of the supply chain (FAO, 2011). In developing countries, more than 40% of food loss occurs at the post-harvest and processing levels whereas in industrialized countries, about 40% of food loss happens at the retail or consumer level (ibid). In the United States, for example, 31% of the available food supply at the retail and consumer level is wasted (Buzby, Wells and Hyman, 2014).

Besides the lost economic value of wasted food, the natural resources and environmental impacts involved in producing the wasted food are also lost. These scale of these resources and impacts can be staggering, in the US, food production accounts for 80% of all freshwater use (USDA, 2015a), 51% of land use (USDA, 2015b), and 15% of the country's energy budget (USDA, 2012). Food waste therefore accounts for 25% of all US freshwater use and 4% of total US oil consumption (NRDC, 2013). In addition to the environmental cost of lost resources, most food waste end up in landfills where it releases methane gas as it decomposes. The carbon footprint of food waste is estimated at 3.3 billion metric tons of CO_2e with cereals and meat accounting for 34% and 21% of that footprint respectively (FAO, 2013).

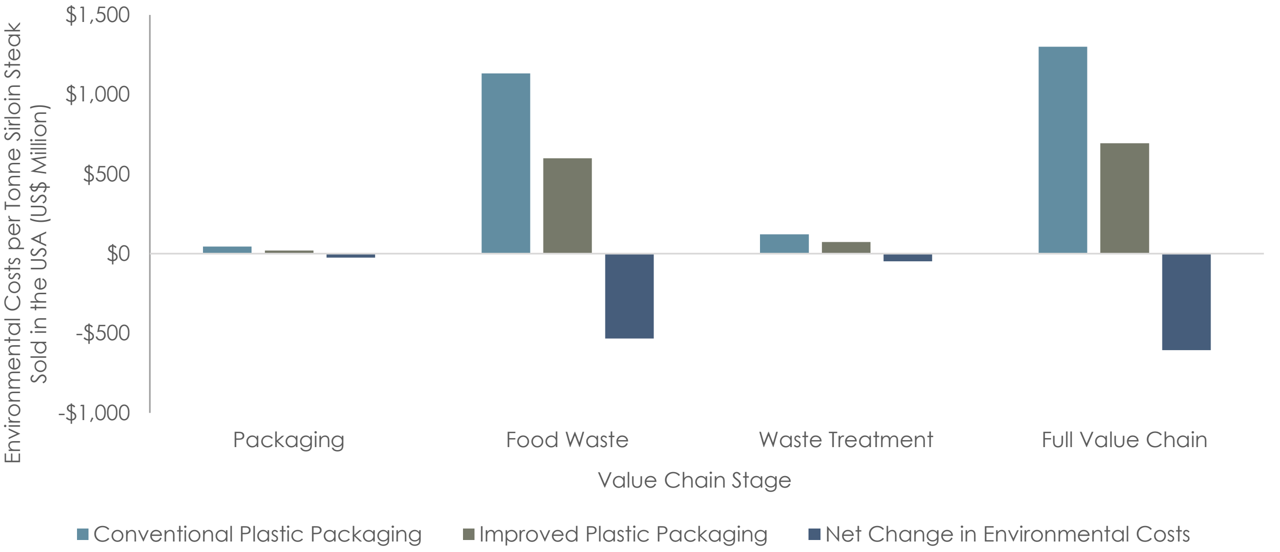
Approximately 60% of household food waste arises from products not used due to being perishable or having a short shelf-life (WRAP, 2016). One of the most effective ways to extend shelf life and reduce food waste is through packaging. Research has shown that how long food stays fresh is a priority for consumers. Packaging innovations such as Modified Atmosphere Packaging (MAP) and vacuum skin packaging (VSP) have been shown to extend freshness (Denkstatt, 2015). Continued innovation and adoption of new packaging technology could further shelf life extension and reduce household food waste, thereby curbing greenhouse gas emissions and natural resources lost to food waste.

In this case study, Trucost examines the potential environmental cost savings associated with packaging to reduce the waste of beef, one of the most environmentally costly food products. This analysis builds upon a study by Denkstatt (2015), which quantified the reduction in food waste achieved through different types of packaging for sirloin steak. The case study considers two options for packaging sirloin steak:

- Conventional packaging including an expanded polystyrene tray sealed with plastic film with a modified atmosphere.
- Improved composite (polystyrene, ethylene vinyl acetate and polyethylene) skin packaging that can extend the shelf life of the steak by 6-16 days and reduce food waste. This packaging also allows the steak to be cut and aged in the package, reducing the need for separate aging packing (Denkstatt, 2015).

The environmental impact associated with the production and disposal of the packaging material, and the production and treatment of waste beef, was estimated to assess the net change in impacts associated with the shift in packaging type. Figure 16 shows the environmental cost per metric ton of sirloin steak sold in the USA in each packaging type and the net change in environmental costs through the use of improved plastic packaging. The net reduction in environmental costs is estimated at $606 per metric ton of steak, primarily due to avoided environmental costs associated with the production of beef that is ultimately wasted. For consistency with other components of this study, this analysis included only environmental costs associated with greenhouse gas emissions, water consumption and the emission of air, land and water pollution. It does not include the costs of land occupation, which can be extensive in beef cattle production. A recent study for the FAO undertaken by Trucost (FAO, 2015) found that the conversion of natural land to pasture for beef production could account for 75% of the environmental cost of production.

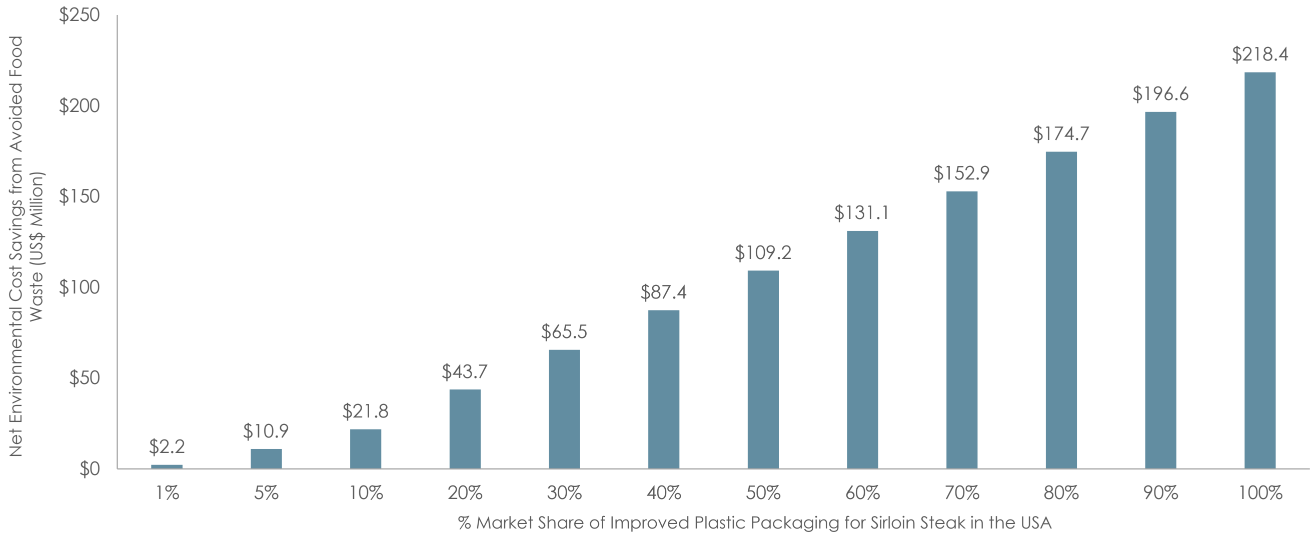
Figure 16: Environmental Costs of Sirloin Steak Packaging and Food Waste per Metric Ton (US$)



Source: Trucost, Denkstatt (2015)

As the current market penetration for improved plastic meat packaging is unknown, Figure 17 estimates the environmental benefits that could be achieved through prevented food waste as the market share for improved packaging formats increases as a proportion of the total US market for sirloin steak. According to the USDA, over 11 Mt of beef was consumed in the US in 2014. Based on market share, this amounts to almost 0.36 Mt of sirloin. If just one percent of sirloin sold in the USA were packaged in improved packaging rather than conventional packaging, then over 544 metric tons of food waste could be avoided. The net environmental savings associated with this change, including the production and disposal or the packaging materials and wasted food, amounts to over US$2.2 million per one percent increase in market share for improved packaging. Trucost estimates that at least $218 million in environmental costs could be saved per annum, in net terms, if 100% of sirloin steak sold in the USA were packaged in improved packaging that reduces food waste.

Figure 17 Estimated Environmental Cost Savings Due to Avoided Food Waste Through the Use of Improved Packaging for Sirloin Steak in the USA (US$ Million)



Source: Trucost

The results illustrate that even small improvements in packaging can lead to large environmental benefits, particularly for high value and high environmental cost food products such as beef.

Conclusions

This study represents a high-level materiality assessment of plastic use and its potential alternatives in the consumer goods sector at a global scale, identifying key hotspots of environmental impact across the lifecycle and important trade-offs between plastics and alternative materials. To more precisely understand the true environmental costs and benefits that could result from the substitution of plastics with alternatives, or vice versa, more detailed investigations of material substitutions in specific product and packaging applications using lifecycle analysis techniques will be needed. Nevertheless, the following important conclusions can be drawn from this study:

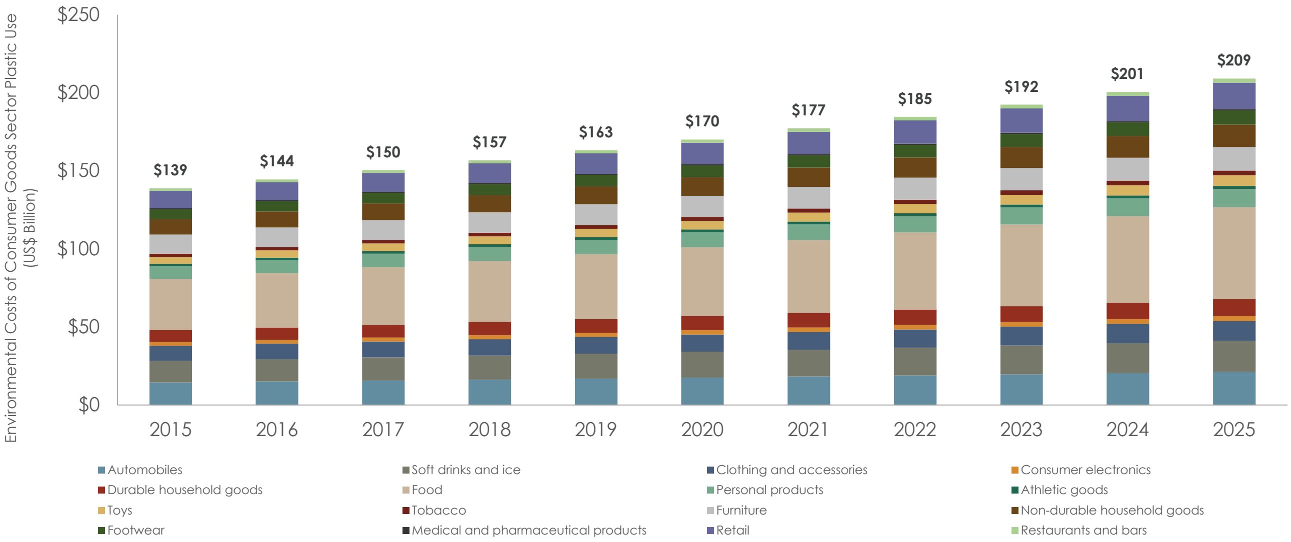
- Replacing plastic with alternative materials in common consumer goods applications using current technology is unlikely to reduce environmental costs at the sector level. The environmental costs of alternatives are estimated to be almost four times that of plastics.
- The higher environmental costs of alternatives to plastic are driven by the poorer material efficiency of these materials when used in common consumer goods applications – on average, replacing one metric ton of plastic requires 4.1 metric tons of alternatives materials across the sector.
- While recycling and energy recovery can contribute to reducing the environmental cost of the sector, costs are primarily concentrated in the upstream production, conversion and transport phases of the lifecycle. Thus greater opportunities to reduce environmental costs may be found in improving plastic use efficiency – using less plastic to achieve the same purpose.
- The cost of plastic marine debris arising from the consumer goods sector is over $4.7 billion per annum, and despite the greater biodegradability of many alternative materials (Ocean Conservancy, 2010), the ocean cost of alternatives is estimated to be 150% greater than this due to the sheer quantity of alternative materials needed to replace plastic. The greatest opportunities to reduce the ocean cost of plastic may lie in investments in waste collection systems in Asia.
- Plastic can offer significant environmental advantages over alternatives in the use phase, including in the lightweighting of automobiles and in the use of innovative packaging formats to minimize food waste.
- The environmental cost of plastic use in the consumer goods sector is equivalent to almost 20% of the total revenue of the global plastic products and packaging industry in that year ($739 billion (IBIS World, 2015)). While not all of this cost can be attributed to the plastics manufacturing sector, the sector has an important role to play in reducing this cost both directly, through changes to manufacturing processes, and indirectly, by facilitating changes in the industries that depend on plastic.

Part B of this report investigates how interventions that change how plastics are used in the consumer goods sector could help to reduce the environmental cost of plastics.

Part B: The Environmental Benefits of More Sustainable Plastic Use

Part A of this study demonstrates that replacing plastic with alternatives under current technologies will not reduce environmental costs, but will instead increase environmental costs substantially. Yet the environmental cost of plastic use in consumer goods is over $139 billion per annum, and if historical growth trends in the consumer goods sector persist (MarketLine, 2014), costs could increase to $209 billion by 2015 (Figure 18).

Figure 18 Projected Future Environmental Costs of Plastic Use in the Consumer Goods Sectors (US$ Billion)



Source: Trucost

Internalization of even part of these costs through regulation, reputational damage or restricted license to operate, represents a material risk to the profitability of the consumer goods sector and the plastics industry more broadly. Consequently, urgent action is needed to alleviate the environmental costs of consumer goods sector plastics use and safeguard the profitability of these sectors into the future.

Part B of this study seeks to explore how the environmental costs of plastics could be reduced through practical interventions at various stages of the plastics life-cycle.

Innovations in Efficient Packaging Design

Plastic offers an incredibly versatile and important packaging solution for food and drinks products and can help to extend shelf lives and reduce food wastage. Trucost estimates that the global food and soft drinks sectors consumes over 32 Mt of plastic resin for use in packaging each year, over half of this occurring in Europe and North America. Through better packaging design and more efficient packaging conversion technology, it is possible that the amount of plastic required to fulfill a given packaging need could be reduced. An important trend in improving packaging efficiency that has been seen in recent years is the shift from traditional rigid packaging formats to flexible formats (Smithers Pira, 2013). Flexible packaging can be significantly lighter than rigid packaging in the same application, has superior barrier properties, enables larger package sizes and is attractive to product manufacturers as it can be more easily decorated and branded (Smithers Pira, 2013). The increased use of flexible packaging is just one example of the potential for the plastics industry to produce innovative value-added plastic packaging formats that create value for customers whilst reducing the quantity of plastic needed per unit of packaging.

In this scenario Trucost modeled the impact of reducing the weight of plastic used in packaging in the food and soft drinks and ice sectors in Europe and North America by 30%, without increasing manufacturing emissions or reducing the recycling rate. A similar improvement was achieved by the Coca Cola Company which reduced the weight of its 600ml PET beverage containers by 25 percent through improved design (The Coca Cola Company, 2012).

If the amount of plastic used in packaging could be reduced by 30% across the Food and Soft Drinks sectors in North America and Europe, what would be the impact on the environmental costs of these sectors?

$7.3 Billion in Environmental Costs • 28 Million Metric Tons CO_2e

Trucost estimates that total environmental costs could be reduced by $7.3 billion per annum and greenhouse gas emissions could be reduced by over 28 Mt per annum. This equates to approximately 5% of the total environmental cost of plastic use in these sectors. While flexible packaging has environmental benefits, it can be more challenging to recycle due to the use of multiple laminated plastic layers and aluminum layers to create high barrier packaging – both of which increase the complexity of recycling processes (Packaging Digest, 2014). However, since the environmental costs of plastic use are concentrated in its production and transport it is likely that more efficient packaging design will deliver a net reduction in environmental costs even if this efficiency gain is achieved through means that reduce recyclability. Environmental costs can be reduced further if recycling rates for new flexible packaging formats are maintained or increased relative to business as usual.

Reducing the Flow of Plastics into the Oceans

As described in Part A, the total environmental costs of the 2.5 Mt of plastic marine debris arising from the consumer goods sector each year is at least $4.7 billion. Trucost estimates that almost 75% of this marine debris originates in Asia and is associated with inadequate waste collection systems and leakage from waste management systems. A recent study by Ocean Conservancy (2015) highlighted expanding access to waste collection systems as a key strategy to reduce plastic inflows to the oceans in the short term and recommended an increase in collection rates to a weighted average of 80% across Asia in the next decade.

If weighted average waste collection rates in Asia were increased to 80%, what would be the impact on marine debris and environmental costs?

1.1 million metric tons (45%) plastic waste diverted from the ocean • $2.1 billion in ocean costs avoided

Increasing municipal waste collection to 80% across Asia would reduce plastic marine debris generation from the consumer goods sector by 1.1 Mt and save $2.1 billion in ocean costs per annum. Assuming an average financial cost of $149 per metric ton to collect municipal waste (Hoornweg and Bhada-Tata, 2012), the total additional waste collection costs in Asia under this scenario would be $1.1 billion (additional 7.2 Mt of plastic collected). This equates to a return on investment of at least $1.9 in avoided ocean damage costs per $1 invested in waste collection services.

However, the reduction in ocean costs could be entirely offset by increases in the financial, disamenity and environmental damage costs of collecting and managing the additional waste. As such, improvements in waste collection services must be paired with increases in material and energy recovery to ensure that a genuine net reduction in environmental and social costs can be achieved.

Opportunities to Green the Plastics Manufacturing Sector

As demonstrated in Part A, over 80% of the environmental costs of plastic use in the consumer goods sector is concentrated in the upstream components of the value chain, with over 43% associated with the manufacturing of plastics. As such, sustainability initiatives implemented in the plastics manufacturing sector have great potential to reduce the environmental cost of plastic use in the consumer goods sector.

Over 48% of greenhouse gas emissions, 12% of land and water pollutant costs, and 86% of air pollutant costs associated with the plastic manufacturing sector (both directly and among direct suppliers) are linked to the purchase of electricity, predominantly from fossil fuel sources. By increasing the share of electricity sourced from low carbon energy sources such as wind, hydro, solar and geothermal, the plastic manufacturing sector can significantly reduce its environmental cost footprint.

How would environmental costs change if the plastic manufacturing doubled its current share of low carbon electricity supply?

38 million metric tons CO_2e saved • $7.6 billion in Environmental Costs Saved

Trucost estimates that if the plastic manufacturing sector doubled the current share of low-carbon energy sources in its electricity supply, greenhouse gas costs from the sector would decrease by 15%, land and water pollutant costs by 4% and air pollutant costs by 28%, resulting in an US$7.6 billion (13%) decrease in the total environmental costs of the plastic manufacturing sector. This equates to a 5% reduction in the total environmental costs of consumer goods sector plastic use. With a shift to 100% low-carbon energy, greenhouse gas, land and water pollution and air pollution costs would decrease by 31%, 8% and 57% respectively, delivering a $15 billion decrease in total consumer goods sector plastic costs. This equates to 25% of total plastic manufacturing sector environmental costs. While a complete shift to low carbon electricity sources may be not be feasible for all plastic manufacturers in the short term, this scenario demonstrates the magnitude of environmental costs that could be avoided through more environmentally sustainable electricity sourcing.

How would environmental costs change if the plastic manufacturing sourced 100% of its electricity needs from low carbon sources?

77 million metric tons CO_2e saved • $15 billion in Environmental Costs Saved

The Environmental Return on Investment in Material and Energy Recovery

The circular economy is an alternative to the traditional linear make-use-dispose economic model, which prioritizes the extension of product life cycles, extracting maximum value from resources in use, and then recovering materials at the end of their service life. An important principle of the circular economy is increasing the capture and recovery of materials in waste streams so that they can be recycled and reused in new products. Recycling and energy recovery is an important means of reducing the net environmental costs of plastic use by displacing primary plastics and energy production with that recovered from post-consumer waste. A 2016 study by the Ellen MacArthur Foundation (2016) found that 95% of plastic packaging material is currently lost due to landfilling and poor waste management practices. The value of the lost material is estimated to be US$80-120 billion per annum in addition to the external environmental costs that are the subject of this report. Under the European Union Circular Economy Package (European Parliament, 2016), a target for reuse and recycling of plastic packaging materials of 55% has been suggested, with a maximum of 10% of all municipal waste to be disposed in landfill by 2025. This represents a significant increase in current packaging recycling rates (currently 20%) and major reduction in landfilling rates (currently 45%).

How would environmental costs change if the plastic packaging recycling rates were increased to 55% and landfilling reduced to 10% in Europe and North America?

$4.8 billion in Environmental Costs Saved if Applied to Packaging • **$3.1 billion in Environmental Costs Saved if Applied to Products**

Trucost sought to assess the potential impact of increases in recycling, consistent with circular economy principles, on the environmental costs of consumer goods sector plastic use by modeling an increase in plastic packaging recycling rates to 55%, reduction in landfilling to 10% (with the remainder sent to incineration with energy recovery) in both Europe and North America in 2015. Under this scenario, the environmental costs of plastic use could be reduced by US$4.8 billion per annum including US$3.9 billion due to the environmental benefits of recovered plastic and energy displacing virgin production. If this were expanded to include both plastic packaging and product waste (excluding automobiles and waste electronics), avoided environmental costs would increase to US$7.9 billion per annum including US$6.3 billion in benefits from material and energy recovery. The benefits of increased material recovery in this scenario outweigh the additional external costs of waste management by a factor of 3.9 demonstrating the significant potential environmental return on investments in recycling.

Other Interventions to Improve the Sustainability of Plastic Use

In addition to the potential interventions modeled quantitatively in this study, there are a range of technologies and strategies, some emerging and some already on the market that could aid in improving the sustainability of plastic use in the future. While not exhaustive, some examples are described below:

- **Bio-based plastic** technologies offer an opportunity to displace fossil fuel based feedstock in the manufacturing of plastic, potentially reducing life cycle greenhouse gas emissions by 30-80% compared to conventional plastic (UNEP, 2014b). However, the source of biomass used to produce bio-plastics can significantly influence their environmental performance. For example, the production of bio-based plastics from commodity food crops such as grains, sugar or vegetable oils can lead to increased commodity prices due to competition and can drive conversion of natural landscapes to agriculture (Broekema, 2014). These challenges could be overcome through the use of biomass feedstock that require limited land and inputs to produce, such as waste biomass streams from other industries or algae biomass (Heikkinen, 2015). These challenges highlight the need for rigorous assessment of the environmental performance of bio-based plastics using life cycle assessment techniques in specific applications and under specific production conditions to determine whether a true net environmental benefit can be achieved.
- **Biodegradable plastic**, including those manufactured from renewable biomass (as described above) or produced from petrochemicals but with additives to enhance biodegradability, offer a potential solution to the problem of persistent plastic debris in the environment (UNEP 2014b). However due to the decomposition of these materials, the switch to biodegradable plastic may not deliver net reductions in greenhouse gas emissions. Furthermore, the rate of biodegradation can vary significantly depending on the disposal conditions and the composition of the plastic. Thus, biodegradable plastics may not necessarily decompose readily in the natural environment and may only deliver true environmental benefits in countries with the infrastructure necessary to capture and decompose these materials (ibid). A recent study by UNEP (2015) finds that on the current balance of scientific evidence, adoption of current biodegradable plastic technologies will not significantly decrease the quantity or impacts of plastic entering the ocean.
- **‘Design for recycling’** strategies can help to maximize the recovery rate for waste plastics, particularly in packaging applications, by reducing barriers to recycling arising from product design. WRAP (2016) has developed guidelines for packaging manufacturers, in conjunction with recyclers, in the UK to help maximize the recycling of common plastic packaging types such as pots, tubs, trays and bottles.

Conclusions

The scenarios and interventions tested in Part B are hypothetical and by no means exhaustive, but serve to illustrate the scale of environmental net benefits that could be achieved through practical changes to the way in which plastics are produced, used and managed. Key conclusions that can be drawn from Part B include:

Enhancing the utilization of low-carbon electricity in the plastic manufacturing sector has significant potential to reduce not only greenhouse gas emissions, but also air, land and water pollution created from the mining and burning of fossil fuels. Trucost estimates that doubling global average low-carbon electricity sourcing in the plastics manufacturing sector could reduce the overall environmental cost of consumer goods plastic use by $7.6 billion, and reduce the plastics sector's own greenhouse gas emissions by 15%. Shifting to 100% low-carbon energy could increase these benefits to US$15.2 billion and 31% respectively. These benefits may be delivered in part as global electricity generation transitions toward low-carbon sources in line with commitments under the UN Framework Convention on Climate Change. However, this process could be accelerated via proactive strategies to make greater use of low-carbon electricity in the plastics sector.

Innovation in plastic material and packing conversion technology that enables the same or superior packaging applications to be delivered with less plastic could significantly reduce the costs of plastic use across the value chain whilst simultaneously creating opportunities to deliver new packaging formats to the consumer goods sector. Reducing the weight of plastics used in packaging for the food and soft drinks and ice sectors by 30%, through for example a switch from rigid to flexible packaging, could reduce environmental costs by over $7.3 billion.

Along with plastic production, transport is among the most significant drivers of the environmental cost of plastic use in the consumer goods sector at over $53 billion in 2015. Modest improvements of 20% in the fuel efficiency of the transport fleet, including modal shifting, advances in engine technology and a transition to electric, hydrogen, hybrid or other low emission vehicles, could reduce transport impacts by $10.6 billion.

Improvements in municipal waste collection systems, particularly in Asia, could have a major impact on reducing the flow of plastic waste into the oceans but may not deliver a net improvement in environmental costs unless combined with improvements in recycling and energy recovery from the waste collected.

Major increases in the recovery of post-consumer waste plastic, consistent with circular economy principles, could reduce environmental costs by over US$7.9 billion per annum if implemented in Europe and North America.

Key Recommendations on the Pathway to More Sustainable Plastic Use

The pioneering Valuing Plastic study (UNEP, 2014) established plastic use in the consumer goods sector as an important natural capital risk, creating significant costs to society, which if internalized through regulation, consumer pressure and other mechanisms, could threaten future revenues and profitability across the sector. This study sought to extend the research presented in Valuing Plastic with an explicit focus on examining how plastic use in consumer products could be made more sustainable. Based on this research, Trucost recommends the following key actions to aid in creating a pathway to more sustainable plastic use in the future.

Environmental Leadership in the Plastics Industry. The plastic manufacturing industry has direct influence, or indirect influence via its supply chain management practices, over a significant share of the environmental costs of plastic use in consumer goods sector, and other sectors. Thus the industry is well positioned to play an enhanced leadership role in driving improvements in the environmental performance of the plastics value chain. Increased sourcing of electricity from low carbon sources (such as wind, solar and hydro) and improvements in the fuel efficiency to the logistics fleet serving the plastics industry represent key opportunities to substantially reduce the environmental costs of the sector in the short to medium term. In the longer term, innovative alternative feedstock technologies that replace fossil fuel feedstock and 'design for recyclability' strategies are among the many opportunities to reduce the environmental costs of plastics across the life cycle.

Innovative Plastic Applications to Improve Environmental Efficiency. The packaging sector is the largest market for plastics in the USA (SPI, 2015) and is expected to grow rapidly to 2020 driven by increasing demand from emerging economies in Asia, the Middle East and Africa (Smithers PIRA, 2016). With this growth come opportunities to continue the plastic manufacturing industry's investment in more efficient packaging products and the technologies needed to manufacture them. Improving plastic packaging efficiency by reducing the amount of resin needed to deliver the desired packaging outcome or enabling reuse, can not only reduce the environmental cost intensity of the plastic manufacturing sector by reducing demand for raw materials and energy, but can also enable environmental gains in the logistics and waste management phases of the value chain by lightweighting consumer products. Enabling reuse may increase the initial quantity of resin needed for a given application, but over multiple cycles of reuse can reduce resin demand over the life cycle. As demonstrated in this study, reducing the mass of plastic used in packaging in the Food and Soft Drinks sectors alone could reduce the environmental costs of plastic by almost $7.3 billion per annum. Furthermore, where innovative packaging designs better protect and extend the shelf life of food products, the environmental benefits of avoided food waste can be many times greater than the costs of producing the packaging. Similarly, the development of novel plastic components that can displace metal components in automobiles offers significant potential environmental benefits through improved fuel efficiency over the life of the vehicle.

Stop the Accumulation of Plastic Waste to the Ocean. The findings of this study reaffirm that of previous research highlighting that poor waste management systems in emerging economies are the most important driver of the flow of plastic (and other mismanaged waste) into the ocean. Increasing the rate of municipal waste collection in these regions could substantially reduce the input of waste into the oceans, and if paired with more effective material and energy recovery, would deliver net environmental and social benefits. The impact of plastic on the global oceans could be further reduced through strategies to better capture littered and mismanaged waste on land before it reaches the ocean, expanding markets for recycled materials to increase the economic incentive to prevent waste leakage, and by limiting the use of harmful plastic additives that can be leached into the ocean over time, impacting on wildlife.

Toward a Circular Plastics Economy. Step change increases in the recycling of post-consumer plastic waste, along with energy recovery, can have a major impact on the environmental costs of consumer plastics use. As shown in this report, increasing the recovery of plastic packaging waste to at least 55% and limiting landfilling in Europe and North America alone could deliver benefits of almost $4.8 billion per annum, increasing to $7.9 billion if expanded to include plastic products. Such interventions would also help to capture some of the $80-$120 billion in lost economic value estimated by the Ellen MacArthur Foundation (2016) due to the single use of plastic packaging materials. The plastics manufacturing industry can play a role in driving this transition to a more circular economy by engaging with recyclers to optimize the efficiency and yields from plastic recovery processes, through for example, greater standardization of materials and packaging format types that enable more effective post-consumer sorting and separation. Furthermore, accounting for the true environmental and social costs of waste plastics and other materials in monetary terms, is an important step in informing better targeting of the incentives and subsidies that drive waste management systems to favor more sustainable plastic management.

Technical Appendix

Appendix 1. Methodology and Key Sources

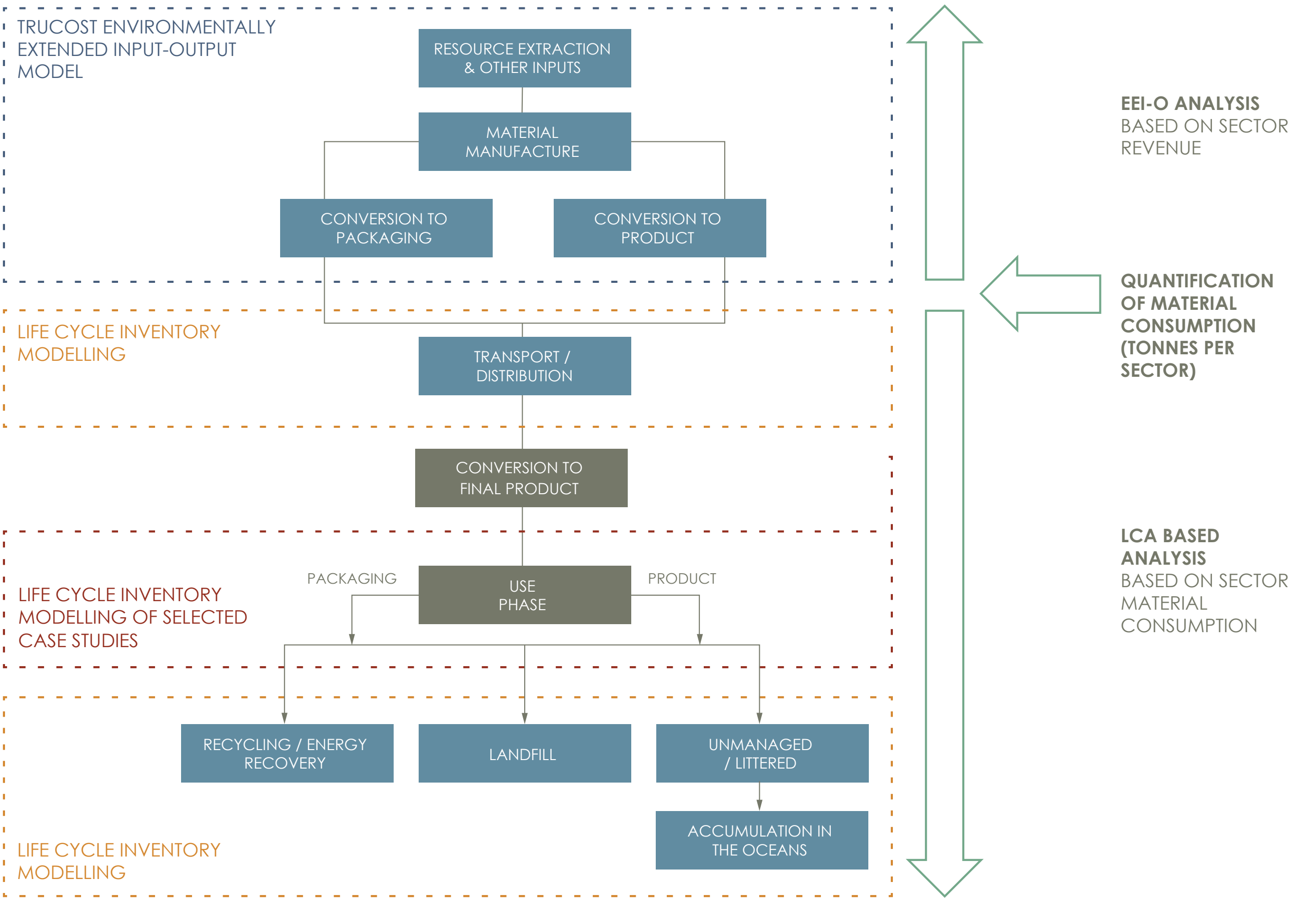
This appendix describes in detail the methodology and important data sources used to model and value the environmental costs of plastic and alternative material use in the consumer goods sector. This methodology included seven key steps:

1. **Consumer Goods Sector Selection and Mapping.** Sixteen consumer goods sectors were selected to align with the Valuing Plastic report (UNEP, 2014).
2. **Quantification of Plastic Demand.** The quantity of plastic demanded in each sector was modeled using input-output modeling.
3. **Substitution Modeling.** Modeling the functionally equivalent substitution of plastic with alternative materials in each sector.
4. **Scope and Boundary Selection.** Scope and boundaries for the quantification of environmental impacts from plastic and alternative material use were determined
5. **Impact Quantification.** Upstream and downstream impacts were quantified using input-output modeling and lifecycle analysis techniques.
6. **Valuation of the Social Cost of Environmental Impacts.** Health, environment and social valuations were applied to all impacts.
7. **Sensitivity Analysis.** Testing the sensitivity of the results to changes in key assumptions.

Figure 19 outlines the methodological approach adopted to model the environmental impacts associated with the baseline scenario, in which plastic is consumed in the consumer goods sectors, and the alternatives to plastic scenario', in which a large proportion of plastic consumption is substituted with alternative materials. Trucost has adopted a hybrid approach which utilizes an Environmentally Extended Input – Output modeling approach to assess the upstream impacts of plastic and substitute material production, and a life cycle assessment approach to assess the downstream impacts of material disposal and recycling. For the purposes of this study:

- Upstream is considered to extend from cradle to the factory gate of the producers of manufactured plastic (e.g. plastic bottles) and alternative material (e.g. aluminum cans) products, and their transport to buyers in the consumer goods sector. Please note that while transport is considered to be upstream of the consumer goods sectors, this activity was modeled using life cycle assessment methodologies consistent with the modeling of downstream activities.
- Downstream is considered to include disposal of plastic and alternative materials at the end of life.
- The use phase and any conversion of manufactured plastic and alternative material products undertaken by the consumer goods sectors is excluded from this scope of the main analysis, but two use phase case studies are considered.

Figure 19: The Business Case for Sustainable Plastics: Modeling Methodology Overview



Source: Trucost

Step 1: Sector Selection and Mapping

Input-output models map the flows of inputs through an economy and associated environmental impacts. Trucost's input-output model comprises 464 sectors spanning primary to service industries. Consumer-facing sub-sectors were selected as part of the scope of this study. All non-consumer facing sectors, such as agriculture, were excluded and may form part of future analysis. Out of Trucost's 464 sectors, 75 consumer goods sectors were selected and aggregated into sixteen higher-level sectors based on two main criteria:

- **Type of product manufactured** – certain sub-sectors were excluded based on the type of product manufactured in that sub-sector.
- **Positions within the supply chain** – certain sub-sectors were excluded based on their upstream position in the supply chain, such as the fiber, yarn and thread mills sector which is positioned upstream of the apparel manufacturing sector and would thus be captured within the supply chain of the apparel manufacturing sector.
- **No distinction was made at this stage between products and packaging.**

Each sector included in the study comprises a series of North American Industry Classification (NAICS) codes as described in Table 3.

Table 3: Sector Selection and Mapping

SECTOR	EXPLANATION	SUB-SECTORS
Athletic goods	Sports goods and equipment manufacturers.	Sporting and athletic goods manufacturing.
Automobiles	Car manufacturers. Does not include car parts manufacturers located further upstream.	Automobile manufacturing.
Clothing and accessories	Clothes and accessories manufacturers. Does include retailers.	Men's and boys' cut and sew apparel manufacturing; women's and girls' cut and sew apparel manufacturing; other cut and sew manufacturing; apparel accessories and other apparel manufacturing; other leather and allied product manufacturing; clothing and clothing accessories stores.
Consumer electronics	Includes computers, TV sets and telephone manufacturing.	Photographic and photocopying equipment manufacturing; electronic computer manufacturing; computer storage device manufacturing; computer terminals and other computer peripheral equipment manufacturing; telephone apparatus manufacturing; broadcast and wireless communications equipment; other communications equipment manufacturing; audio and video equipment manufacturing.
Durable household goods	Includes utensil, small electrical appliances and large household appliances manufacturing.	Cutlery, utensil, pot and pan manufacturing; hand tool manufacturing; power-driven hand tool manufacturing; small electrical appliance manufacturing; household cooking appliance manufacturing; household refrigerator and home freezer manufacturing; household laundry equipment manufacturing; other major household appliance manufacturing.
Food	Processed food producers and manufacturers. Does not include agricultural sectors.	Dog and cat food manufacturing; other animal food manufacturing; flour milling and malt manufacturing; wet corn milling; soybean and other oilseed processing; breakfast cereal manufacturing; sugar cane mills and refining; beat sugar manufacturing; chocolate and confectionery manufacturing from cacao beans; confectionery manufacturing from purchased chocolate; non-chocolate confectionery manufacturing; frozen food manufacturing; fruit and vegetable canning, pickling, and drying; fluid milk and butter manufacturing; cheese manufacturing; dry, condensed and evaporated dairy product manufacturing; ice cream and frozen desert manufacturing; animal (except poultry) slaughtering, rendering and processing; poultry processing; seafood product preparation and packaging; bread and bakery product manufacturing; cookie, cracker and pasta manufacturing; tortilla manufacturing; snack food manufacturing; coffee and tea manufacturing; flavoring syrup and concentrate manufacturing; seasoning and dressing manufacturing; all other food manufacturing.
Footwear	Clothes and accessories manufacturers. Does include retailers.	Footwear manufacturing.
Furniture	Furniture manufacturers. Examples include mattresses, carpet and blind manufacturing.	Carpet and rug mills; curtain and linen mills; wood kitchen cabinet and countertop manufacturing; upholstered household furniture manufacturing; metal and other household furniture manufacturing; mattress manufacturing; blind and shades manufacturing.
Medical and pharmaceutical products	Medicine manufacturers. Does not include medical appliances.	Pharmaceutical preparation manufacturing.

SECTOR	EXPLANATION	SUB-SECTORS
Non-durable household goods	Includes stationary product, soap and cleaning compounds and equipment manufacturing.	Stationary product manufacturing; sanitary paper manufacturing; all other converted paper product manufacturing; soap and cleaning compounds manufacturing; all other miscellaneous manufacturing; broom, brush, and mop manufacturing.
Personal products	Personal hygiene product manufacturing, such as shampoos and make-up.	Toilet preparation manufacturing.
Restaurants and bars	Includes food and drinking places.	Food services and drinking places.
Retail	Includes general, food and clothing retailers. Does not include online retailers.	Food, beverage, health and personal care stores; general merchandise stores; miscellaneous store retailers.
Soft drinks	Soft drinks bottlers and manufacturers. Does not include wineries, distilleries and breweries.	Soft drinks and ice manufacturing.
Tobacco	Tobacco producers. Does not include agricultural sectors.	Tobacco product manufacturing.
Toys	Includes toys, dolls and games manufacturers.	Doll, toy and game manufacturing.

Source: Trucost

Step 2: Quantification of Plastic Demand

Plastic use per sector was then modeled using input-output modeling. This approach overcame the limited available data on the consumption of resin at the sector level, by function, and with global coverage. The input-output model represents inter-industry spend patterns through each tier of the supply chain for each sector using government census data. Fourteen sectors in the input-output model relate to plastic and plastic product manufacturing, which in-turn produce 115 unique plastic commodities. The fourteen plastic manufacturing sectors were disaggregated into 115 unique plastic manufacturing sub-sectors based on market share data from the US BEA (2007). Each of the plastic manufacturing sub-sectors was then mapped to one of a series of plastic functions or applications, such as plastic bottles, rigid plastic packaging or fabricated plastic components. The amount spent by the selected consumer goods sectors in the plastic manufacturing sub-sectors was modeled and converted from a financial figure (US$ million spent) to a quantity (metric tons) using a weighted average plastic price for the mix of plastic resins commonly used in each application (Plastic News, 2016) to derive an average plastic intensity (metric tons per US$ million revenue) per sector and industry. The sector intensity was multiplied by total sector revenue to estimate the total plastic demand for each sector in 2015 (MarketLine, 2014).

Total plastic consumption was disaggregated into ‘plastic-in-product’, ‘plastic-in-packaging’, and ‘plastic-in-supply-chain’.

1. **‘Plastic-in-product’** includes the quantity of plastic directly used in the product, as well as any losses that were incurred during the manufacturing process. An example is the plastic used in the bumper of a car or a polyester t-shirt.

2. **'Plastic-in-packaging'** includes the quantity of plastic directly used in the packaging of the product, as well as any losses that were incurred during the manufacturing and packaging stage. This covers items such as plastic bags and films, as well as disposable cutlery and shampoo bottles.

3. **'Plastic-in-supply-chain'** includes the quantity of plastic used indirectly by consumer goods businesses via their supply chain but is not destined to be either in the final product or in packaging. This covers all activities in the economy. For example, this includes the plastic containers of fertilizers applied in the agriculture sector, further down the supply chain of the food sector. Trucost calculated 'plastic-in-supply-chain' to put the first two categories into perspective but did not calculate the related natural capital cost.

Several limitations should be noted. First, the input-output model is based on average transactions in the economy and may not be representative of individual companies, activities or sub-sectors. Second, the estimated quantity of plastic demanded for product and packaging applications is based on is based on modeled data and should be considered as an estimate.

Step 3: Modeling the Substitution of Plastic with Alternative Materials

A substitution model was used to determine the quantities of alternative materials that would be needed to replace plastic in specific applications. The substitution model was constructed by integrating substitution ratios defined in Franklin Associates (2013) and Denkstatt (2011), and developed by Trucost, for each plastic function. The substitution ratios describe the quantities of a mix of alternative material needed to replace plastic, taking account of the volume of material required, the density of each material, and the market share of the alternatives to plastic in each application. For example, if a consumer goods sector were estimated to consume 1,000 metric tons of substitutable plastic resin per annum for use in beverage containers in the baseline scenario, this sector would require 16 metric tons of tin plate, 321 metric tons of aluminum, 3,869 metric tons of glass and 502 metric tons of paper in the alternatives to plastic scenario.

The following alternatives materials were included in the study:

- Steel and tin plate
- Aluminum
- Glass
- Paper and Paperboard
- Textile
- Wood
- Mineral Wool
- Leather

The following alternative materials identified in Franklin Associates (2013) and Denkstatt (2011) were excluded due to a lack of data and the substitution shares for these materials were proportionally re-allocated to the other substitute materials for each function.

- Zinc coated steel, Cast iron, Copper, Stainless Steel (combined with Steel and Iron)
- Stone (excluded)
- Concrete (excluded)

The substitution ratios were applied consistently for all regions included in the study, with the exception of packaging in Europe where Europe specific packaging substitution ratios were used from Denkstatt (2011). A fraction of plastic consumption in each application was assumed to be non-substitutable, since in some cases the alternative materials are not able to realistically replace plastic, and this fraction was included as plastic consumption in both the business-as-usual and alternatives to plastic scenarios.

The alternative materials were then mapped to relevant sectors in the input-output model that represent the production of the raw material and its conversion into a manufactured product, such as an aluminum can or paperboard container. Table 4 describes the mapping of alternative materials to input-output model sectors and the source of price data used to estimate the required spending on alternative materials in each consumer goods sector.

Table 4: Substitute Material Price Data Sources and Mapping to Trucost EEI-O Model Sectors

ALTERNATIVE MATERIAL	PRICE DATA SOURCE	RELEVANT INPUT-OUTPUT MODEL SECTORS
Steel and tin plate	Ecoinvent (2005) Federal Reserve Bank of St Louis (2015a)	Iron and steel mills and ferroalloy manufacturing; Steel product manufacturing from purchased steel
Aluminum	IMF (2016)	Alumina refining and primary aluminum production, Aluminum product manufacturing from purchased aluminum
Glass	Ecoinvent (2005) Federal Reserve Bank of St Louis (2015a)	Glass container manufacturing Other pressed and blown glass and glassware manufacturing
Paper and Paperboard	RISI (2016) Federal Reserve Bank of St Louis (2015a)	Paper mills, Paperboard Mills, Paperboard container manufacturing
Textile	USDA (2015)	Fiber, yarn, and thread mills; Textile bag and canvas mills; Textile and fabric finishing mills Fabric coating mills; Broadwoven fabric mills; Textile bag and canvas mills
Wood	IMF (2016)	Sawmills and wood preservation; Logging; All other miscellaneous wood product manufacturing; Reconstituted wood product manufacturing; Wood windows and doors and millwork; Veneer and plywood manufacturing; Prefabricated wood building manufacturing; Wood container and pallet manufacturing
Leather	IMF (2016)	Leather and hide tanning and finishing
Mineral Wool	Trucost analysis of market prices	Mineral Wool Manufacturing

Source: Trucost

Figure 20 presents the calculated average substitution ratios between plastic and alternative materials in each consumer goods sector, taking account of the mix of plastic functions demanded in each sector (modeled by Trucost) and the function specific plastic substitution ratios specified in Denkstatt (2011) and Franklin Associates (2014).

Figure 20: Calculated Sector Average Substitution Ratios per Metric Ton of Plastic (Metric Tons per Ton)

Consumer Goods Sector	Business as Usual Scenario	Plastic Alternative Scenario									
	Plastic	Aluminum	Glass	Paper	Textile	Wood	Steel and Iron	Mineral Wool	Leather	Non-Substitutable Plastic	Total
Automobiles	1	0.18	0.14	0.53	0.17	0.17	0.81	0.02	0.00	0.25	2.27
Soft drinks and ice	1	0.29	6.46	0.34	0.02	0.01	0.11	0.01	0.00	0.03	7.27
Clothing and accessories	1	0.11	0.03	0.78	0.33	0.04	0.21	0.00	0.00	0.03	1.54
Consumer electronics	1	0.46	0.19	1.09	0.14	0.12	0.79	0.02	0.00	0.11	2.93
Durable household goods	1	0.30	0.25	1.81	0.13	0.14	0.73	0.02	0.00	0.12	3.49
Food	1	0.27	2.91	0.92	0.16	0.03	0.31	0.02	0.00	0.05	4.67
Personal products	1	0.22	3.54	0.21	0.15	0.05	0.90	0.03	0.00	0.09	5.19
Athletic goods	1	0.28	0.05	1.89	0.11	0.12	0.45	0.00	0.00	0.26	3.16
Toys	1	0.40	0.06	2.62	0.12	0.15	0.56	0.00	0.00	0.04	3.94
Tobacco	1	0.18	0.22	0.07	0.10	0.07	0.44	0.02	0.00	0.51	1.62
Furniture	1	0.17	0.08	0.76	0.59	0.12	0.37	0.03	0.00	0.13	2.25
Non-durable household goods	1	0.29	1.00	1.77	0.17	0.13	0.58	0.01	0.00	0.06	4.03
Footwear	1	0.29	0.19	1.43	0.23	0.15	0.78	0.02	0.00	0.12	3.22
Medical and pharmaceutical products	1	0.23	2.10	0.59	0.20	0.08	0.80	0.04	0.00	0.15	4.21
Retail	1	0.26	0.59	1.10	0.19	0.15	0.92	0.04	0.00	0.17	3.43
Restaurants and bars	1	0.23	0.68	0.51	0.08	0.10	1.20	0.02	0.00	0.21	3.03

Source: Trucost

Step 4: Scope and Boundary Selection

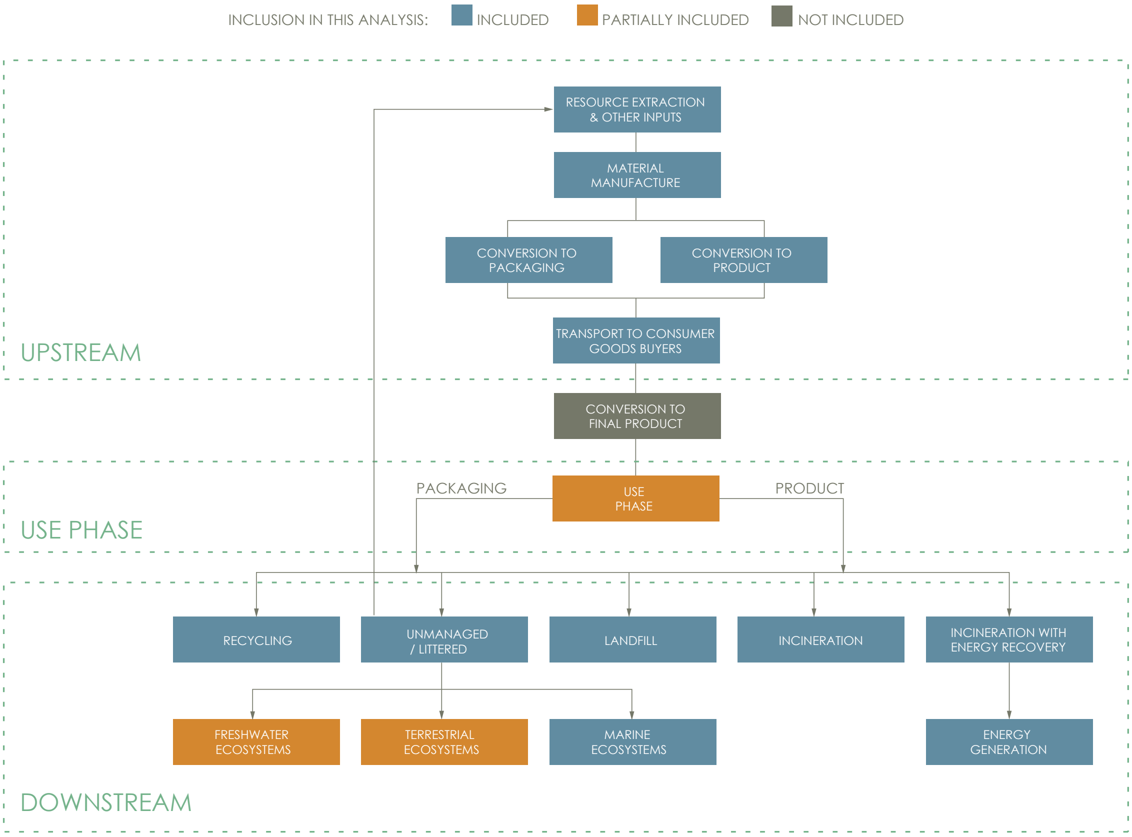
Once plastic use, and estimated alternative material requirements, in metric tons was calculated for each sector, the next step is to set up the boundaries that will be used to estimate the impacts on the environment. Lifecycle boundaries must first be set, i.e., what lifecycle stages are included in the analysis. Then, impacts to be quantified at each lifecycle stage must be determined.

Figure 21 highlights the lifecycle stages included in the analysis. Upstream lifecycle stages quantified in the analysis include raw material extraction and processing into feedstock materials, manufacturing of plastic and alternative material commodities and transport to buyers in the consumer goods sector. Additional conversion and manufacturing activities undertaken within the consumer goods sector to produce the finished product were excluded from the analysis due to a lack of sufficient data to accurately represent these processes at a sector scale. Furthermore, transportation of consumer goods containing plastic and alternative materials to final consumer goods markets was also excluded due to around sector specific transport distances. Exclusion of this stage underestimates upstream impacts, as manufacturing processes and transport can be energy intensive.

The use phase, covering the period from the purchase of the consumer good to its final disposal, is partially included in the form of two use-phase case studies. While this is not a comprehensive assessment of the use phase impacts, the study if focused on functionally equivalent replacements for plastic and thus in many cases there will not be significant differences in the use phase for the product or packaging. This analysis does not cover the human health assessment of the use phase. As illustrated in the case studies, the use phase may also be important in terms of the benefits of plastic.

Downstream stages include the disposal of plastic and alternative materials after its use. Five end-of-life routes are included in this study, namely littering, landfilling, incineration, incineration with energy recovery and recycling. Other routes such as conversion to fuel and composting have not been included for lack of country-specific statistics on the quantity of waste diverted to these routes. The benefits of recycling and incineration with energy recovery have been included and the relevant assumptions are explained in the quantification section of this methodology. When plastic is littered, it may reach different environments. Freshwater and terrestrial environments have only partly been included due to a lack of data.

Figure 21: Scope and Boundary



Source: Trucost

The second step is to determine which impacts can be quantified at each lifecycle stage selected within the scope of the analysis. Table 5 highlights included and excluded impacts.

Table 5: Impact Inclusion and Exclusion

IMPACT	INCLUDED/ EXCLUDED	DESCRIPTION
Non-renewable resource consumption	Excluded	Natural gas and crude petroleum are non-renewable resources which if over-exploited may not be available for future generations. The opportunity cost of using non-renewable resources has not been included as part of this analysis. The impact of extracting and processing these resources, on the other hand, is included.
Greenhouse gases	Included	Impact of extracting and processing raw materials, manufacture into commodity products, and transport to consumer goods sector markets
Air/land/water pollutants	Included	
Water consumption	Included	
Occupational hazards of chemicals use	Excluded	Lack of consistent and global data
Use-Phase		
Greenhouse gases	Partially Included	Included for two use-phase case studies focusing on enhanced meat packaging and passenger vehicle light-weighting.
Air/land/water pollutants	Partially Included	
Water consumption	Partially Included	
Additives leaching	Excluded	Lack of data
Downstream - Landfilling		
Waste of recyclable resources	Excluded	Insufficient data
Greenhouse gases	Included	
Air/land/water pollutants	Included	
Water consumption	Included	
Disamenity	Included	Extrapolated from primary studies of disamenity due to waste management
External Waste Management Costs	Included	Cost to public authorities for the provision of waste collection and management services
Downstream - Incineration Without Energy Recovery		
Waste of recyclable resources	Excluded	Insufficient data
Greenhouse gases	Included	
Air/land/water pollutants	Included	
Water consumption	Included	
Disamenity	Included	Extrapolated from primary studies of disamenity due to waste management
External Waste Management Costs	Included	Cost to public authorities for the provision of waste collection and management services
Downstream - Incineration With Energy Recovery		
Waste of recyclable resources	Excluded	Insufficient data
Greenhouse gases	Included	
Air/land/water pollutants	Included	
Water consumption	Included	

IMPACT	INCLUDED/ EXCLUDED	DESCRIPTION
Residual ash disposal	Included	
Energy production	Included	Avoided energy production burdens
Disamenity	Included	Extrapolated from primary studies of disamenity due to waste management
External Waste Management Costs	Included	Cost to public authorities for the provision of waste collection and management services
Downstream - Recycling		
Greenhouse gases	Included	
Air/land/water pollutants	Included	
Water consumption	Included	
Residual disposal	Included	Assumed disposal in landfill
Recovered materials	Included	Avoided production burdens
External Waste Management	Included	Cost to public authorities for the provision of waste collection and management services
Downstream - Littered		
Waste of recyclable resources	Excluded	Insufficient data
Disamenity	Included	Extrapolated from primary studies of disamenity due to waste management
Terrestrial and freshwater pollution of littered plastic	Partially Included	Exclusions are described in further detail in the following sections
Marine pollution of littered plastic	Included	Exclusions are described in further detail in the following sections
Additive leaching	Included	Leaching of toxic plastic additive to the environment

Source: Trucost

Step 5: Impact Quantification

The quantification stage comprises two separate stages, upstream and downstream impact modeling and quantification.

Upstream Modeling and Impact Quantification

The term ‘upstream’ refers to impacts generated from ‘cradle-to-gate’, i.e., the extraction of raw materials such as crude oil and natural gas to the manufacturing of plastic commodity products, such as fibers, shapes or packaging film. In the presentation of the results, transport to consumer goods buyers is also notionally included in the upstream phase, as these activities occur upstream of the consumer goods sector, but are quantified using the ‘downstream’ quantification method described in the following section.

Upstream impacts considered include greenhouse gases, water abstraction, air pollutants, and land and water pollutant. Trucost used its environmentally-extended input-output model to calculate the global environmental impact of producing the plastic and alternative materials used in each sector. The environmentally-extended input-output model goes one step further than the input-output model by overlaying environmental impact intensity data with the financial exchange information included in the input-output model. Each sector also has a global environmental profile per unit of output, which is derived from numerous sources, including the US Toxic Release Inventory, UK Environmental Accounts, Japanese Pollution Release and Transfer Register and Australia’s National Pollution Inventory. The economic magnitude of a sector’s input from another sector defines its environmental impact, and so on through the supply chain, until all economic flows to produce a unit of output at the top of the supply chain have been accounted for. The model is adjusted on an annual basis to take into account changes in the environmental impact of a unit of output for each sector.

Use Phase

The methodologies used to model the two use phase case studies presented in this report are described below.

Fuel Efficiency Gains through Light-Weighting of Passenger Vehicles with Plastic Components

Changes in passenger vehicle fuel consumption associated with the substitution of plastic components with alternative materials were estimated based on the expected change in vehicle weight associated with this substitution. A model developed by Koffler & Rohde-Brandenburger (2010) was used to estimate the fuel required to move a defined mass (in this case the net change in the weight of passenger vehicles sold in the USA due to the replacement of plastic components with alternative materials) over a defined distance. Efficiency rates for naturally aspirated gasoline and diesel engines were assumed to be 0.073 L/MJ and 0.061 L/MJ respectively based on Koffler & Rohde-Brandenburger (2010), and 5% of engine energy was assumed to be lost due in the automatic gearbox (PE International, 2012).

The estimated mass-induced fuel consumption was multiplied by the average annual driving distance for cars, light trucks and light duty vehicles in the USA (18,401 km based on data from the US Department of Energy (2015)) and the net change in vehicle weight associated with the substitution of plastic components with alternatives. This assumes a market share for gasoline and diesel passenger cars and lights trucks in North America or 83% and 2% respectively (EIA, 2015).

Environmental impacts associated with the production, distribution, and use-phase combustion of gasoline and diesel fuel were estimated based on life cycle inventory data from the Ecoinvent database (Weidema et al, 2013) applying the ReCiPe life cycle impact assessment methodology, and valued using the environmental valuation methodologies described in this report. Future environmental costs associated with the excess consumption of fuel over the life of the vehicles were estimated assuming an average vehicle lifespan of 150,000 miles and 13 years, and discounted to a present value in 2015 (PE International, 2012).

Improved Packaging to Reduce Waste in the Food Sector

This case study explores the potential environmental benefits of avoided food waste achieved through the adoption of improved plastic packaging for sirloin steak sold in the USA. This analysis was extrapolated from a 2014 study Denkstatt on the contribution of packaging to reducing food waste (Denkstatt, 2015). This study describes two types of plastic packing for sirloin steak and reports the proportion of food wasted under each packaging type, as shown below.

Conventional Packaging
20g PE/EVA + PE/PVdC/EVA + PE vacuum-bag
11g EPS tray
4g EVOH/PE/PA film
358g Packaged food
34% Food waste

Improved Packaging
19g PS/EVA/PE
300g Packaged food
18% Food waste

Life cycle inventory data from the Ecoinvent database (Weidema et al, 2013) was used to model the environmental impacts associated with the production and disposal of the packaging used in the conventional and improved packaging scenarios. The environmental impacts associated with the production of beef were estimated based on a life cycle assessment of beef production in Mexico authored by Huerta et al (2016), supplemented with water consumption data from the Institution of Mechanical Engineers (2013). The end of life management of waste plastic and food was modeled using the same datasets and assumptions as used in other aspects of the report and described in Appendix 1. The calculated environmental impacts were then valued using Trucost's environmental valuation methodologies described in Appendix 2. The net estimated environmental cost savings associated with packaging one 300g portion of sirloin steak in the improved packaging format was extrapolated to a range of potential market shares of all sirloin steak sold in the USA in 2014.

Downstream Modeling and Quantification

The term 'downstream' refers to impacts occurring when the consumer discards the product. The first step is to estimate the share of waste distributed to each treatment route at the end of life. The second step is to understand the impact of each treatment route.

In this report, the impact of plastic and alternatives is estimated differently depending on how it is handled at end-of-life. Region-specific end-of-life statistics for plastic-in-packaging and plastic-in-product across five different routes were derived: littering, landfilling, incineration, incineration with energy recovery and recycling. Region specific route shares were calculated based on a GDP weighted average of country level data in each region. Other end-of-life routes exist for plastic, such as conversion-to-fuel and composting, but represent a small proportion overall and were not included in the analysis. Due to the lack of national and international standards for waste treatment data collection, compilation and disclosure, Trucost combined several sources, such as the US Environmental Protection Agency (EPA, 2014), Eurostat (2016), the United Nations (2011), the World Bank (Hoornweg and Bhada-Tata, 2012) and academic articles. Table 6 details specific assumptions.

Table 6: End of Life Treatment Routes: Sources and Assumptions

WASTE TYPE	END OF LIFE ROUTE	SOURCE(S)
Packaging	**Littering:** Percentage of the population served by collection system used as a proxy. All other routes: • Europe: Eurostat data on material specific waste management. • United States: US EPA data on material specific waste management. • Australia and New Zealand: Australian Bureau of Statistics data on material specific waste management. • Other: Domestic municipal waste used as a proxy, adjusted for the ratio of the USA municipal waste recycling or incineration rate and the US material specific recycling or energy recovery up using US EPA ratio between recycled energy recovery rates.	(EPA, 2012; EUROSTAT, 2016; Hoornweg and Bhada-Tata, 2012; ABS, 2012; UN Statistics Division, 2011; Staudinger and Keolian, 2001; Bio Intelligence Service, 2011; Biddle, 2004; Wiedema et al, 2013)
Automobiles	**Littering:** a minimum of 6% of cars are littered, scaled up by country's specific littering rates for overall waste. **All other routes:** Managed waste is either recycled or incinerated with energy recovery. The remainder is landfilled.	
Electronics and household durables	**Littering:** percentage of the population served by collection system used as a proxy. **All other routes:** Managed is either recycled or incinerated with energy recovery. The remaining is landfilled.	
All other products	**Littering:** Percentage of the population served by collection system used as a proxy for littering.	
	All routes: Domestic waste treatment routes used as a proxy. **Recycling:** Domestic municipal waste used as a proxy, adjusted for the ratio of the USA municipal waste recycling or incineration rate and the US material specific recycling or energy recovery up using US EPA ratio between recycled energy recovery rates.	

Source: Trucost

International data on the waste treatment routes used for plastic packaging and plastic products is often lacking and/or inconsistent. Trucost used several datasets to compile end-of-life statistics, as listed in Table 6. As a consequence, all assumptions used in constructing these datasets also apply to this report. In particular, recycling data from many countries does not include industry closed-loop systems, waste recycled outside the country, and waste-picking activities, which may all increase the proportion of waste recycled. In addition, there may be some differences within each category – for example, recycling rates of film packaging, bags and trays (all under 'packaging') may differ (Wang et al, 2013).

Quantified environmental impacts for each end-of-life route were calculated and include greenhouse gases, air pollutants, water abstraction and land and water pollutants. Additional impacts have been included for plastics that are littered. Table 7 provides information on how these impacts have been calculated. In particular:

- Trucost used lifecycle analysis databases such as Ecoinvent (Weidema et al, 2013) for most end-of-life routes. For littered plastic waste, further impacts have been calculated based on an academic literature review.
- For plastic that is recycled or incinerated with energy recovery, both positive and negative effects have been allocated. Positive effects, or credits, include displacing primary plastic production through recycling and heat production through incineration with energy recovery. Negative effects, or burdens, include the impacts generated by the recycling process and incineration with energy processes, such as the emission of greenhouse gases and other air pollutants.
- Credit for positive effects and burdens for negative effects were allocated using the Output Oriented approach, also known as Substitution or Avoided Burden, was adopted to account for the avoided environmental impacts associated with the recovery of materials and energy that displace production of virgin materials and energy from other sources (Ligthart and Toon, 2012).

Table 7: LCA Datasets Used to Model End of Life Management and Allocation Assumptions

END OF LIFE ROUTE	LCA DATASETS	COMMENTS
Incineration	Lifecycle analysis data for the municipal incineration route for the following materials (Ecoinvent Database , 2016): • Scrap Aluminum • Waste Glass • Scrap Steel • Scrap Tin Sheet • Waste Paperboard • Waste Plastic Mixture • Waste Textile • Waste Wood • Municipal Solid Waste (proxy for leather and mineral wool)	Burdens include all raw material inputs needed to incinerate as well as the disposal of ash slag.
Landfilling	Lifecycle analysis data for the municipal landfill route for the following materials (Ecoinvent Database , 2016): • Waste Mineral Wool (inert landfill) • Waste Glass (inert landfill) • Waste Paperboard (sanitary landfill) • Waste Plastic Mixture (sanitary landfill) • Scrap Steel (inert landfill) • Scrap Tin Sheet (inert landfill) • Waste Wood (sanitary landfill) • Waste Aluminum (sanitary landfill) • Municipal Solid Waste (proxy for textile, leather	Burdens include all raw material inputs needed to landfill as well as landfill leachate.

END OF LIFE ROUTE	LCA DATASETS	COMMENTS
Incineration with energy recovery	Lifecycle analysis data for the municipal incineration route for the following materials (Ecoinvent Database , 2016): • Scrap Aluminum • Waste Glass • Scrap Steel • Scrap Tin Sheet • Waste Paperboard • Waste Plastic Mixture • Waste Textile • Waste Wood • Municipal Solid Waste (proxy for leather and mineral wool)	Burdens include all raw material inputs needed to incinerate as well as the disposal of ash slag. Avoided burdens assume displacement of industrial heat from natural gas burner taking account of calorific values of each material and conversion efficiency.
Recycling	Lifecycle analysis data for the collection, sorting and recycling of the following materials (Ecoinvent Database , 2016): • Aluminum Scrap • Glass • Recycled postconsumer HDPE (proxy for plastics) • Steel • Paperboard	Burdens include air, land and water emissions as well as water consumption of the recycling process itself as well as the extraction and manufacturing of secondary raw materials used.
Littering	Leaching of plastic additives and impacts of litter in the marine environment. Methodologies used to model both impacts are described in further detail in the following sections.	A model was developed to model the conversion of litter / mismanaged waste into marine debris and its impacts on marine environments. The analysis excludes terrestrial and freshwater impacts of plastic litter, such as freshwater economic impacts to fishing, tourism, and agriculture, and ecological impact to freshwater and terrestrial species. Refer to the following sections for a detailed discussion of this end-of-life route.

Source: Trucost

Step 6: Valuation of the Social Cost of Environmental Impacts

The penultimate step of the calculation involved transforming the physical environmental impacts of plastic and alternative material use into monetary values using Trucost's Natural Capital Valuation techniques. These techniques estimate the value of environmental goods or services in the absence of a market price and aggregate them into a single figure.

Trucost applied region-specific valuations for water abstraction, land and water pollutants, and air pollutants, and global averages greenhouse gasses and littered waste ending up in the ocean. The impacts of greenhouse gases are global, regardless of the location of emission. Finally, little information exists on the dispersion of plastic and other wastes in the ocean, hence the use of a global valuation wastes ending up in the ocean. Other environmental impacts are region-specific.

Packaging and single use products were assumed to be disposed in the same year that they were produced. Durable products were assumed to have a lifespan of multiple years (depending on the product) and thus the value of future environmental costs resulting from their disposal was discounted to a present value in 2015.

Appendix 2 details the valuation methodology used for each impact. The following table provides an overview of Trucost's natural capital valuation methodology.

Table 8: Trucost Environmental Valuation Methodology Summary

IMPACT CATEGORY	VALUATION SCOPE	METHODOLOGY SUMMARY	GEOGRAPHICAL SCOPE
GHGs	Greenhouse gasses that contribute to climate change expressed as CO_2e.	Social Cost of Carbon estimate published by the USA Interagency Working Group on Social Cost of Carbon (US$128 per tonne in 2015).	Global average
Air pollution	Classical air pollutants including ammonia, sulfur dioxide, particulates and nitrogen oxides.	Adaptation of impact pathway analysis studies estimating Disability Adjusted Life Years (DALYs) lost per tonne of air pollutant emitted, weighted for country specific population density. Valuation of DALYs lost at a global median income elasticity adjusted Value of a Life Year (VOLY).	Region-specific
Disamenity	Trucost's valuation of waste focuses on disamenity, which can be defined as the localized impacts of landfill and littering activity that generate negative reactions from those located in the immediate vicinity of a site.	The most common valuation method used in literature for disamenity is to use the hedonic pricing method. This method is based on the idea that the utility that individuals obtain from a particular good, and therefore the 'value' that they place on that good, is a function of the characteristics such as house size, house age, number of rooms, proximity to amenities such as schools, etc.	Region-specific
External Waste Management Expenses	Costs to public authorities associated with the provision of municipal waste collection and management services.	Weighted average regional values adapted from estimated published by the World Bank (Hoornweg and Bhada-Tata, 2012)	Region-specific
Water consumption	Trucost's water valuation focuses on the environmental services of water, which can be assimilated to the in stream services of water (services provided by water in its natural environment).	Trucost has developed a methodology linking the environmental services of water to its scarcity in the region where it is abstracted. As defined by the Food and Agriculture Organization, water scarcity is the freshwater withdrawal as a percentage of total renewable resources.	
Land and Water pollution/ Additives	Human and ecosystem toxic metals and organic and inorganic chemicals emitted to land and water.	Life cycle analysis models that quantify the health and ecosystem impacts per tonne of pollutant emitted to air, land and water. Health impacts are valued at a global median income elasticity adjusted VOLY. Ecosystem impacts valued based on the value of lost ecosystem services provided by a given ecosystem, drawing on data from the Ecosystem Service Value Database.	Region specific

IMPACT CATEGORY	VALUATION SCOPE	METHODOLOGY SUMMARY	GEOGRAPHICAL SCOPE
Plastic in marine environments	Trucost developed a valuation for one kilogram reaching marine environments taking into account the economic impact on fisheries and aquaculture, tourism, and the opportunity cost of volunteer time; and the entanglement and ingestion impacts on marine species.	Trucost used secondary literature on the economic impact of plastic and on the quantity of marine species impacted by plastic entanglement and ingestion. Willingness-to-pay studies were used to assess the value that society puts on marine species.	Global average

Source: Trucost

Step 7: Sensitivity Analysis

Sensitivity to Resin Price

The average price of fourteen different resin types were used to convert between the estimated consumer goods sector spend on plastic and the estimated mass of plastic consumed in each sector. Thus the analysis is sensitive to the prices used to convert between spend and mass. In the main analysis, the midpoint price for each resin (sourced from Plastic News (2016)) was used to estimate plastic consumption. Table 9 presents the changes in estimated resin consumption and environmental costs resulting from the use of the high and low range prices for each resin.

Table 9: Sensitivity Analysis: High and Low Resin Price Assumptions

SENSITIVITY SCENARIO	TOTAL MATERIAL DEMAND	TOTAL ENVIRONMENTAL COSTS	PERCENTAGE CHANGE FROM MAIN ANALYSIS
Minimum Price per Metric Ton for All Resins	BAU: 91 Mt Alternatives: 370 Mt	BAU: $146 billion Alternatives: $580 billion	BAU: + 5% Alternatives: + 8%
Maximum Price per Metric Ton for All Resins	BAU: 74 Mt Alternatives: 307 Mt	BAU: $130 billion Alternatives: $474 billion	BAU: - 6% Alternatives: - 10%

Source: Trucost

Sensitivity to Substitution Ratios

The substitution mass ratios used to model the mass of each alternative material needed to replace plastic in each function are an important driver of the total environmental costs in the alternatives to plastic scenario. To test the sensitivity of the analysis to these assumptions, the substitution ratios were varied to identify the ‘break even’ ratio at which the environmental costs in the business as usual and alternatives to plastic scenarios are equal. This analysis finds that an average substitution ratio across all materials of approximately 0.84 metric tons of alternative material per tonne of plastic is required to equate the total environmental costs in the business as usual and alternatives to plastic scenario.

Appendix 2. Trucost Natural Capital Valuation Methodologies

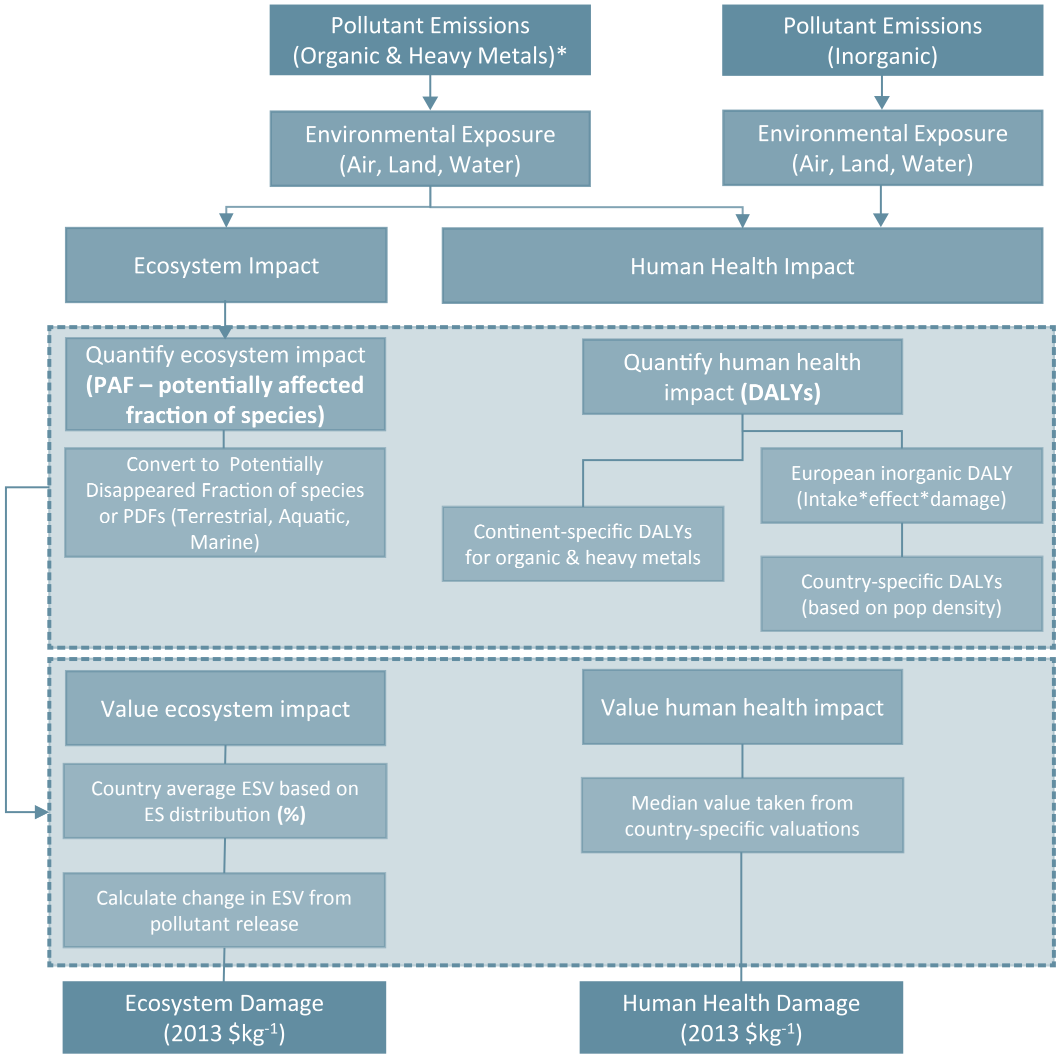
The following is an extract of Trucost's natural capital valuation methodology describing the methods underpinning the valuation of environmental costs and benefits in this study.

For more information on the methodologies summarized below, as well as sensitivity analysis for selected parameters, please refer to the full Trucost valuation methodology. This is available on request by emailing **info@trucost.com**.

Air, Land and Water Pollutants

Figure 22 summarizes the overall approach used to value the emission of air, land, and water pollutants.

Figure 22: General overview of Trucost valuation process for Air, Land and Water Pollutants



ESV: Ecosystem Services Value
DALY: Disability Adjusted Life Years
ES: Ecosystem Services
Inorganic pollutants include carbon monoxide (CO), sulphur dioxide (SO2), nitrous oxides (NOx), ammonia (NH3), particulate matter (PM), and volatile organic compounds (VOCs)
*Organic pollutants and heavy metals are grouped together due to the similarity in methodology, not chemical properties.

Source: Trucost

Impact on Human Health

Biophysical Modeling

Organic Substances and Heavy Metals

Trucost uses disability adjusted life years as a measure of the human health consequences of environmental impacts. In order to calculate the quantity of DALYs lost due to the emission of pollutants to air, land and water, Trucost used USES-LCA2.0 (EC, 2004; National Institute of Public Health and the Environment, 2004). This model, originally developed in the context of life cycle assessment (LCA) studies, provides estimates of the DALYs lost due to emission of over 3,300 chemicals to: freshwater and seawater; natural, agricultural and industrial soil; and rural, urban and natural air. USES-LCA2.0 takes into account the impact of cancer and non-cancer diseases caused by the ingestion of food and water, and the inhalation of chemicals.

The output of this analysis step is the number of DALYs lost due to the emission of each pollutant, to a specific media, at the continental level.

Note that organic substances and heavy metals are grouped together due to the similarity in methodology, not their chemical properties.

Sulfur Dioxide, Nitrogen Oxide, and Particulate Matter (PM_{10})

USES-LCA2.0 does not estimate DALY impacts for common inorganic air pollutants such as sulfur dioxide, nitrogen oxide and PM_{10}. Adaptation of USES-LCA2.0 to model these substances would result in higher than acceptable uncertainty due to the different characteristics of organic and inorganic substances. Trucost conducted a literature review to find an alternative method to quantify the DALY impact of emission of these pollutants.

Economic Modeling

Trucost values DALYs lost due to environmental impacts based on a global median estimate of the value of a life year adapted from a willingness to pay study conducted for the New Energy Externalities Development for Sustainability (NEEDS) project (Desaigues et al., 2006; 2011). This is a proactive cost estimate, which takes into account the perceived effects of morbidity and mortality. The value of a life year was adapted for each country based on national income per capita and an income elasticity of 0.5 (Desaigues et al, 2006, 2011), and a global median was calculated and used in all study countries. This approach avoids the ethical challenges associated with assigning a higher value to human health impacts in high income countries compared to low income countries.

Impact on Ecosystems

Biophysical Modeling

Organic Substances and Heavy Metals

USES-LCA2.0 models the impact of polluting substances emitted to air, land and water, on terrestrial, freshwater and marine ecosystems. This model was adopted by Trucost for assessing the ecosystem damage caused by organic substances and heavy metals. It follows the same modeling steps as for human toxicity, namely exposure assessment, effect assessment, and risk characterization. USES-LCA2.0 has also been adapted to generate results at a continental level.

USES-LCA2.0 estimates the potentially affected fraction of species (PAF) per unit emission of pollutant to air, land and water. Trucost adjusted the PAF results to reflect the proportion of species disappeared (PDF) using assumptions from the Eco-Indicator 99 model (Goedkoop & Spriensma, 2000). This adjustment was necessary to link pollutant related impacts on species to the value of ecosystem services provided by the species in an ecosystem.

Ozone, Sulfur Dioxide, Nitrogen Oxide, and Particulate Matter

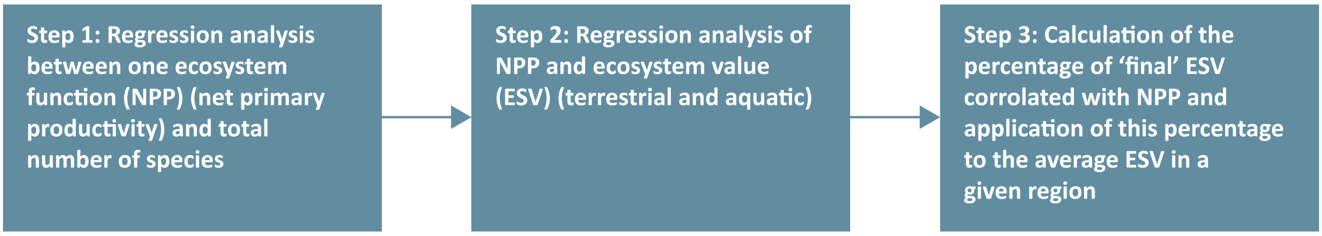
Impact on ecosystems has not been included for ozone, sulfur dioxide, nitrogen oxides and PM_{10}.

Economic Modeling

Valuing The Impact on Ecosystems In This Study

Trucost’s approach to valuing a change in the PDF of species follows a three-step process, as shown in Figure 23.

Figure 23: Steps for Calculating the Value of Ecosystem Services Linked Directly to Biodiversity



Step 1: Regression analysis between one ecosystem function (NPP) (net primary productivity) and total number of species

Step 2: Regression analysis of NPP and ecosystem value (ESV) (terrestrial and aquatic)

Step 3: Calculation of the percentage of ‘final’ ESV corrolated with NPP and application of this percentage to the average ESV in a given region

Source: Trucost

In this methodology, Trucost estimated the link between biodiversity, measured species richness (IUCN, 2015), net primary productivity (NPP) (Costanza et al., 2007), and ecosystem service value (ESV). NPP was chosen over other ecosystem processes, such as nutrient cycling, due to data availability and its direct link with key ecosystem services. A monetary value for the provisioning, regulating and cultural services generated for each terrestrial ecosystem type was first calculated based on the analysis of De Groot et al. (2012). This was combined with the country specific ecosystem distributions (Olson et al., 2004) to estimate an ecosystem service value per hectare in each country. De Groot et al. calculate the minimum, maximum, median, average and standard deviation for each service provided by key terrestrial and aquatic ecosystems. Finally, Trucost calculated the percentage change in ESV per unit emission of pollutant at the country and substance level, and applied this percentage to the average value of one square meter of natural ecosystem in each region globally.

Greenhouse Gases

Trucost values greenhouse gas (GHG) emissions using an estimate of the social cost of carbon (SCC). The SCC represents a best estimate of the marginal externality cost of greenhouse gas emissions as it reflects the full global cost of the damages caused by GHG emissions over their lifetime in the atmosphere. This is in contrast with the market prices observed in emissions trading schemes (ETS), or estimates of the marginal abatement cost (MAC) of GHG reductions.

Emission trading schemes are generally promoted for their flexibility to reduce emissions at the lowest cost for the economy, as well as their steadily increasing global reach (World Bank Group, 2014). However, traded market prices currently face a number of limitations which restrict their effectiveness in decision-making. For example, they do not reflect non-traded carbon costs nor the impact of other market-based mechanisms such as subsidies for fossil fuels or low-carbon technologies (Krukowska, 2014). Traded carbon prices have also been historically slow to come about, schemes have not been distributed equally, and they can be impacted by sudden economic changes which reduces the carbon price to levels that undermine the incentive for polluters to cut emissions (Ibid).

The marginal abatement cost is based on the known actual costs of existing reduction efforts. This renders it a valuable tool for informing policy discussions, prioritizing investment opportunities and driving forecasts of carbon allowance prices. However, the MAC does not reflect non-traded carbon costs, and thus underestimates the true cost of GHG emissions. Furthermore MAC curves are highly time and geography specific with costs of reduction fluctuating over time, by sector and by geography, and influenced by fossil fuel prices, carbon prices and other policy measures.

The SCC is an estimate of the monetized damages associated with an incremental increase in GHG emissions in a given year. To estimate the SCC, Integrated Assessment Models (IAMs) are used to translate economic and population growth scenarios, and the resulting GHG emissions, into changes in atmospheric composition and global mean temperature. Trucost bases its SCC valuation on the work conducted by the Interagency Working Group on the Social Cost of Carbon. Trucost uses the values reported at the 95th percentile under a 3% discount rate, which represents an upper bound estimate of the future damages caused by climate change (IWGSCC, 2013). This decision has been taken to address material methodological omissions that arise due to modeling and data limitations, such as the unknown nature of resulting damages, and because the latest scientific data and methods incorporated into these models naturally lags behind the most recent research.

Biophysical & Economic Modeling

Over 300 studies attempt to put a price on carbon, quantifying and valuing the impact of climate change on agricultural productivity, forestry, water resources, coastal zones, energy consumption, air quality, tropical and extra-tropical storms, property damages from increased flood risk and human health. The IAMs approximate the relationship between temperature changes and the economic costs of impacts. These economic costs arise from changes in energy demand, changes in agricultural and forestry output, property lost due to sea level rise, coastal storms, heat-related illnesses, and diseases such as malaria.

Out of the many studies that attempt to calculate the SCC, Trucost has chosen to use SCC estimates provided by the Interagency Working Group on the Social Cost of Carbon based in the United States (IWGSCC, 2013). The reasons for this choice include:

- The IWGSCC's analysis is based on three well-established Integrated Assessment Models, which render the estimate more robust and credible than other approaches.
- The SCC takes into account the timing of emissions, which is key to the estimation of the SCC. For example, the SCC for the year 2020 represents the present value of the climate change damages that occur between the years 2020 and 2300, and are associated with the release of GHGs in 2020.
- Results are presented across multiple discount rates (2.5%, 3% and 5%) because no consensus exists on the appropriate rate to use. This allows flexibility in the choice of discount rate according to project objectives.
- The methodologies employed are continuously improved through regular feedback workshops, engagement with experts, and integrating the latest scientific evidence. As a result, the latest 2013 update provides higher values than those reported in the 2010 technical support document, and incorporates updates of the new versions of each underlying IAM.

Limitations

SCC valuations are contingent on assumptions, and in particular assumptions relating to the discount rate, emission scenarios and equity weighting. Estimates of the SCC are most sensitive to the following key categories of assumptions:

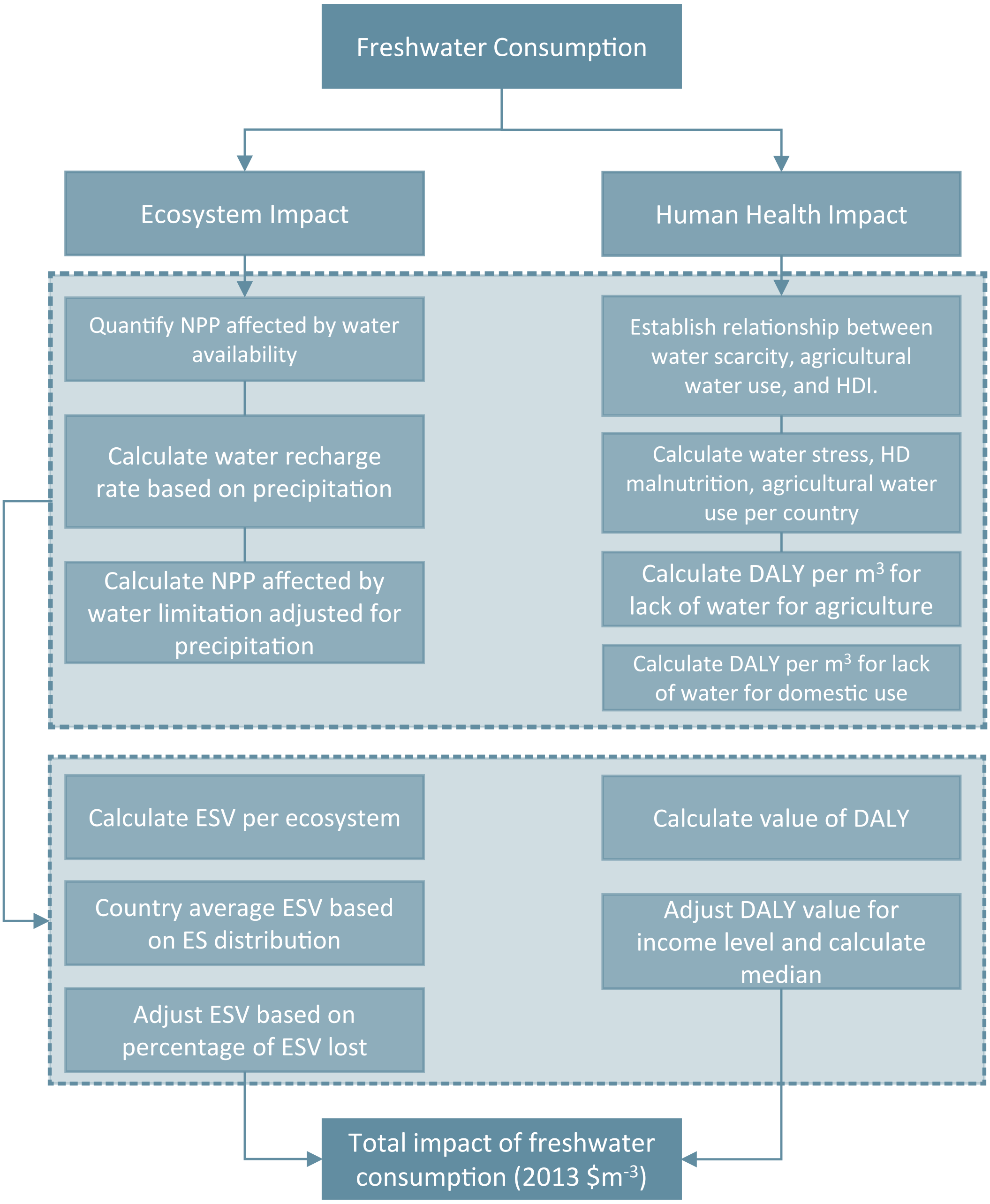
- **Emissions scenarios:** The assumptions made on future emissions, the extent and pattern of warming, and other possible impacts of climate change, then deriving how these factors translate into economic impacts.
- **Equity weighting:** This refers to the spatial and temporal dimensions of climate change impacts. Some studies take account of equity weightings which adjust SCC estimates for differences in climate change impacts depending on the development and wealth of nations (Stern, 2006; Tol, 2011).
- **Uncertainties:** The variation in SCC valuations is influenced by uncertainties surrounding estimates of climate change damages and related costs.
- **Discount rate:** Higher discount rates result in lower present day values for the future damage costs of climate change. The long time horizon of climate change impacts makes the choice discount rate crucial as well as controversial (IPCC, 2014). For example, Stern (2006) uses a discount rate of 1.4% compared to a range of between 2.5% and 5% by the US EPA (2013).

The SCC used in this analysis was US$128 per tonne CO_2e in 2015 prices.

Water Consumption

Figure 24 summarizes the approach used to value water consumption.

Figure 24: General overview of Trucost valuation process for water consumption



NPP: Net Primary Productivity
ESV: Ecosystem Services Value
HDI: Human Development Index
DALY: Disability Adjusted Life Years

Source: Trucost

Impact on Human Health

Biophysical Modeling

The quantification methodology for human health impacts due to water consumption was developed based on estimates of the disability adjusted life years lost per unit of water consumed as modeled in Eco-indicator 99 (Goedkoop & Spriensma, 2000). This approach quantifies the human health impacts resulting from a lack of water for irrigation and lack of domestic water in terms of DALYs lost per cubic meter of water abstracted.

Lack of Water for Irrigation

In order to quantify human health impacts associated with malnutrition as a result of lack of water for irrigation, Trucost used the methodology developed by Pfister (2011). This methodology estimates the human health impact of water scarcity related malnutrition based on a series of variables including local water stress, share of total water withdrawals used for agricultural purposes, country human development index, and per-capita water requirements. The outcome of this modeling is an estimate of the number of DALYs lost per cubic meter of water abstracted in each country.

Lack of Domestic Water

Lack of access to domestic water for sanitation can lead to the spread of disease. This impact on health was estimated based on country specific factors derived from Motoshita et al. (2010). This model, which is based on a multiple regression analysis, estimates the human health impacts associated with the water deprivation related incidence of diarrhea and three intestinal nematode infections: ascariasis, trichuriasis, and hookworm disease. The outcome of this modeling is an estimate of the number of DALYs lost per cubic meter of water abstracted in each country.

Economic Modeling

Trucost values DALYs lost due to environmental impacts based on a global median estimate of the value of a life year adapted from a willingness to pay study conducted for the New Energy Externalities Development for Sustainability (NEEDS) project (Desaigues et al., 2006; 2011). This is a proactive cost estimate, which takes into account the perceived effects of morbidity and mortality. The value of a life year was adapted for each country based on national income per capita and an income elasticity of 0.5 (Desaigues et al, 2006, 2011), and a global median was calculated and used in all study countries. This approach avoids the ethical challenges associated with assigning a higher value to human health impacts in high income countries compared to low income countries.

Impact on Ecosystems

Biophysical Modeling

Restricted access to water can impact upon the net primary productivity of ecosystems. Net primary productivity is the rate of new biomass production by plants in an ecosystem and is used by Trucost as an indicator of ecosystem functioning. Net primary productivity was considered here as a proxy measure of ecosystem health as it is closely linked with the function of vascular plant species (Pfister, 2011) that form a critical primary element of the food chain and are thus essential for the healthy functioning of an ecosystem (Ibid). It is this assumed that damage to vascular plants is representative of damage to all fauna and flora species in an ecosystem (Delft, 2010).

NPP can be affected by a range of parameters, including temperature, radiation and water availability (Nemani et al., 2003). The objective of the biophysical modeling is to determine the fraction of NPP which is limited only by water availability, and thus captures the vulnerability of an ecosystem to water deficiencies. Trucost used country specific estimates of NPP limitation due to water availability (NPP wat lim) derived from Pfister (2011).

However, as the effects of water consumption on ecosystems depend on local water availability, NPP wat lim is adjusted to take into account the prevailing water scarcity. To achieve this, precipitation was used as a proxy for water scarcity, with country-specific precipitation data sourced from Aquastat (FAO, 2014b). In that sense, countries with the same NPP wat lim but higher water scarcity (lower precipitation) will be affected by ecosystem damage to a greater extent. Thus, the parameter NPP wat lim adjusted reflects the percentage of 1 m^2 that will be affected by the consumption of 1 m^3 of water in a year (units are m^2 year per m^3).

Economic Modeling

Trucost valued the impact on ecosystems due to water consumption based on the following three steps:

- Mathematically link ecosystem functioning to ecosystem service provision
- Quantify the effect on ecosystems due to water consumption
- Calculate the monetary value of the effect on ecosystem services

Trucost first calculated the average baseline NPP for each country in its database, based on the average NPP per ecosystem type and the ecosystem split per country. Average NPP per ecosystem type is based on the values reported by Costanza et al. (2007). Ecosystem split is based on a calculation of the area of each ecoregion in each country (Olson et al., 2004), and then mapping these ecoregions to the ecosystems in the Ecosystem Valuation Database or ESVD (de Groot et al, 2012).

Trucost then calculated the change in NPP per unit of water consumption based on the biophysical modeling described in the previous section. Trucost then estimated the link between NPP and ESV using regression analysis and used this to quantify the change in ESV per 1 m^2 in each country per cubic meter of water consumption. A GDP weighted average valuation was calculated for each region considered in this study and was used to value the ecosystem impacts of water consumption.

Leaching of Plastic Additives

The impacts of plastic additives on human health and ecosystems were valued using the Trucost Air, Land and Water Pollutants methodology described in the previous section. However, an additional analysis step was required to estimate the quantity of plastic additives leached into the environment over time. Trucost quantified and valued the leaching of plastic additives using the framework described in Figure 25, developed in the Valuing Plastic study (UNEP, 2014).

Figure 25: Plastic Additive Leaching Valuation Framework

Source: Trucost

Quantification of Toxic Constituents

Trucost calculated the quantity of additives contained in each type of plastic using a study of plastic additives by the Organization for Economic Co-operation and Development (OECD, 2009). This information was used to estimate the quantity of three classes of plastic additives (flame retardants, plasticizers, and antioxidants) in plastics sold in each of the sixteen consumer goods sectors.

Leaching

Trucost has estimated the health and environmental costs arising from the leaching of plastic additives into the environment, however it is acknowledged that this is an emerging field and available data is limited and uncertain. Trucost used the leaching rate calculated by OECD (2009) for plastics “outdoor, leaching to environment”, of 0.16% per year, implying the leaching of 100% of the additive content over a period of 625 years. The environmental costs of plastic additives were estimated over this time period and discounted to a present value in 2015 using a discount rate of 1.4% per annum, consistent with the Stern Review of the Economics of Climate Change (Stern et al, 2006). While it remains unproven that 100% of additives will eventually be released in the environment, the long duration over which additives are assumed to leach and the use of discounting of future costs means that the costs associated with the impacts of any residual additives remaining within plastics will be negligible.

Quantification of Toxic Impacts

Trucost quantified the environmental costs of leaching of plastic additives from unmanaged waste on land and in the oceans. Life cycle analysis characterization models can be used to estimate the human, terrestrial, freshwater and marine toxicity of thousands of substances when released in different media. Trucost used a global adaption of ReCiPe by EUSES-LCA to model the human health and ecosystem impacts of a representative chemical in each of the three classes of plastic additives studied (flame retardants, antioxidants and plasticizers) (Sleeswijk and Heijungs, 2010; Lijzen and Rikken, 2004; Goedkoop et al, 2013; NEEDS, 2006). The Trucost Air, Land and Water Pollutants valuation methodology described above was then applied to value these impacts in monetary terms.

Disamenity

In the context of waste management, disamenity generally refers to the localized impacts of landfill sites and other waste management activities on the perceptions of environmental quality among populations in the immediate vicinity (Eshet, Baron and Shechter, 2007). The European Commission described disamenity as the ‘nuisance’ caused locally as a result of the presence of landfill – noise, dust, litter, odor, the presence of vermin, visual intrusion and enhanced perceptions of risk. The magnitude of the effects will depend on distance from the site, type of waste (non-hazardous or hazardous), status of site (existing, new, or proposed), management practices, topography and prevailing wind directions.

Only a limited number of studies have been undertaken to value the disamenity impacts of the waste sector (European Commission, 2000). A number of studies were conducted in the US in the 1980s and early 1990s (especially for landfills). Only two European studies have been identified (European Commission, 2000). Disamenity impacts were excluded entirely from the Exiopol study in 2009 because these impacts were perceived as too site specific to be applied more widely - The study only indicates an order of magnitude based on a study from 2006 by Walton (1 Euro per metric ton) (Walton, Boyd and Markandya, 2014).

Disamenity impacts are commonly studied using the hedonic pricing method which seeks to correlate variation in residential property process with variation in environmental quality (such as proximity to a landfill site or incinerator), controlling for other factors that influence property prices (such as the number of bedrooms). Application of a hedonic pricing approach to this study would require extensive site specific data, including the locations of waste management sites globally, and thus was deemed beyond the scope of this study.

It is likely that disamenity impacts would be greater in countries where waste was managed poorly (as the disamenity effects such as noise, nuisance, vermin, etc are likely to be higher). Most studies have been carried out in countries with high quality waste management (the percentage of waste going to a formal disposal method was used as a proxy for the general quality of waste management in a country). However one study undertaken in South Africa provides an assessment the cost of disamenity in a country with a lower standard of waste management than is commonly seen in high income countries - approximately 60% of waste is formally collected in South Africa (Nahman, 2014). When the disamentity cost (adjusted for PPP to adjust for differences in house prices) was plotted against formal waste collection rates, an inverse relationship was identified between percentage of waste formally collected and the disamenity cost.

For the purposes of this study, and considering the limited available data on the locations and characteristics of waste management sites globally, Trucost developed a methodology to estimate the disamenity cost of waste management in all study regions based on extrapolation from previous published studies. A disamenity scale was derived by plotting the PPP adjusted disamenity cost of landfill sites against the municipal waste collection rate (as a proxy for general quality of waste management in the country) in each of the prior study countries. The disamenity cost per metric ton of waste managed via landfill, incineration or recycling was then estimated at the country level based on the waste collection rate in that country. The resulting estimate was adjusted for PPP to take account of differences in price data between countries. Adjusting for PPP is a widely used technique, especially for transfers between countries (OECD, 2009).

External Waste Management Costs

The provision of municipal waste collection services and the management and operation of waste processing facilities (landfills, incinerators) can be costly and are generally not paid directly by the producers of consumer goods products. These costs are borne largely by Governments at various levels and taxpayers, and thus represent externality costs from the perspective of the consumer goods sector. Thus the burden of management the disposal of packaging and product waste from the consumer goods sector represents a cost to society that is not internalized by the consumer goods sector. Data from the World Bank (Hoornweg and Bhada-Tata, 2012) was used to estimate the cost of waste collection and management for each country included in the study based on their income level. A weighted average based on GDP was then calculated for each of the six regions included in the study and used to value the external financial cost of each metric ton of consumer goods wasted disposed.

Impacts of Marine Debris on the Oceans

In the report Valuing Plastic (UNEP, 2014), Trucost described a novel approach to estimate the quantity of consumer goods waste reaching the ocean, and the value the impacts of marine debris in monetary terms. This methodology was further developed and improved in this study to incorporate more recent scientific research published since 2014. The methodology for estimating the impact of marine debris on the ocean involves two key stages: modeling the transfer of land based consumer goods waste into the ocean; and valuing the physical, chemical and economic impacts of waste reaching the ocean.

Modeling the Transfer of Land Based Waste to the Oceans

In 2015, a seminal paper by Jambeck et al (2015) was published in the journal Science which described a methodology for quantifying the input of plastic into the oceans from land based sources. This model considered the quantities of unmanaged waste generated by coastal populations (within 50km of the coast) and developed a model describing the conversion rate for land-based litter into marine debris. This paper culminated in the best estimate to date of the annual inflow of plastic waste into the ocean at between 4.8 and 12.7 Mt globally.

Building on this research, and other recent developments in marine debris research, Trucost refined its methodology for quantifying and valuing the impacts of marine litter, developing the model described in Figure 8 in the Results section. The model first calculates the quantity of mismanaged coastal waste generated from the consumer goods sector in each or six regions using estimated of the regional average waste mismanagement rate (Table 6) and coastal population data from Jambeck et al (2015). A conversion rate between coastal mismanaged waste and marine debris, derived by Jambeck et al (2015), was then applied to estimate the quantity of marine debris arising from each sector in each region. Trucost used the upper bound transfer rate described by Jambeck et al (2015), as the objective of this analysis was to arrive at a conservative estimate of the cost of plastic (and other material) waste to the oceans per metric ton. Based on the findings of a recent study by The Ocean Conservancy (2016), which found that 25% of plastic debris in the ocean arises from leakage from waste collection and management systems, the estimated total quantity of marine debris created in each region was inflated to account for leakage from waste management systems. Table 10 outlines the key assumptions used to model the generation of marine debris in each region. All region specific assumptions were calculated as a regional GDP weighted average.

Table 10: Key Assumptions: Modeling Marine Debris Arising from the Consumer Goods Sector

REGION		% WASTE MISMANAGED	% COASTAL POPULATION	COASTAL WASTE TO MARINE DEBRIS CONVERSION RATE	ADJUSTMENT FOR LEAKAGE FROM WASTE MANAGEMENT SYSTEMS
Asia	Packaging	54%	29%	40%	Multiply by 133%
	Product	54%			
	Automobiles	30%			
	Durables & Electronics	31%			
Europe	Packaging	2%	34%		
	Product	2%			
	Automobiles	13%			
	Durables & Electronics	3%			
North America	Packaging	0%	36%		
	Product	0%			
	Automobiles	12%			
	Durables & Electronics	1%			
Latin America and the Caribbean	Packaging	15%	37%		
	Product	15%			
	Automobiles	32%			
	Durables & Electronics	32%			
Middle East and Africa	Packaging	48%	20%		
	Product	48%			
	Automobiles	39%			
	Durables & Electronics	46%			
Oceania	Packaging	8%	80%		
	Product	8%			
	Automobiles	12%			
	Durables & Electronics	1%			

Source: Trucost, Jambeck et al (2015), Ocean Conservancy (2016)

The mechanisms modeled to estimate the transfer of plastic waste to the ocean are also likely to apply to other materials. As such, the same modeling approach was applied to estimate the quantities of alternative materials reaching the ocean in the alternatives to plastic scenario, but with important modifications that recognize the different physical and chemical properties of plastic and alternatives. The economic and physical impacts of plastic marine debris are potentially similar to that of the alternative materials – for example, an aluminum can has potential to be washed up on beaches or to entrap marine wildlife in a similar way to a plastic bottle. However, the physical and economic impacts of marine debris are likely to be a function of the time taken for the debris to decompose – the longer time decomposition time, the more likely the debris is to impact upon the economy and the environment. Many alternatives to plastic, such as paper and textiles, have more rapid decomposition rates than plastic (Ocean Conservancy, 2015) and thus the ocean impact valuation for alternative materials has been adjusted for the relative decomposition time of each material compared to plastic. Key assumptions used in this adjustment are shown in Table 11.

Table 11: Ocean Impacts of Alternative Materials: Decomposition Time Weighting

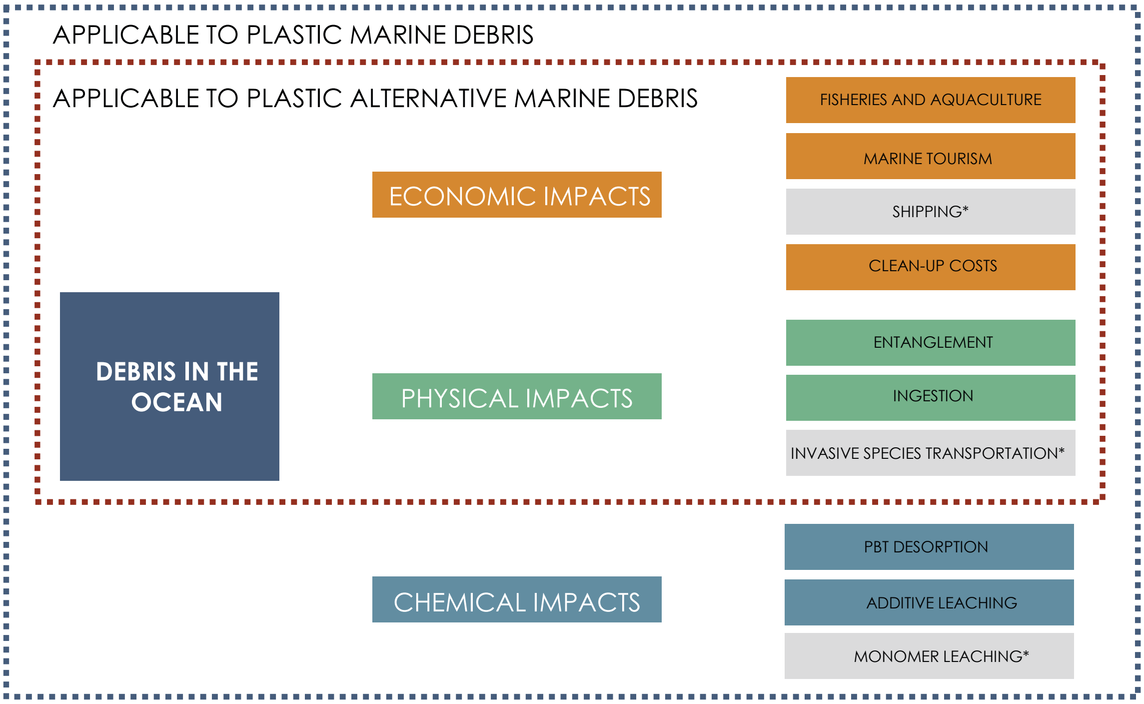
MATERIAL	DECOMPOSITION TIME WEIGHTING (MULTIPLIER)
Plastic	1.00
Aluminum	0.69
Steel and Tin Plate	0.17
Paper	0.00
Wood	0.01
Textile	0.01
Glass	1.00
Leather	0.17
Rubber	0.28
Steel and Iron	0.17
Mineral Wool	1.00

Source: Ocean Conservancy (2015)

Identifying the Impacts of Marine Debris

Once the quantity of marine debris arising from each consumer goods sector in each region was quantified, the next step is to identify and then value the impacts of this debris on the oceans. In the report, Valuing Plastic (UNEP, 2014), Trucost presented a simplified model of the most significant known impacts of plastic on the oceans based on an extensive review of available literature. This model was adapted to represent the impacts of marine debris, both plastic and non-plastic, in the ocean as shown in Figure 27. Grey boxes represent potential impacts, which have been excluded from the valuation. For example, the valuation excludes the potential impacts of microplastics due to lack of adequate data.

Figure 27: The Impacts of Debris in the Ocean



* Excluded from the valuation model

Source: Trucost

The following key categories of impact were included in the valuation methodology.

Economic Impacts

Marine debris can generate economic impacts which are often paid by those affected rather than the producers or consumers of waste materials. Economic impacts relate to the loss of revenue caused by marine debris. Industries concerned by this issue include fisheries and aquaculture, marine tourism and shipping. Furthermore, marine litter washed up on beaches will impose costs on local authorities, volunteers or other groups when removed (UNEP, 2005).

Ecological Impacts

Ecological impacts refer to the morbid or lethal effects endured by marine wildlife. These impacts can be broken down into physical impacts, referring to the impacts coming from the shape of marine debris objects, and chemical impacts, referring to the impacts associated with toxic substances present in plastic marine debris (this aspect is not considered for non-plastic debris).

Physical impacts

Entanglement: marine wildlife such as marine mammals can be entangled in marine debris, which can lead to suffocation, starvation, drowning or increased vulnerability to predators.

Ingestion: marine species can ingest debris particles by mistaking it for food. This can lead to starvation, malnutrition or internal injury (GEF, 2012).

Transportation of invasive species: floating marine debris can act as vector of invasive species which would alter community structure (Rochman et al, 2013). This impact has not been included in the valuation model due its complexity and the lack of quantitative data.

Chemical impacts

Persistent Bioaccumulative Toxic substances (PBTs) desorption: plastics can act as a carrier for the ingestion of PBTs such as Polychlorinated Biphenyls (PCB) and Polycyclic Aromatic Hydrocarbons (PAH) (Mouat, Lopez-Lozano and Bateson, 2010). PBTs are chemicals that degrade slowly in the environment and accumulate in organism tissues. Due to industrial activity, the oceans now have varying concentrations of PBTs to which marine life is already exposed. However, due to its chemical characteristics, plastic in the ocean can absorb these PBTs increasingly over time. If the plastic is then ingested by marine wildlife, it is possible that PBTs can be transferred to the animal and potentially bio-accumulate in the food chain (Rochman et al, 2013). While recent research by Koelmans et al (2016) suggests that ingestion of microplastics by marine life is unlikely to increase exposure to PBTs (relative to much greater exposure via the consumption of prey species), the leaching of absorbed PBTs has been included and valued as a possible impact of plastic in the ocean. The contribution of this impact to the overall ocean cost of plastic is however negligible relative to the ecological and economic impacts of plastic.

Additives leachate: additives are chemicals added to plastic granules in order to enhance their properties including but not limited to heat and corrosion resistance, hardness and colors. The quantity of additives varies based on the type of plastic and its usage – for example plasticizers are often used in PVC products to improve flexibility and flame retardant in electronics and automobiles for safety reasons.

Monomers leachate: the molecules bonded together to form plastics are called monomers. When plastic degrades, these monomers can leach and be ingested by biodiversity. Some of the monomers are hazardous, such as styrene which is the monomer of polystyrene. This impact has not been included in the valuation model due its complexity and the lack of quantitative data.

Valuing the Impacts of Marine Debris

Trucost developed a set of methodologies to quantify and value the impacts of marine debris in each of the categories above in monetary terms. While this methodology is not exhaustive due to a lack of robust data and models describing the impacts of marine debris, Trucost has endeavored to capture the most material impacts.

Economic Impacts

The main approach to value economic impacts generated by marine plastics is based on calculating the yearly revenue loss attributable to plastic and non-plastic marine debris.

Fisheries and Aquaculture

Mouat et al. (2010), estimates marine fisheries and aquaculture losses due to marine debris at 2.3 percent and 0.03% of total revenue respectively. Extrapolating to the global fisheries and aquaculture sectors, Trucost estimates total combined losses of $3.4 billion in 2015 due to marine debris (FAO, 2014a). Considering that plastics comprise between 50% and 80% of marine waste, Trucost estimates that plastic debris is responsible for an annual revenue losses of $2.2 billion per annum for the fisheries and aquaculture sectors (Thompson et al, 2009). This approach was also used to value the potential impact of alternatives to plastic, adjusting for the difference in degradation rate.

Marine Tourism

Marine tourism includes seawater and freshwater angling, sailing and boating, water sports, and inland cruises. Studies estimate that beach litter in Sweden was responsible for an annual loss of tourism revenues of between one and five percent (Gold et al, 2013). Extrapolating to the global marine tourism sector and assuming revenue losses of 3 percent, Trucost estimates total losses in 2015 of $4.6 million due to marine plastic debris. This approach was also used to value the potential impact of alternatives to plastic, adjusting for the difference in degradation rate.

Clean-up Costs

To estimate the costs of clean-up activities required to remove marine debris washed up on beaches, Trucost estimated the opportunity cost associated with volunteer time dedicated to clean-up activities based on data from the Ocean Conservancy International Coastal Clean-Up Database (Ocean Conservancy, 2016). In 2014, more than 560,000 volunteers in 91 countries participated in coastal clean-up activities (ibid). The opportunity costs associated with volunteer time spent cleaning up beaches was estimated based on an average of one half day per person spent undertaking clean-up activities and the weighted average global annual income per capita (World Bank, 2016). Trucost estimates the global opportunity cost of volunteer time spent cleaning marine debris from beaches at $7.8 million per annum. While there are other possible benefits of beach waste collection, such as volunteers becoming more aware of the environment for example, these costs were not included in the analysis.

In order to normalize the economic impact valuations per unit of marine debris created, the total cost estimates must be divided by the annual input of plastic to the ocean each year. Trucost used the mid-point estimate for plastic input to the ocean from Jambeck et al (2015), 8.75 Mt, as the best available recent estimate in the literature. However it is noted that there is no current consensus on the annual inflow of debris to the oceans and any estimate will be uncertain due to the complexity involved in monitoring or modeling this process. This approach was also used to value the potential impact of alternatives to plastic, adjusting for the difference in degradation rate.

Ecological Impacts

Physical impacts: entanglement and ingestion

The Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel, reports that 26 to 45% of marine mammal species, 0.24 to 0.39% of fish species and 21 to 28% of sea bird species have been identified as affected by ingestion or entanglement in marine debris (GEF, 2012). Trucost valued these impacts based on a contingent valuation study undertaken by Ressurreição. et al (2011), which assessed how much people would be willing to pay to avoid a loss of 10% and 25% of different categories of marine species. Contingent valuation is a survey-based technique in which respondents are asked to disclose their willingness to pay for the preservation (or increased provision) of an environmental (or other) non-market good or service. This technique is often applied to assess non-use value of different aspects of the natural environment, such as the existence of species. The study by Ressurreição et al (2011) did not consider the actual ecosystem services provided by each individual species, but instead the perceived services that these animals render to society, as perceived by the survey respondents.

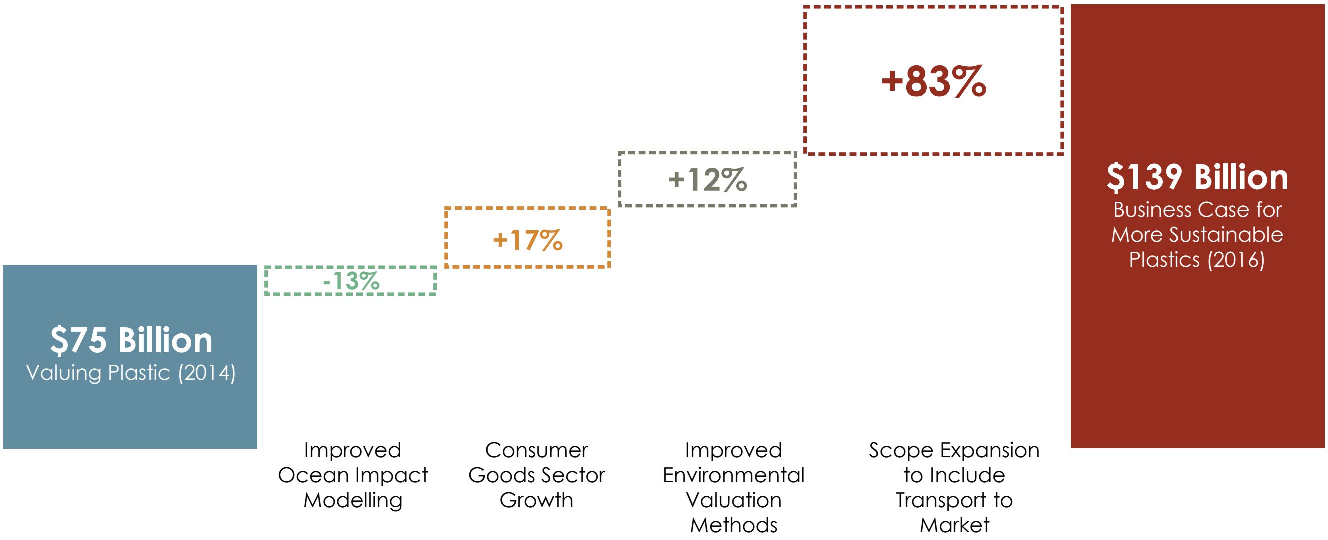
Chemical impacts

Chemical impacts associated with desorption of PAH and PCB chemicals absorbed by plastic in the ocean, and the leaching of plastic additives, were valued using the methodology described for ‘Additive Leaching’ in the previous section.
The environmental costs associated with chemical impacts are small relative to the economic and physical impacts, at less than 1% of the overall estimated cost per metric ton.

Appendix 3. Improving Estimates of the Environmental Cost of Plastic

The 2014 Valuing Plastic report (UNEP, 2014) estimated the total environmental, or natural capital, cost of plastic use in the consumer goods sector at $75 billion per annum, including the production and end of life disposal phases along with impact on the ocean. This study expands the scope of this initial analysis to include the transport of plastic and alternative materials to market and incorporates newly available data and methods to refine the estimate of the total environmental cost of plastic. These refinements have led to an increase in the estimated total environmental cost of plastic use $139 billion per annum. Figure 28 outlines the key factors driving this increase in estimated environmental cost. The inclusion of the transport to market phase of the life cycle is the most important driver of the increase in the estimated cost of plastic use in consumer goods, with smaller contributions from growth in the consumer goods sector and improvements in Trucost's environmental valuation methodologies. Furthermore, refinement of the modeling and valuation of mismanaged plastic debris in the ocean.

Figure 28 Improving Estimates of the Environmental Cost of Plastic in Consumer Goods



Source: Trucost

Glossary

TERM, ACRONYM OR ABBREVIATION	MEANING
Benefit transfer	Technique by which an environmental value is transferred from one location to another
Burden	Negative environmental impacts
Credit	Positive environmental impacts
Direct environmental impacts	Impacts from a company's own operations
Downstream	Life cycle state once the product is discarded by the consumer.
Disamenity	Nuisance caused by noise, odor, presence of vermin, etc.
EIO	Environmentally extended input-output model; a model that maps the flow of inputs and environmental impacts through an economy
Indirect environmental impacts	Impacts from a company's supply chain
Natural capital	The finite stock of natural assets (air, water, and land) from which goods and services flow to benefit society and the economy. It is made up of ecosystems (providing renewable resources and services), and non-renewable deposits of fossil fuels and minerals
Natural capital cost	Expresses the total natural capital cost, derived by multiplying the natural capital intensity by revenue.
Natural capital intensity and revenue-at-risk	Expresses the natural capital cost of all environmental impacts per million US$ revenue. This can be understood as a measure of risk – if all environmental and social impacts generated by plastic were to be paid for by businesses, this percentage of their total revenue would be at risk.
Natural capital valuation	The value to people from environmental goods and services. When no market price exists, it can be estimated in monetary terms by using environmental valuation methods. It is often a cost borne by third parties not taking part in the economic activity which generated it.
Normalized natural capital cost	Expresses the total natural capital cost weighted by the average service life of a typical product within the sector of interest.
Plastic	Synthetic material derived from petrochemicals. Can be classified in families depending on properties. Microplastic refers to smaller pieces, less than 5mm in size.
Plastic-in-packaging	Includes the quantity of plastic directly used in the packaging of the product, as well as any losses that were incurred during the manufacturing and packaging stage
Plastic-in-product	Includes the quantity of plastic directly used in the product, as well as any losses that were incurred during the manufacturing process.
Plastic-in-supply-chain	Includes the quantity of plastic used indirectly by consumer goods businesses via their supply chain but is not destined to be neither in the final product nor in packaging. It encompasses every single activity in the economy.
Upstream	Life cycle stage spanning from the extraction of raw materials to plastic granule manufacturing.

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