Introduction

Most people would agree that we need to look after our planet, so that we and future generations can enjoy it. I certainly feel that way and it is good to see so many articles bringing attention to the topic. They make people want to act. Our leaders, major corporations and even children are demanding action. But what actions are the wisest? How can we be sure that we are helping and not harming our environment? As a scientist, I wanted to see the facts, but I didn't find any in the articles online. Hardly any of the articles referenced scientific studies. I began to realize that just about all we believe about the environment is based on LinkedIn headlines, YouTube videos and articles that are just opinion pieces, without any solid foundation. That made me uneasy.

This page is the culmination of my personal search for all the solid data I could find. To give one example, before writing anything on marine litter and microplastics, I read over 50 scientific articles and one book to get a balanced view of the topic. That's the proper scientific way to approach a new topic. Collect all the evidence you can find, digest it and then form an opinion. It's the opposite of what many people do. For the layperson, it can be tempting to form an opinion first and then look only for evidence that supports that pre-conceived view. People are welcome to do it that way, but that is not the path to wise decision-making. Our environment and our kid's future deserve better than that.

Here you will find lots of data and links to the original sources so that you can read it all for yourself. That includes both articles that are for and against plastics. If you have information to add, please send it. I will try to keep the page updated, although I am doing this in my spare time, without any funding so, bear that in mind. I just put this page up in January 2019, so please bear with me as I improve and add content to it.

It all started with plastic bags

Why did I start down this path? I had been reading a lot of articles online about plastic bags and proposals to ban them. But I did not see a single piece of data to support that decision. It may surprise you to hear that I find plastic bags to be one of the ugliest things imaginable. However, I realise ugliness alone is not sufficient reason for a ban. So, with all the options including paper, cotton, conventional PE bags, reusable PP bags, biodegradable plastic bags and so on, how can we know which one is best? There are many different companies telling us their bags is green, but how do we know who is right?

It all started with a Google search. I looked for the terms “plastic bag lifecycle analysis” and “plastic bag LCA” because lifecycle analysis is the only internationally accepted standard to determine what is good and bad for the environment. GreenPeace uses it and so do governments and major companies. It’s expensive and includes everything from cradle to grave including all the “inputs” (raw materials and energy), and “outputs” (emissions to the air and water, by-products and wastes disposal) for making a product. Because it’s so expensive, I wasn’t sure I would find any, but I was happily surprised to find some right away. You can type “LCA plastic bag” into Google and find many of the same hits I did. These are all the studies I have found so far.

In the interest of fairness, these are exact quotes copy-pasted from the executive summary or conclusions of each study:

- **Clemson University Study**
- **UK Study**
- **Franklin Study**
- **Reason Foundation Study USA**
- **Danish EPA Study**
- **Australian Study**
- **Californian Study**
- **Slovenian Bag LCA**
- **South African Study**
- **Swiss LCA Study**
- **Australian Study 2**
- **Indian Study**
- **Franklin Reviews LCA Studies**
- **Canadian Bank Note LCA**
- **English Bank Note LCA**
- **McKinsey LCA Report**
- **Austrian Packaging Study**

"A compilation of all of the statistically-based, scientific studies of litter in the U.S. and Canada over an 18 year period shows consistently that "plastic bags" (which includes trash bags, grocery bags, retail bags and dry cleaning bags) make up a very small portion of litter, usually less than 1%."
"Our results also show that Paper bags, even with 100% recycle content, have significantly higher average impacts on the environment than either of the reusable bags or single-use plastic retail bags"
"Our results in this study show that these regulations and policies may result in negative impact on the environment rather than positive. Even though Paper bags come from a renewable resource and are easily recycled, it is likely that they are not the best environmental choice."

In summary, they found that paper bags are much worse for the environment and that the best two choices were reusable polypropylene bags or single-use polyethylene bags.

Download the full Clemson LCA Study

Summary – plastic bags

Lifecycle assessments (LCA) are the only internationally accepted method for comparing the environmental impact of materials and products. They are used by governments, companies and environmental groups, including GreenPeace and are independently audited. The LCA method takes into account all the energy, materials, water, emissions and so on associated with the manufacture and disposal of a product. No tool is perfect, but LCA is by far the best, most widely-accepted way to see what is really green.

LCA analyses are done by government agencies in the US, Canada, UK, Australia and Denmark. They all agree that the single-use polyethylene bags we use today have much lower environmental impact than potential replacements such as bioplastics, paper, unbleached paper, cotton or organic cotton. The other leading green solution is reusable PP bags (think of the iconic blue Ikea bags). Those are actually the best option, as long as they are reused several times.

To replace plastic bags with paper bags requires 2.7x more energy, 1.6x more carbon dioxide emissions and 17x more water usage. It has also been estimated that replacing the plastic bags in the EU would require cutting down an astonishing 2.2 million more trees per year and require 60 000 Olympic swimming pools more water.

I believe this to be the largest collection of LCA studies on this topic. Why did I spend so much time to collect every study I could find? The reason is that this is an important topic and people are convinced that plastic is harming our environment. Because the findings go against popular opinion, there is an added burden of proof when trying to dispel the myth that has evolved around the topic. If I had found one LCA that said plastic was better, or if I had found only a couple of studies funded by the plastics industry, I would have been skeptical. Instead what I found instead was multiple studies from several countries and all of them funded by impartial parties. The conclusions are unanimous and solid.

What does this mean?

I was surprised to find that our traditional PE and PP bags are far greener than the alternatives that are being thrust upon us. That means that the bans being implemented are actually harming our environment. Plastic bags are being taxed to discourage use. That may be a nice source of revenue, but it is counterproductive. This is exactly why we need facts before we act. Without hard data, we end up doing harm instead of good. Governments, companies and the environmental groups have not done their due diligence. They are making statements and taking policy decisions without checking the data first.

This opened my eyes and showed me that it is not safe to trust what we've been told. We have to stop parroting the same old sound-bites and headlines from articles written by people who did not spend the time to check the veracity of their words. I was also deeply disappointed with the so-called environmental groups. I had assumed that they had done their homework and given us good advice. After all, they collect millions in donations and have had decades to find the best path forward. How is it that with all that funding they did not find ten minutes to type "LCA plastic

bag” into Google? Why are they advocating bans that harm our planet? It makes me seriously question their competence and motives.

What about other uses for plastics? What do the lifecycle studies show for other applications of plastic versus renewable materials? I went looking for more information and found LCAs done by the Bank of Canada and the Bank of England. Both showed that polypropylene plastic bank notes were far greener than cotton notes. In fact, after several days of searching, every LCA I have found shows plastics to be the best solution.

Plastic food packaging

CNN featured news about the World’s first supermarket aisle free of plastic packaging. They touted the move to “new compostable bio-materials as well as traditional materials” such as glass, metal and cardboard.” That sounds admirable enough, but they presented no evidence that what they had done was actually green. So, is their idea environmentally sound or just a publicity stunt? The only way to be sure is to look for the evidence.

A good starting point is a leaflet called Preventing Food Waste from the American Chemistry Council. It shows that plastics are incredibly good at protecting our food and preventing waste. The food is protected during transportation and then it helps prevent spoilage. Cucumbers last 11 days longer, bananas last 21 days longer and beef 26 days longer. They showed that good packaging can save many billions of dollars and millions of tons of food.

Here's a statement from the conclusions of a detailed report called Plastics & Sustainability published by the American Chemistry Council.

"Plastic packaging has many properties that are vitally important for packaging applications, including light weight, flexibility, durability, cushioning, and barrier properties, to name a few. This substitution analysis demonstrates that plastic packaging is also an efficient choice in terms of environmental impacts."

"For the six packaging categories analyzed – caps and closures, beverage containers, stretch and shrink film, carrier bags, other rigid packaging, and other flexible packaging –14.4 million metric tonnes of plastic packaging were used in the US in 2010. If other types of packaging were used to substitute US plastic packaging, more than 64 million metric tonnes of packaging would be required. The substitute packaging would result in significantly higher impacts for all results categories evaluated: total energy demand, expended energy, water consumption, solid waste by weight and by volume, global warming potential, acidification, eutrophication, smog formation, and ozone depletion, as shown previously…"

From this we can see that plastic packaging is by far the best solution for our environment. In fact, another study showed that plastic packaging also leads to enormous reductions in CO_2 emissions because they help food stay fresh longer. Food production is a major cause of carbon dioxide production and plastic packaging greatly reduces CO_2 even accounting for the carbon dioxide from plastic production.

Then comes the question of litter

When I wrote about this on LinkedIn, I was expecting a huge backlash because I was writing the opposite of what we have all been taught. Therefore, it was a relief to see how much support I got. Most people were glad to see an article that finally presented them with information they could use to make up their own minds. Probably the biggest pushback was from people saying something like, “OK, maybe plastics are the greenest solution but what about the litter and the oceans”?

Of course, litter is a separate topic and I didn’t have the answers, so once again, I had to go looking for them. There is a surprising amount of information about litter. For example, the EPA in the US have collected extensive data on all waste since the 1960s. It’s available for download but there’s so much that I could not make any sense of it. I had to ask a professional Data Architect to make graphs so that we could see the trends.

AnnaLytix™ did an outstanding job of making interactive graphics which allow me and you to look through the EPA data and apply filters (see below).

Data trends from 1960 onwards on US waste (source EPA)

Business intelligence based on data analytics is a relatively new field and many people don’t know what it is, or what’s possible. To give some idea, I have taken publicly available data from the US EPA and made it visual and interactive. The raw data is available to all but it doesn’t tell a story when you just stare at columns of data in Excel. That’s where expertise in Microsoft Power BI and Tableau can help. They allow you to understand the data at a glance. What’s more, unlike old-style static graphs, with the new tools the data becomes interactive, so you can explore and get insights that are meaningful to you and your business.

AnnaLytix™ did an outstanding job of making interactive graphics which allow me and you to look through the EPA data and apply filters (see below).

What we see is that plastics waste grew rapidly at first, because it was a new material. However, in the last couple of decades, the growth of plastic waste has slowed and now follows population growth. Population growth rate passed through a maximum many years ago and has been decelerating ever since. We can expect waste generation to follow that trend.

Here is a quote from a peer-reviewed article written about this EPA data:

"A comparison of waste generation rates for each material category found in MSW reveals that plastics increased by nearly 84 times from 1960 to 2013 while total MSW increased only 2.9 times. The increase in plastic waste generation coincides with a decrease in glass and metal found in the MSW stream. In addition, calculating the material substitution rates for glass, metal and other materials with plastics in packaging and containers demonstrates an overall reduction by weight and by volume in MSW generation of approximately 58% over the same time period."

They conclude that plastic dramatically reduced the amount of municipal solid waste (MSW). This is in line with the other studies that found replacing plastics would lead to far more material usage, waste and environmental burden.

Interactive data analytics on US waste (source: US EPA)

The graphs allow us to see more than that. I just read a post on LinkedIn saying that 90% of plastic waste has never been recycled. That sounds dramatic, so I went to the graphs and could see what that number means in context. We can see that 9% of plastic in the US is recycled compared to 5% of food waste, 34% of metal, 16% of wood, 15% of textiles, 67% of paper and 26% of glass. Why was only plastics mentioned in the post as

though plastics were of special cause for concern? It is not productive to demonize plastics. Instead we should look at all the data to see that there is clearly huge room for improvement for all material types.

Plastics account for just 13% of all US waste by weight. Why is it then that people only talk about plastics waste? I have never in my life seen an article complaining about glass waste or metal waste. Why are people obsessed with 13% of our waste and disinterested in the rest? I think that there are several reasons. Firstly, plastics was something new and people saw its dramatic growth. Another reason is that much of the common plastic floats, so we can see it on the surface of the water. In contrast, metal and glass both sink. There are many sunken ships. The Titanic alone weighed over 50 000 tons but no-one talks about it in terms of ocean litter. In fact, it is common to intentionally scuttle ships in order to make for good diving sites. I have seen TV shows talking about how great sunken ships are in creating artificial coral reefs. The Gen. Hoyt S. Vandenberg, a massive World War II ship weighing 17 000 tons was intentionally scuttled for divers. Why is it that metal is treated as a delight to nature and plastics are vilified? It's something to think about. I don't think any kind of ocean litter is good and we should treat it all with equal disdain. It has been estimated that the Great Pacific Garbage Patch weighs 80 000 tons. That's the same as the Titanic and the Gen. Hoyt S. Vandenberg combined. The patch is in the news all the time but the ships are not.

In looking for data on litter in the USA, I found the website of Keep America Beautiful who have studies and reported on this topic for decades. They actually study litter as it happens, noting the circumstances and whether or not the act was intentional. Here is a quote from their report:

Litter is primarily the result of individual behaviors.

- About 85% of littering is the result of individual attitudes. Changing individual behavior is key to preventing litter.

- Nearly one in five, or 17%, of all disposals observed in public spaces were littering. The remainder (83%) was properly discarded in a trash or recycling receptacle.
- Most littering behavior—81%–occurred with notable intent. This included dropping (54%), flick/fling of the item (20%), and other littering with notable intent (7%).

What does this mean? The conclusion is clear. People are responsible for dropping the litter and 81% of the time, it's intentional. You can literally watch them do it on purpose. Of course, these are the same people blaming plastics for the litter problem. They are not honest enough to look themselves in the mirror and admit where the real problem lies. Instead, they drop the litter on purpose and then blame the litter. What is the consequence? People are pushing to ban plastics, conclusively proven to be the greenest option, when the problem lies with human behavior. As mentioned elsewhere, replacing plastics with other materials does about 4x more harm than the plastic does and creates 4x more litter as well. Is that what you want?

Myths about plastic

- **The Plastic Lasts Forever Myth**
- **The Plastics / Microplastics are Toxic Myth**
- **The Black Plastic Can't be Recycled Myth**

I've seen so many articles stating that plastics are stable indefinitely and last for hundreds or thousands of years in the environment. Any competent plastic materials expert will tell you that's just not true. Museums even struggle to preserve plastic items that have been kept indoors, protected from the elements. These museum items are just a few decades old and are already falling apart. Neil Armstrong's

space suit is just one example, but one of my good friends worked as a plastics conservator at a major museum and he saw similar cases every day.
Plastics are organic materials and like any material made of carbon, hydrogen and oxygen, they degrade with time, heat and UV light, including sunlight. Plastics experts know that you have to add stabilizers to protect the plastic and without stabilizers they would fall to pieces. Two of the most common plastics found in waste are polyethylene and polypropylene. Both degrade readily. Polypropylene (PP) is so unstable that it loses strength and degrades in just one year at room temperature. Does that sound like a material that lasts forever? I have added about ten peer reviewed articles to support what I've just stated. It's common knowledge amongst plastic materials experts. In fact they spray stabilizer on PP the instant it's made, to prevent instant attack by oxygen in the air.
So, what looks like a stable material in your hand, is only surviving because of added stabilizer. As soon as the stabilizer is washed out or used up, the PP becomes unstabilized again and will start to degrade in about a year. This has all been known since the 1950s and published widely. There's even a journal devoted only to this (Polymer Degradation and Stability, Elsevier). Polyethylene is more stable than PP but it too has been found to literally fall apart, even at room temperature and without sunlight. At higher temperature and with sunlight, the degradation is much faster.
Articles also claim that conventional plastics do not biodegrade. That is not true either. Experiments show that they are attacked by bacteria. For example, PP film buried in a landfill.

"The results show that high-molecular-weight polyethylene can really biodegrade under bioactive circumstances if the test period is long enough."

Source: Biodegradation of Low-Density Polyethylene, Polystyrene, Polyvinyl Chloride, and Urea Formaldehyde Resin Buried Under Soil for Over 32 Years

Polyethylene and polypropylene have been shown to biodegrade. Polystyrene is more resistant but does degrade in sunlight. As we saw in the interactive waste charts, paper makes up most of the waste (40% by volume) and it doesn't degrade in a landfill because they are not designed to encourage degradation. The items get buried without enough oxygen and that slows down the process.

"There are the 40-year-old hot dogs, perfectly preserved beneath dozens of strata of waste, and the head of lettuce still in pristine condition after 25 years. But the hands-down winner, the one that still makes him shake his head in disbelief, is an order of guacamole he recently unearthed. Almost as good as new, it sat next to a newspaper apparently thrown out the same day. The date was 1967."

Seeking the Truth in Refuse, New York Times

Marine litter and microplastics

Do you remember all the articles about the plastics beads used in facial scrubs and how they were causing huge problems? I decided to take a look at that subject. Another topic drawing a lot of attention is that of plastics in the ocean and microplastics, i.e. plastic particles formed as plastics break down. What do we know about them? What kinds of plastics are involved? Are animals eating them? If they are, is it causing any harm. As mentioned

earlier, I read 50 articles and one book on this topic to work out the answers. Here is what I found.

You may have read about the great garbage patch. They analyzed its contents and found it was about half discarded nylon fishing nets. That's something that should be addressed in particular, such nets have been shown to entangle and harm birds. Just as we saw for land-based litter, much of it is created intentionally. Education and heavy fines may be suitable actions to take. As for the rest of the ocean litter, it comes from 10 rivers in Africa and Asia.

> "The 10 rivers that carry 93 percent of that trash are the Yangtze, Yellow, Hai, Pearl, Amur, Mekong, Indus and Ganges Delta in Asia, and the Niger and Nile in Africa. The Yangtze alone dumps up to an estimated 1.5 million metric tons of plastic waste into the Yellow Sea."
>
> Source: Stemming the Plastic Tide – 10 Rivers Contribute Most of the Plastic in the Oceans – Scientific American

Why are we banning plastic products in the US and EU when the litter doesn't come from there? That seems nonsensical to me.

The countries involved are behind us in that they have not had time to get used to plastics and have not yet developed the infrastructure to handle their waste. The problem has been addressed in the US, EU, Scandinavia and other regions. The same measures need to be applied to the developing countries. We know the solutions, so this can be handled successfully.

Here's an analogy to think about. If you saw clothes on your kid's bedroom floor, would your solution be to ban clothes? That would be an outrageous overreaction. In fact, the correct analogy would be that you visit a friend in another country and see clothes on their kid's floor and your solution is to go home and ban clothes at your house. I think everyone can see how silly that would be.

What are microplastics?

Microplastics are defined as plastic fragments of 5mm or less across. They first came to the public's attention when articles started showing up about the polyethylene microspheres used in some facial scrubs as a mild exfoliant. There was a huge uproar, as this was perceived as a major problem and now the PE spheres are no longer used.

A recent report gives an excellent overview (see Primary Microplastics in the Oceans- a Global Evaluation of Sources IUCN 2017). The report says that the global release of primary microplastics in the oceans is estimated to be about 1.5 Mtons/year. So, we know that microplastics are real and the quantities are enough to be concerned about.

I looked for the data and it turns out that just 2% of the plastic particles in the sea were from in facial scrubs. I was surprised at how low the amount was, in light of the huge amount of attention the topic received. So, what is responsible for the microplastics in our oceans? Here's the breakdown:

- Washing of synthetic textiles ~35%
- Erosion of car tires while driving ~28%
- City dust ~24%
- Road markings ~7%
- Marine coatings ~4%
- Personal care products ~2%
- Plastic pellets ~0.3%

Microplastics are abundant – but are they causing harm?

For a substance to present a danger, it has to be toxic and there has to be an exposure route. For example, a bottle of poison on the moon would not be a threat to people on Earth so there would be no danger. In that example, there is toxicity but no exposure. Conversely, we may be exposed to something but if it turns out to be harmless, then there is no cause for concern.

I looked at many studies and we know for sure that birds and fish do eat plastic. Microplastics can be found in their digestive system.

"Plastic was detected in 49 out of 64 fish (77%), with 2.3 pieces on average and up to 15 pieces per individual" and "Most were polyethylene (52.0%) or polypropylene (43.3%)."

Source: Microplastic fragments and microbeads in digestive tracts of planktivorous fish from urban coastal waters

So, the exposure component is there. What about the toxicity aspect? Are these plastic particles harmful to the marine wildlife?

It is interesting to see that PE and PP are the main plastics. It should not be too surprising, as they are the two most commonly used plastics and they both float on water, making them more visible and more likely to be ingested by fish. PE and PP are also two very safe plastics that we use all the time to package food. PE is used for sealable food bags in the kitchen and PP is used for sealable food containers. Both have been used safely for several decades.

Here are the conclusions from the studies online:

Albatross Chicks Study

"Our results indicate that ingested plastic is not a significant direct cause of death in albatross chicks"

Source: The effects of ingested plastic on growth and survival of albatross chicks

Microplastics in fisheries and aquaculture study

The press has drawn the public's attention to studies claiming that plastics leach toxins, but when we look at those studies, it turns out that the plastic was shown to be safe and only released toxins after the plastic was intentionally soaked in toxins by the experimenters. These studies are not only misleading but irresponsible. We could soak more or less anything in poison and then show that it released some poison once placed in clean water. Interestingly, other workers showed that plastics absorb toxins from water and hold them tightly so that even when ingested by fish, they are able to protect the fish. Have you ever seen a headline highlighting those studies? I have not. Why is that?

"Bio uptake in worms was lower by 76% when PCBs were associated with polypropylene compared to sediment. The presence of microplastics in

sediments had an overall impact of reducing bioavailability and transfer of HOCs to sediment-ingesting organisms. Since the vast majority of sediment and suspended particles in the environment are natural organic and inorganic materials, pollutant transfer through particle ingestion will be dominated by these particles and not microplastics. Therefore, these results support the conclusion that in most cases the transfer of organic pollutants to aquatic organisms from microplastic in the diet is likely a small contribution compared to other natural pathways of exposure."

Differential bioavailability of polychlorinated biphenyls associated with environmental particles: Microplastic in comparison to wood, coal and biochar

Another study states the following about microplastics (MP):

"Thus, despite their ubiquity, MP are unlikely to have a measurable impact on food intake or the total body burden of hydrophobic contaminants in Baltic herring."

Hydrophobic organic contaminants are not linked to microplastic uptake in Baltic Sea herring

Both polyethylene, and polypropylene, by far the most abundant microplastics in the ocean, have been proven to absorb toxins from water and sequester them, thereby protecting marine wildlife. Nylon has been shown to do the same, thE PA (polyamide) particles were themselves harmless and reduced the amount of BPA in the water:

"The PA particles themselves did not induce negative effects, while the effects of BPA alone followed a typical dose-dependent manner. Sorption of BPA to PA particles prior to exposure led to a reduction of BPA in the aqueous phase."

Microplastics Reduce Short-Term Effects of Environmental Contaminants. Part I: Effects of Bisphenol A on Freshwater Zooplankton Are Lower in Presence of Polyamide Particles

Conclusions

So, we have learnt a lot. Let's look back and summarize what all of this new information means.

- Plastics like PE and PP are far greener than cotton, paper or biodegradable plastic (as proven by LCA)
- Replacing them with sustainable or biodegradable options like paper, cotton or bioplastic harms would do significant harm to the planet (more CO_2, more warming, more chemicals, energy and water used)
- Reusable PP bags come out as the best solution, assuming they do get reused several times
- Litter is a totally separate issue
- Using plastics has significantly reduced the overall amount of litter
- Only 13% of litter is plastics but inexplicably, it commands 100% of the media attention
- Ocean plastics are eaten by fish and birds but the PE and PP are non-toxic
- In fact, both PE and PP have been shown to absorb toxins from the ocean and thereby protect marine wildlife
- Of course, we still need to dramatically reduce the amount of litter going into our oceans

I hope that you found this page of some use. Some people will be happy to see so much solid, independent data. Other people will remain sceptical. If you are sceptical, I would ask you to try and remember how you formed the view you have now. Was it from some LinkedIn headline, YouTube video or FaceBook rant? If it was from an online article, did they quote a multitude of peer-reviewed scientific studies as I have done? I have collected well over 100 on this topic and will be adding more, as time permits.

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