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Paper Bags or Plastic Bags? – A Brief Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Plastics are one of the most widely and abundant substances in today's society. Worldwide the usage of low-density polyethylene bags create pollution on land and in the oceans, especially when they break down in macro and micro plastics. On all continents, governments try to establish solutions on how to fight plastic pollution form shopping bags by banning their use, implant fees for their usage and replace plastic bags with a more renewable material. Paper bags are a valid solution, especially when manufactured from recycled materials. It is estimated, that In the United States, enough material is available to cover the replacement of the 100 billion plastic bags uses yearly with 100% recycled paper bags.

The required investment is roughly 6 billion dollars for new paper machines and mills, creating up to 10,000 new jobs in states where the paper machines would be installed and operated.

Keywords: Micro plastics; paper bag; paper making; plastic bag; pollution; recycling.

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1. INTRODUCTION

Throughout the world, an estimated five trillion plastic retail bags are used annually [1]. The first commercially manufactured paper bags were produced in Bristol, England in the 1840s, with the first machine for producing them patented with U.S. patent No. 9,355 October 26, 1852 [2] by Inventor Francis Wolle [2]. Over a century later in the mid-1970s the first plastic bags, made of polyethylene, arrived in grocery stores and rapidly gained popularity [3]. By 1990, over 23 billion plastic bags were used each year accounting for 60% of all bags used [3]. According to Oceanwatch Australia, today over 5 trillion plastic bags are used per year, 160,000 every second and over 700 a year for every single person on the planet [4].

2. NORTH AMERICA

In the United States, approximately 100 billion plastic bags are used annually according to the Center for biological diversity [5]. However, other sources estimate that up to 380 billion plastic bags are used each year in the U.S., with only 1% winding up in recycling facilities [5-6]. Annual plastic production is about 300 million tons per year, with roughly 50% are used a single time and disposed of [7]. Plastic bags, which account for much as 80% of the grocery and convenience markets, are manufactured from non-renewable petroleum and are typically polyethylene (PE) products [8].

Plastics are one of the most widely and abundant substances in today's society. They contribute significantly to the materialistic culture. The plastic pollution of land, oceans, and coastal areas due to human activity is a growing concern worldwide [9].

In 2010, 4.8 - 12.7 megatons of plastic waste entered the global ocean system. Which directly results in estimates that plastics make up 80% of all marine litter [7].

The Plastic Oceans Foundation estimated that 8 million tons of plastic is discarded into the ocean each year [10].

A major problem occurs when low-density polyethylene bags in particular is the abundance of micro plastics that arise when they break down mechanically. Micro plastics are any plastic particle less than five millimeters in length (NOAA, “What are micro plastics?”) [11].

Plastic particles, according to Xantos and Walters, can be grouped as macro plastics (>5 mm) or micro plastics (<5 mm), the latter being divided between primary micro plastics and secondary microplastics from macro plastic degradation [7]. It is estimated that marine plastic discharge will increase significantly in the future, and that plastic will subsequently be fragmented and degraded into smaller pieces [7].

The result of mismanaged plastic waste ending up in the ocean is the creation of micro and nano plastics [12-17]. These plastics are easily transferable and devastating to marine life. Plastic bags are one of the leading causes of environmental and socio-economic problems worldwide [1-13]. They are especially problematic due to being lightweight and easily blown around with wind [14-16].

If discharged into water bodies, plastic particles float. Exposure to Ultraviolet (UV) radiation and higher temperatures on the water bodies’ surface, result in further plastic degradation [15].

This degradation allows macro plastic particles to break down into micro plastic particles and even further breaking down micro plastic particles into even smaller particles [18].

About 70 to 80 percent of ocean litter is estimated to be micro plastics. Exposure to these particles can cause respiratory malfunction starting as mild irritation and resulting in chronic bronchitis. These micro plastics can even cause problems in the food chain when ingested by aquatic animals [16]. Oysters experience health damage when exposure to micro plastics at the concentration estimated to be in the oceans where they are caught in the North Atlantic. The reproductive system in particular is harmed, with lowered egg count and diameter in exposed female oysters. Exposed male oysters exhibit far lower male sperm velocity than in the controls [17]. It has also been found, that micro plastics inhibited crab growth [19]. The morality, size, and fertility of copepods are affected Copepods have their mortality greatly affected [20]. Plastics that have not yet broken down can be fertile breeding grounds for mosquitoes [21]. The very low rate of plastic recycling causes great harm to the ecosystems off the coast of North America and other continents.

Even the plastic bags that are recycled are not a perfectly circular economy. Even if the bags are recycled, thirty-three pounds of fossil fuels, a

non-renewable resource, and fifty-eight gallons of fresh water are consumed for every one thousand five hundred bags produced [22]. That means that if every bag used in the US were recycled every year, approximately $2.2 * 10^9$ pounds of fossil fuels would be used up each year. Adding to this, some of the recycled portion is incinerated for energy or sent to other countries as opposed to being used for production. The incineration of plastic bags for energy is not an environmentally friendly process [22]. The amount that is recycled does not negate the negative environmental aspects of the plastic bags.

The persistence of plastic bags has pushed policy makers around the world makers around the world to create rules and regulations in an attempt to reduce the negative impact. For instance, these rules and regulations, many countries are attempting to make the switch to paper bags. These provide a more environmentally friendly alternative to plastic bags while maintaining the convenience of single use products.

For example, recently in the state of New York, where over 23 billion plastic bags are typically used per year; a ban on plastic bags went into Law effective on March 1, 2020 [23].

Many governments in North America are taking actions against plastic bags. In 2010, many states in Mexico adopted a bag ban [24]. In the U.S., due to the federalized system of governance, the matter of plastic bags is left largely in the hands of the state or municipality government. The East Coast largely favors economic incentives, such as taxes or mandated fees on plastic bags, or mandated discounts for people using reusable bags. Meanwhile, the West Coast largely prefers local government bans on the bags [25]. More than one hundred twenty California towns have adopted a plastic bag ordinance of some sort [21]. Canada already has curbside pickup for plastic bags [26]. Despite this, approximately ninety percent of Canada's plastic waste is not recovered in any legally determined way [27]. Additionally, Bill 82 amended Ontario's Resource Recovery and Circular Economy Act of 2016 to require the Minister of Environment of Ontario to identify a measurable target for reduction of plastic waste. It also amended definitions such that "re-use" does not include incineration processes, among others. It also adds in a clause guaranteeing Ontario to be completely free of distribution or supply of single-use plastic bags [28].

3. EUROPE

As of 2017, the average European Union resident used approximately 198 plastic bags per year, leading the member countries to enact a series of legislation which has the goal of reducing their use of plastic shopping bags across the region [29]. At a consumption rate of 450 bags per person, Estonia, Hungary, and Latvia are the biggest consumers of plastic in the EU, whereas Denmark and Finland's consumptions are below 100 bags per person [30]. Some of the EU member countries such as Austria, Belgium, France, and Denmark went with a full blown plastic bag ban, forbidding use of any single use lightweight (<50um) plastic carrier bags [29]. Other countries in the EU such as Germany, Netherlands, Spain, and the UK decided that a plastic carrier bag fee was more appropriate to discourage plastic use and pollution [29]. Finland's legislation does not specifically target plastic carrier bags, but more generally aims to reduce plastic consumption, while Italy only requires that the bags distributed by retail stores be certified compostable and made from biodegradable plastic [29].

Europe produces 21% of the world's plastics, and therefore has a strong pro-plastics lobbying presence which leads to less stringent policies in terms of plastic bag use [24]. Plastic pollution is a high environmental risk at both the macro and micro scales, as macro plastics were ranked the most dangerous common marine pollutant due to entanglement [24].

4. AFRICA

Africa has unprecedented population growth, that is expected to add 1.3 billion people to the planet by the year 2050. The highest population growth and urbanization will be heavily concentrated in the coastal regions on the continent [30]. This raises concerns for mismanaged plastic waste making its way into our oceans. Africa lead the world in plastic bag regulations. With thirty-four countries with bans or taxes, thirty one of which are sub-Saharan Africa, the poorest regions. Kenya has some of the world's harshest penalties, with anyone caught with one could be face a $38,000 fine or four years in jail [31]. Despite the increasing number of countries placing plastic bag regulation, there is little information on its effectiveness in reducing plastic waste. An analysis of the South African plastic bag levy mostly found the new policies

were only a temporary success. The consumption of the bags decreased for a short time before beginning to increase once again [32].

5. RUSSIA

Greenpeace has estimated that over 26 billion plastic bags are used and handed out in Russia each year [33] Russia has reported increasingly polluted beaches due to micro plastics, specifically in the Kaliningrad region [34]. These micro plastics are circulating in the ocean and contributing to the decreasing killer whale populations in the region [35]. A 2019 article discusses the potential of a plastic bag regulation in the works, but currently nothing definite has been enacted. Although multiple sources stated that roughly, 80% of Russians said that they were in favor of going without plastic bags [36]. Further information of plastic usage is scarce and hard to come by and lacking in detail.

6. ASIA

Throughout Asia, plastic bag pollution is continuing to suffocate marine life, suck up non-renewable resources, and lay motionless in landfills for hundreds of years prior to decomposing. These silent enemies clog drainage systems and litter the beaches of coastal Asian countries [37]. Many countries throughout the vast continent, such as Thailand, have implemented plastic bag bans, which is a small start to heading in the right direction. After all, achieving a sustainable future should be everyone's goal on modern planet Earth, as we are doing more harm to our wild life and environment than ever. In fact, plastic bags account for nearly 7% of waste that is sent to landfills in Hong Kong each day. Besides that, another unsettling fact is that on average, 10,000,000 plastic bags are disposed of in Hong Kong daily. Keep in mind, plastic bags are non-renewable and take hundreds of thousands of years to decompose [38]. Petroleum is the primary feed material used to create plastic bags. Petroleum is a non-renewable resource that is being wasted in the production of plastic when there are other viable options available, such as paper; a renewable source. Incineration of plastic bags leads to air pollution, which is already a large problem throughout Asian countries like China and Japan [38]. Muthu et.al conducted a life cycle impact assessment (LCIA) in which they found that the reuse of plastic bags is the best option for environmental concerns [8,39-40]. However, with today's modern day culture and society, reduce, reuse, and recycle are not everyone's top priority. In fact, one percent of plastic bags are returned for recycling each year, averaging out to 15 bags recycled per family, per year (biologicaldiversity.org) [5]. The other 99 percent of these bags either wind up as litter or in landfills. Plastic bags in landfills are not a solution either, as they do not fully decompose but rather partially degrade into micro plastics. These micro plastics absorb toxins and continue to harmfully pollute the environment. China has become a major source of marine-life pollution, as 60% of all plastics leaking into global water came from mainland China [40]. Good news is, the Chinese government realized their ongoing harmful pollution and placed a complete ban on plastic waste importation. Of course, improvements in the standard of living costs us the consumption of resources, but paper bags resources are renewable and will not go away. In fact, the paper bag market in Asia has risen by nearly 4% [41]. China, Japan, and India are large contributors to the Asia-Pacific paper bag market due to rapid growth and urbanization or the industrial settings. Many of these Asian countries have already shown signs of slowing the production and use of plastic bags and implementing paper bag markets, meaning slowing the rate of air and land pollution. Overall, these are minor steps in solving the world crisis in pollution with sustainable technologies and economy in correlation with consumption and resources [42].

7. MIDDLE EAST AND SURROUNDING COUNTRIES

Micro plastic pollution due to plastic grocery bag usage is a huge issue across the world, and the Middle East is no exception. For starters, plastic bags have a carbon footprint of 6kg CO2/kg plastic [43]. In one year, 238,204,800 plastic bags were disposed by families in the city of Al-Kuhns, Libya [44]. Replacing these bags with more environmentally friendly alternatives, such as paper bags, would put a significant dent in worldwide micro plastics pollution. However, this is far easier said than done. Before plausible solutions can be agreed upon and put into action, certain things will need to happen. First, there needs to be greater awareness of the harm caused by plastic bags, as that will increase for demand of change, which will in turn encourage businesses to adapt to meet the consumer base's demands for green options [45]. For instance, in Cairo, knowledge and concern of the

issues faced due to single use plastic bags was generally under fifty percent. Egypt will not see a green revolution to stem their micro plastic usage until the public is aware and demands it [46]. An issue faced in Bahrain is that although people generally know plastic bag use creates environmental hazards, the cheap cost, durability, versatility, and availability of plastic bags has many people convinced plastic bags are still the best option [43]. Therefore, to be an effective replacement for plastic bags in these regions, paper bags would need to rival plastic in those areas. Should the cost of plastic bags be cheaper than the cost of paper bags and the cost of paper bags cannot be lowered to compete with that of plastic, one idea could be to raise the price of the plastic bags by way of taxation. A study in Hadishahr County, Iran, found plastic bag usages high in the area. While programs to increase education on the health and environmental risks posed by the grocery bags were recommended to reduce use, it also seemed necessary to institute a tax on plastic bags in order to decrease their use [47]. This is just one of many methods that can be used to make paper bags the better option in areas of financial struggle.

Recent studies suggest that risks of micro plastics (including degraded macro plastics, microbeads, and micro plastic fibers) in the marine environment may pose more of a threat than macro plastics [7]. Both micro and macro plastics can harm the environment in many ways. Entanglement in plastic items, particularly discarded fishing gear (or plastic bags) is a serious threat to marine animals. Ingestion of stranded and fragmented plastic items can have fatal consequences for marine species [48]. By harming the ocean ecosystem, the food chain will be disturbed. The occurrence of debris among their food was infrequent. In the eastern Mediterranean Sea, many fish species have ingested plastics. Ingested debris included primarily plastics (86.5%) and to a lesser extent pieces of metal and wood. Among ingested plastics, fragments of hard plastic material constituted the highest proportion (56.0%), followed by plastic bag fragments (22.0%), fragments of fishing gears (19.0%) and textile fibers (3.0%). Among the species with ingested debris, *G. melastomus* swallowed all debris categories; *P. violacea* and *S. blainville* ingested plastic bag fragments, whereas pieces of hard plastics were found in *E. spinax* and *P. Bogaraveo*. [49]. Studies have shown that micro plastics have done more harm than macro plastics. The plastic size distributions showed a gradual increase in abundance toward small sizes indicating an efficient removal of small plastics from the surface. Nevertheless, the relative abundance of small fragments (< 2 mm) was higher within the 1-km coastal water strip, suggesting a rapid fragmentation down along the shoreline, likely related with the washing ashore on the beaches [50]. This a very common problem for countries that surround the Mediterranean Sea, with plastic waste being washed away. There has been a study that also claims how micro plastics have affected the surface sediments in the Persian Gulf. This study addresses that MP quantification and morphology to assess the abundance, distribution, and polymer types in littoral surface sediments of the Persian Gulf were performed. Micro plastics were found in 80% of the samples [51]. Ingestion of micro plastics that have been in contact with some chemicals, such as Bisphenol A (BPA), has been shown to interfere with our hormonal system. By reducing the usage of plastic bags, we can avoid all this harm not just to the environment, but to others as well.

8. AUSTRALIA & SOUTH AMERICA

Plastic has been the standard input material for producing bags for years. Annual plastic bag usage in one chain of stores across Australia was more than 3.2 billion single use plastic bags [52]. One state alone in Australia used nearly one billion plastic bags a year, with close to 690 kilograms (more than 1,520 pounds) of waste going to landfills in Australia. [52-53]. In Chile, plastic bags were introduced in the 1970s and their popularity grew in the 1980s and 1990s. By the turn of the century, they were regularly used in commerce [54].

Plastic accounts for 50 to 80% of debris that goes into marine habitats [55]. These bags have had disastrous effects on the ecosystem, including smothering coral reefs and killing sea turtle population. It has been estimated that plastic debris has affected 267 species around the world, 28% of all marine mammals and 86% of all sea turtles [56]. Plastic pieces less than five millimeters in size are categorized as micro plastics. Main sources of micro plastics include manufactured plastics of microscopic sizes and pellets. They also are derived from the breakdown of plastic products and negatively impact organisms by influencing their development and survival [55]. Micro plastics can absorb chemical pollutants such as hydrophobic

organic compounds, persistent bio accumulative and toxic substances, and antibiotic resistant bacteria, thus posing as a human health risk [57]. Results from a study evaluating Microplastics in the inner zone of the Rio de la Plata estuary in South America demonstrated a significant relationship between the worsening of coastal habitat quality and micro plastic concentration [55].

Potential ways to reduce micro plastic pollution are plastic micro bead removal from personal care products, use of biodegradable materials, improved separation efficiency at wastewater treatment facilities, improved reuse, recycle, and recovery of plastic, and development of bioremediation and clean-up technologies. Australia is pushing to phase out or ban plastic microbeads. Using plastic waste as an energy source and recovering valuable products from such waste would fight micro plastic pollution. For improved separation efficiency, filters within washing machines could be altered to prevent micro plastic fibers from entering the sewer [58]. An environmentally friendly strategy to tackle micro plastic pollution is the biodegradation of plastic polymers by organisms such as bacteria, fungi, and mealworms [59].

With environmental concerns in mind, Australia has taken action to decrease their plastic bag consumption. Only one out of eight states in Australia have not yet imposed a plastic bag ban. New South Wales is last on that list and yet legislation to ban the bags just passed the NSW Parliament Upper House. After two of Australia's supermarkets stopping their use of plastic bags in 2018, there was an over 80% reduction in the consumption across the continent and more than six billion bags have been taken out of circulation [60]. The ban includes compostable, degradable, and biodegradable bags, and the ban applies to both in person and online shopping. Woolworths stores have switched to offering paper bags made from 70% recycled paper, with all paper being sourced responsibly, as certified by the Forest Stewardship Council [60].

Certain countries in South America have followed Australia's example. Localized bans on plastic bags have been initiated in Argentina, Brazil, and Chile. However, the effect of the ban is limited [61]. A price was placed on plastic bags in a significant number of stores in Salto, Uruguay. It was discovered that six months after the charge was placed, the demand for bags decreased by 75% [62].

Interest in the paper bag market has grown due to environmental and public health concerns leading to decreased plastic usage. Increased paper bag consumption would lead to micro plastic reduction. In order to compete with plastic bags, paper bags must possess certain characteristics and meet quality standards.

9. THE SOLUTION

The driving force of plastic bags usurping their paper counterparts is widely recognized as economic, since plastic bags can be produced faster and less expensively (Petroski, 2003) [3]. Paper bags take about four times the energy to produce and two times the energy to recycle and create more air pollution when compared to plastic bags (Camann et. al, 2010) [6]. Camann et. al. also note that paper bags when landfilled take up more space than plastic bags, and decompose at the same rate (2010). Muthu et. al. reported that when a recycling system is available and utilized there is little difference in the life cycle assessment between paper and plastic bags [8].

The rival to plastic bags are multi-use bags and paper bags which can also be considered multi-use bags. Based on my own observations shoppers use paper bags with handles multiple times. Paper bags serve as collecting container to hold recycling materials and waste containers before discharged or returned into the recycling stream.

Bags made out of paper material are not utilized nearly as much as plastic bags are around the world. However, there is some speculation that paper bags also cause harm to the environment. Although paper is a renewable source, as it is derived from many kinds of tree species, and people are not so sure they are more environmentally friendly. On one side, paper decomposes in landfills and paper based materials can also be immediately reused to make more new paper products. Also, should paper bags be incinerated, studies have shown they release lower net emissions of toxic fumes [63].

On the other hand, plastic bags as stated before, contribute heavily to air pollution when they are incinerated, yet also cause marine pollution when left in coastal continent landfills. Questions arise such as: Where are the plastic bags supposed to go? How will they be disposed of knowing that only a fraction is realistically recycled. How will

we save our petroleum supply? Part of the answers might be to switch to reusable bags and recyclable paper bags in retail and grocery stores.

Many countries are beginning to make the switch to paper bags to reduce plastic waste and switch to multi-use and paper-based products, such as: Nonwoven products, cotton bags, biological degradable plastic bags, Low Density Polyethylene (LDPE) plastic bags, and other forms of fabric products [64].

Paper and cardboard production reached nearly 72 million metric tons in the U.S., and 420 million metric tons worldwide in 2018, with an estimated market value of over 81 billion dollars in the US [65-68]. Today, paper and packaging board represents 69% of the US paper production today.

Paper bags are a biodegradable, renewable, and recyclable product when compared to their plastic bag counterparts. The common brown colored grocery bags used in many stores and industries today are made from a fiber material known as Kraft pulp and or recycled Old Corrugated Container (OCC) material.

The Kraft pulp process was invented and patented by the German Scientist Carl Friedrich Dahl in 1879 [68] and was first used commercially in Sweden in1885 [9]. Since its invention, the Kraft process has been developed and improved over more than 140 years and is today the most common chemical extraction process, for cellulosic fiber material worldwide for softwood (SW) and hardwood (HW) fiber materials [69-71].

The need for sustainable, biodegradability, and Eco-efficient packaging material replacing plastic packaging that might end up as micro plastics in the oceans led to a rediscovery of paper-based packaging products [72].

Consumption of paper products can be used to assess a countries wealth. Leading industry nations such as the U.S. and Germany use over 202 kg and 250 kg of paper per person per year whereas emerging counties such as China use below 70 kg per person per year [73-75]. A potential increase in the rate of paper consumption will be controlled by the market for paper goods over the next years and decades [75].

In 2019 the U.S. paper and cardboard production reached nearly 78 million metric tons with an estimated market value of over 83.5 billion dollars in the US alone. Worldwide about 420 million metric tons of paper products were produced [76]. According to the American Forest and Paper Association (AFP) the U.S. paper industry is among the 10 top manufacturing employers in 45 states employing nearly 950,000 people and supporting over one million jobs through the supply chain [77].

During the past two years internet sales have risen steadily in the U.S. and are expected to rise in 2022 to one trillion dollars, compared to the 2021 forecast of more than $ 930 billion spending [73]. According to the U.S. Department of Commerce [17] consumer spent in 2016 nearly $390 billion. Consumers spent $598 billion in 2019 and $792 billion on the web for retail purchases in 2020, a roughly 32% increase compared to $598 billion in 2019. Forecasts for 2021 are above $930 billion and for 2022 to reach on trillion dollars [72,74-75].

The steadily increasing internet sales through the pandemic years in 2020 and 2021 resulted in a boost of board and packaging products requiring producers to expand their production capacities. For example, the U.S. containerboard production increased in 2021 by 5.6% for the ninth time in 10 years [76]. This triggered companies to invest in new locations and machinery. For example: Nine Dragons one of the world largest paper-based manufacturer headquartered in China acquired in 2018 two board mills in Wisconsin and Maine and has invested over 300 million dollars in upgrades during 2019 and 2020 [78]. Palm the largest family-owned paper manufacturing business in the paper industry located in Germany invested over 500+ million Euro in a new board production site producing 750,000 metric tons of board product annually [79-80]. Green Bay Packaging in Wisconsin invested in a new 500+ million-dollar production facility to produce 685,000 short tons (621,422 metric tons) of paperboard products. The plant started producing paperboard products in March of 2021 [81-83].

A recent study by the New York State Department of Environmental Conservation (NYSDEC) showed that according to total energy used, greenhouse gas emissions, solid waste production and freshwater consumption single use plastic bag have the least environmental impact, followed by the paper bag and the recycled polyethylene bag using 40% post consumed recycled content. However, the paper

bag has the highest fresh water usage [84]. Cotton bags are an alternative, but use over 5,000 gallons of water and would need to be used over 400 times to be under the global warming potential of the polyethylene bag, whereas the paper bag would need to be used three times, the Low density polyethylene bag 12 times and the non-woven bag 33 times [84]. However, generation of micro plastics and pollution of the environment have not been assessed to a full extent. However, single use paper Kraft bag with and without 100% recycled material content have the lowest marine litter biodiversity impact, making the paper bag an environmentally friendly alternative to the single used plastic bag.

The amount of recycled packaging grade paper needed was assessed on the paper bag used by US retailer Target as shown in Fig. 1.

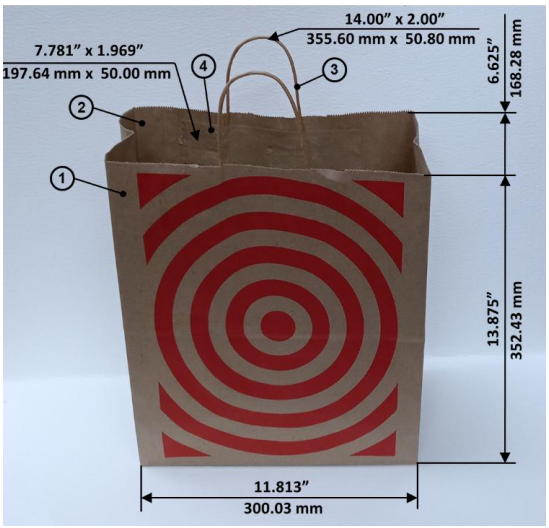

Fig. 1. Commercial Paper Bag [85]

The paper bag (1)used for the assessment has a high of 13.875 in (252.43 mm), a width of 6.625 in (168.28 mm), a length of 11.813 in (300.03 mm), and a glue strip (2) of 1.00 in (25.4 mm). The two carrying handles (3) are manufactured as a handle sub-assembly, consisting of two paper bag handles (3) that are made out of twisted board paper material with a length of 14.00 in and width of 2.00 in (255.60 mm x 250.80 mm). The handle (3) is embedded in two glued together rectangular board paper stripes (4) of 7.781 in x 1.969 in (197.64 x 50.00 mm). The two handle sub-assemblies are glued to the inside of the paper bag (1). Based on this, the total paper sheet size to produce one paper bag is approximately 6.18 ft² (0.574 m²) incorporating 10% of cutting waste. At a basis weight of the paperboard of 107 g/m² a paper bag will require 61.42 g of paper board packaging material.

Based on the assumption that pulp can be produced at a yield of 45%, followed by paper making process yielding 95%, 1052.6 metric tons (mt) of pulp material will be needed to produce 1000 mt of packaging board day. The produced packaging board material in a 24-hour day can be converted into 16,020,506 paper bags. Assuming 8000 production hours per year, 5,340,168,166 paper bags can be produced on a yearly basis.

To produce enough paper bags made from recycled paper materials to replace the approximately 25 billion plastic bags used in NYS approximately 4.6, 1,000 mt/ day paper machines would need to be built.

Based on a the 2021 Green Bay Packaging paper board paper machine, that is able to produce 621,422 metric tons of paper board packaging materials per year, requiring an associated investment of over 500 million dollars, over 2.5 Green Bay Packaging board paper mills would have to be built [80-81].

In addition, according to Packaging Gateway press releases, a new paper production site such as the Green Bay Packaging plant in Wisconsin, will create over 200 direct, and 135 indirect related jobs.

Based on the above, to fully replace the 25 billion plastic bags, an investment of over 1.5 billion dollars in New York State alone will be needed, with an job creation potential of over 830 new jobs.

The numbers of actual plastic bags used differ greatly and range from an estimated 100 billion plastic bags yearly to 380 million used in the U.S. [5-6]. Some states in the U.S. (California, Delaware, Hawaii, New Jersey, Maine, New York, Oregon, Vermont, Washington) have legislation in place to ban plastic bags. Other states have enacted taxes, or are in the process of or have enacting a plastic bag legislation [84].

We estimated, in order to replace all plastic bags used in the U.S. would require, based on the above a minimum of 100 billion plastic bags used [5], a utilization of over 6,214,220 metric tons of recycled paper products. The required amount might be 3.8 fold based on [6] requiring the

utilization of 23,614,036 metric tons of recycled material. A minimum investment of roughly 6 billion dollars for new paper machines would be needed to produce the minimum required amount of paper bags. This investment would create up to 10,000 new jobs in the states these paper machines would be installed and operated.

According to the EPA 67.4 million short tons of paper and paperboard were generated in 2018. About 46 million short tons were recycled at a recycling rate of 68.2% and 4,200 million short tons have been used to produce energy [86].

Based on that, an estimated potential of 17,220 million short tons (15,622 million metric tons) of recycled paper material might be available for the production of paper bags. However, some of the recycled materials such as tissue towels, paper plates and cups, bags and sacks, and other paper packaging material are not suitable to be used as recycled material for paper production [87]. Therefore, the actual available material might be less than half, but it can be estimated, that enough recycled material is available to replace the U.S. consumed plastic bags on a yearly basis.

10. CONCLUSION

Plastics are one of the most widely and abundant substances in today's society. Worldwide the usage of low-density polyethylene bags create pollution on land and in the oceans, especially when they break down in macro and micro plastics, and are further broken down by ultraviolet radiation. Micro plastics can harm marina animals and disrupt their food chain.

Estimations say that over five trillion plastic retail bags are annually used, and that an estimated eight million tons of plastic are discarded into the ocean each year.

On all continents, governments try to establish solutions on how to fight plastic pollution form shopping bags by banning their use, implant fees for their usage and replace plastic bags with a more renewable material.

Paper bags can be considered a valid solution, especially when manufactured from recycled materials. It is estimated, that In the United States, enough recycled paper material may be available to cover the replacement of the 100 billion plastic bags used yearly with 100% recycled paper bags. However, the required investment is estimated to be about six billion dollars for new paper machines and paper mill operations. This investment could create up to 10,000 new jobs in states where the new paper machines and paper mills would be installed and operated.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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