MSc Program
Environmental Technology & International Affairs

A General Assessment of Plastics Production, Consumption, and Waste on a Global Scale. Analysis Based on the Case Studies of Brazil, Europe, and the United States.

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"Master of Science"

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Abstract

Today plastics are a substantial of the modern society. Living without them would be almost impossible. Being particularly versatile materials, mainly due to their molecular structure and additives, plastics have found many different positive applications that eased humans' life since the beginning of the 20th century.

Global plastics production accounts for approximately 245 million tonnes a year. In this work, a comparison between Europe, the United States (US), and Brazil highlights the differences arising in plastics production, consumption, and disposal in developed versus developing countries. As expected, developing countries have a much lower production, consumption, and waste generation rate than big economic colossuses. Brazil produces about 27 kg plastics per capita and year, while in 2008 NAFTA countries generated approximately 186 kg and Europe 120 kg. Moreover, while Europe and the US make business with plastics exports, Brazil consumes about 4% more than it produces. Plastics consumption rates per day are proportional to the production values, namely 77g per capita in Brazil, 300g in Europe, and almost half a kg in the US. Eventually, plastic wastes are generated. Most of it is disposed, but the ways of disposal are very different for developed and developing countries. While approximately 70% of Brazil's waste lands on open dumping sites, *lixões,* Europe and the US make use of sanitary landfills. Plastics recovery rates, including recycling and incineration with generation of energy or district heating, are the highest in Europe with 39%, while the US recovers 25% and Brazil 20% of its polymeric waste. However, although exact numbers are difficult to estimate, a far too big part of trash ends, through various ways, in natural environments. Lakes, rivers, and streams form an extensive network that can carry trash, and especially easily floating plastics waste, across continents and straight into the seas. Plastics in the seas are a widely discussed problem on an international basis, since they cause increasing damage to marine environment and biodiversity. Despite significant mobilization in order to denounce marine debris, the issue is still widely unknown and its risks are underestimated as well as still poorly understood.

Keywords: Plastics – Material Flow Analysis – Life Cycle – Environment – Marine Debris

I. Introduction

"I just want to say one word to you.
Just one word... Plastics!...
There's a great future in plastics"

(From the movie 'The Graduate', dir. Mike Nichols, 1967; family friend to Dustin Hoffman)

The importance of plastics in our society is undeniable. Since the 1950s the plastic industry has grown parallel to the increasing demand for plastics consumption of the population and parallel to the invention of new technologies that needed plastics as resistant and mouldable materials for constructing and gaining maximal efficiency. The fact that the world's population is booming and expected to reach 9 million people by 2050 (OECD, 2009) gives the certitude that the growth of the plastics market won't stop in future.

Plastics are used for packaging 50% of Europe's goods (Plastics Europe, 2010b). Plastics are used as building and construction material. Plastics made a crucial contribution to the development of transportation. Plastics are important for electrical and electronic applications. Plastics are also fundamental to agriculture and modern healthcare. Plastics revolutionized even sports and clothing. Plastics are everywhere, all the more in the most unthinkable and remote places. Due to their particular characteristics, in many situations their application results more efficient and easier than the use of other materials.

However, as many plastics are produced, as much is consumed and consequently dumped in legal or illegal ways. Like plastics consumption, also the types of plastics disposal vary from country to country and especially from developed to developing parts of the world.

Unfortunately not all plastics consumed are adequately disposed and scientists studying their impacts on nature are more and more worried about the consequences littered plastics might have at present times and may lead in future.

The aim of the research on which this thesis is based, is to make a general assessment of the importance and the impact of plastics from its production to its disposal. What is the history behind polymers? How does the molecular construction affect plastics and what kind of impacts arises from their additive substances? What is the role of polymers in our society? Which are the quantitative plastics needs that the world requires today? Which consumption differences might there be between developed and developing countries and what happens with plastics after their end-use?

The results of the work are divided in three main parts. The aim of the first part is to give a general introduction to plastics as such, in order to set the dimension in which the following parts are going to develop. The historical development of plastics during the last century, their composition, the different kinds of plastics existing, and their advantages and disadvantages will be treated.

Part number two reports the actual applied study dealing with quantitative analyses of plastics production, consumption and consumption patterns, as well as plastics disposal. The original aim was to make a study on global plastics statistics. However, due to the lack of sufficient data, it was decided to continue on the basis of three case studies, namely Brazil, Europe, and the US. To characterize Europe the term *Europe zone* was chosen, meaning the European Union of the 27 states (EU 27), Norway, and Switzerland. Some data regarding the US refer to the North Atlantic Free Trade Agreement (NAFTA).

The third and last part introduces the reader to the consequences of inadequate disposal of plastic wastes, as the timeless end-destination of plastics that are not being recycled, incinerated, or properly landfilled: it deals with plastics in the sea and the dramatic negative impacts that these may have on the marine environment and on human activities themselves.

The overall result of this thesis is to prove that plastics are necessary and ineluctable to our modern world, but that their final disposal might be problematic.

II. Methodology

The results of the Master thesis can be divided in two main types of data collection. While part one and three can be rather seen as literature reviews, part two focuses on data from statistics and on primary data generated in order to complete the frame of information found.

The literature sources used for part one deal with general information on plastics. These were mainly found on books introducing the basics of plastics, journal articles relating to plastics and waste management, official websites of international and national plastics manufacture and distribution associations, and national authorities.

Part two data were collected in order to set up an overview of polymer production, consumption, and waste generated, as well as to consequently create a material flow analysis (MFA) for plastic products in Brazil, Europe, and the US. The data presented originate mainly from official national surveys for the countries analyzed, but also from international organizations such as the Organization for Economic Cooperation and Development (OECD) and the European Union (EU), international plastic converter associations, and market research groups as Plastics Europe Market Research Group (PEMRG). Some other data reported were generated through own calculations and by deduction from the retrieved official data.

The STAN program created by technicians of the Technical University in Vienna, was used in order to create three plastics MFA-figures for the areas studied.

The third part of the study-results relates to sources coming from international governmental organizations and programs for the protection of marine environment such as the United Nations Environmental Program (UNEP), as well as non-governmental organizations from the same field, and journal articles on polymers and studies regarding marine environments.

III. Results

Part 1: An Introduction to Synthetic Polymers.

This first part of the results will introduce plastics as a material by taking into account its historical evolution, its structure, its composition, and its various typologies. This part is important to understand the role of plastics in our society, our environment, and our "modern world".

Plastics, a short history

The term plastic is derived from the Greek word "plasticos" which literally means having the capacity of being shaped or moulded by heat. Shaping plastics by using heat is a basic part of nearly all plastics manufacturing processes. Due to their particular molecular structure, plastics are generally also called polymers.

There is a large variety of plastics types and the first distinction that can be made is between natural versus synthetic plastics. Humans have benefited from the use of natural plastic materials since approximately 1600 BC when ancient Mesoamericans are reported to have processed natural rubber into balls, figurines, and bands (Andrady and Neal, 2009). Naturally occurring plastic materials may be animal bones, horns, tortoise shells, the fossilised resin from pine trees (amber), the albumen in egg, the sap from various tropical trees, and the wax from bees. For example, before the introduction of glass, transparent sheets from ox-horn were extensively used as windows (Smith, 2010).

However, developments in the 19th and 20th century lead to the establishment of synthetic plastics. In 1839, Charles Goodyear invented *vulcanite* by deliberately chemically modifying a natural polymer (rubber latex). Later, in 1862, the metallurgist Alexander Parkes created *Parkesine* and first displayed it at the Great Exhibition in London of the following year. Today Parkes is considered to be one of the fathers of synthetic plastics. However, despite the initial success of Parkesine at the international exhibition and its versatility in producing many kinds of domestic items, this product of cellulose dissolved in nitric acid (cellulose nitrate) was still very expensive and extremely flammable (Making the Modern World, 2010).

It was the game of billiards that provided the unlikely trigger for the eventual commercial success of cellulose nitrate. Looking for a substitutive material to ivory for the production of billiard balls, the Hyatt brothers managed to produce a much more mouldable version of cellulose nitrate by mixing it with camphor (Plasticseurope, 2010a; Plastiquarian, 2010). The early commercial success of this kind of celluloid lay not only in billiard balls that eventually blew up by banging together, but also in dental plates for false teeth (Plasticseurope, 2010a).

At the beginning of the 20th century the flammability of cellulose nitrate prevented its use in high temperature moulding techniques. However, the rapid development of cellulose would get around this problem in the course of the century (Plastics Europe, 2010a). *Bakelite*, the first truly synthetic plastic, was patented in 1907 by the Belgian chemist Leo Baekeland. He was looking for a synthetic replacement of *shellac*, a black resin secreted by Asian beetles used as electrical insulation, to seal out moisture, and to produce gramophone records until the advent of vinyl in the 1940s. Bakelite, the condensation product of phenol and formaldehyde, was first used as electrical insulation in cars and other industrial products. Thanks to its easy manufacture and its relative low price, the material was soon applied for the production of other items. Because of its brittleness, Bakelite was mixed with wood dust to strengthen the material. This is the reason why early Bakelite is frequently of brown colour.

Despite the first developments of synthetic plastic material during the early 20th century, the growth of the polymer industry was restricted by the considerable lack of understanding of the nature of polymers. In 1901 Emil Fischer was the first one assuming that natural polymers were linked chains of molecules. However, until the 1920s the common believe was that polymers consisted of physically associated aggregates of small molecules. Only in 1922 the chemist Herman Staudinger proposed a new theory stating that polymers are made of very large molecules containing long sequences of simple chemical units linked together by covalent bonds. He first used the term *macromolecules*. However, only a few scientists gave credence to his viewpoint (Plastiquarian, 2010; Young and Lovell, 1998).

After the invention of Bakelite, many other types of plastics were subsequently developed, e.g. PVC (Polyvinyl Chloride) in 1912 and Cellophane in 1913, and the period between the two world wars is frequently called the “poly era” as some of the most important plastics were invented in those years. In that period, plastics became a widespread material to use in the manufacture and for domestic products. In the 1920s plastic designed radios and telephones were developed and during the 1930s mass production of plastic items was initiated, mainly because manufacturers learned how to produce plastics from petroleum (e.g. polystyrene (PS), PVC, and acrylic polymers). Furthermore, the production process of injection moulding was improved and completely automated. These changes dropped prizes and put plastics within easy grasps for everyone. Additionally, in the 1930s, the first synthetic fibre, nylon, and polyethylene, one of the most common types of plastics found today, were produced.

World War II turned plastics into a very important military material and manufacture switched from domestic products to wartime needs. Its development was highly secret and plastics were essential for the development of radar technology, aircraft canopies, and also smaller items such as defence phones and aviator goggles (IAPD, 2009).

After the war the plastics industry went back to peacetime production and boomed, satisfying the needs of the masses. Plastic production became of large volume and cheap, but badly made and badly designed. These attributes were the reasons for the negative connotation that plastic products have been carrying along in general jargon until today.

It was only from the late 1950s on that plastics raised again the designers' interest and gave expression to the idea of a modern world (Plastiquarian, 2010). Plastics eventually entered into everyday domestic life with a wide range of products, such as for example Tupperware, invented in 1949 by the American manufacturer Earl S. Tupper. Also the cloth industry used intensively plastic products, such as polyester, nylon, and Lycra.

In the 1960s plastics played an important role in the "space race" and spacecraft components, since their lightness and versatility made them to a crucial material for the success of space exploration (Plastics Europe, 2010a).

Synthetic polymers continued to evolve ever since and it is possible to find them everywhere in our surroundings. Plastics are extremely useful and our world would be impossible without them.

The polymeric structure

As their “second” name recalls, plastics are made of polymers. The word *polymer* as well, has Greek roots. Whereas the Greek *mer* means “part” and *poly* stands for “many”, *monomer* is “one part”. Various monomers hold together by very strong attractive forces between molecules form a polymer, which can be seen as a very long chain. Molecular chains in plastics are hooked up by the so-called process of polymerization. However, the simplest definition of a polymer is “a useful chemical made of many repeating units (mers)”.

Polymeric macromolecules have repeating units that are often made of carbon, hydrogen, and sometimes oxygen, nitrogen, sulphur, chlorine, fluorine, phosphorous, and silicon compounds.

The basic structure of a polymeric chain is called backbone and the most common classes of polymers have backbones composed of carbon atoms bonded together. Additionally, the carbon atoms can bind one or more different atoms to themselves creating a more complex polymer with a multidimensional backbone. Examples for polymers containing only carbon and hydrogen atoms are: polyethylene, polypropylene, polybutylene, polystyrene, and polymethylpetene. Because of their carbon atom in the backbone units, these polymers are defined as *organic*. Variations to the above mentioned classic organic polymers containing hydrocarbons (HC) are PVC that binds chlorine and Teflon that binds fluorine to each carbon atom of their backbone. Other examples for organic polymers are nylons that additionally contain nitrogen in their backbone units, and polyester and polycarbonates having their carbon atom bound to oxygen atoms.

Inorganic polymers have silicon or phosphorus instead of carbon in their backbone. Examples are the silicon-based polymers in Silly Putty (American Chemistry, 2010), “the real solid liquid”, as some of its commercial packaging suggested.

Figure 1.1: Silly Putty, a silicon-based mouldable plastic material, popular as children's toy.
Source: Crayola Store (2010)

In reference to their molecular structure, polymers can be cross-linked or linear and serve specific needs. There are three main types of polymers: thermosettings, thermoplastics, and elastomers.

Thermosets are manufactured polymers with a three-dimensional network, i.e. each chain of the polymer is connected to all other by a sequence of junction points and other chains (Young and Lovell, 1998). The main characteristic of thermosets is that they do not melt once formed. Such polymers are said to be cross-linked or non-linear.

Other polymers can be two-dimensional, therefore defined as branched polymers, or one-dimensional linear polymers.

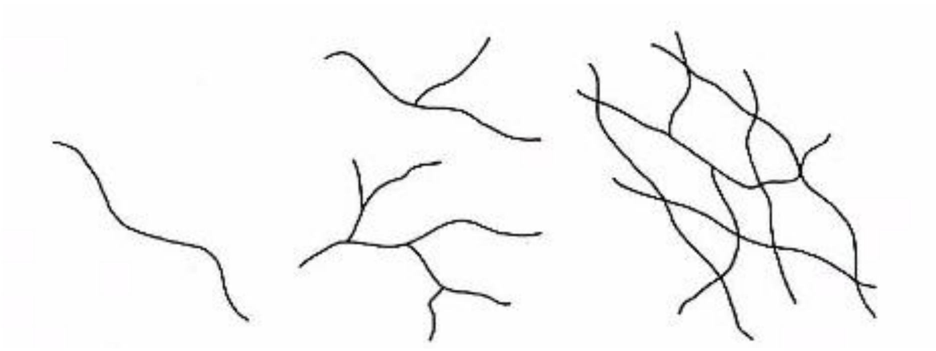

Figure 1.2: Representative skeletal structures of linear and non-linear polymers.
Source: Young and Lovell, 1998.

Linear polymers are called thermoplastics and they have the particular feature of being able to be remoulded over and over after being melted. Most of the plastics produced and consumed are thermoplastics (American Chemistry, 2010). These can be well-known everyday items like plastic bottles, films, cups, and fibres.

Elastomers are cross-linked rubbery polymers (i.e. rubbery networks) that can stretch easily to high extension and rapidly recover their original dimensions when the applied stress is released.

Thermoplastics, these can be classified according to their degree of crystallinity. With 80%, thermoplastics reach the maximum value of crystallinity in order to be able to melt and are defined as semi-crystalline. 100% of crystallinity would mean that the polymers would not be able to melt. A crystalline arrangement of polymeric chains is when the molecules are disposed according to a distinct pattern, i.e. similar to table salt and gemstone structures. The opposite of high crystallinity materials are amorphous materials. These have no patterned order and the arrangement of their polymers could be visually compared to a bowl of disordered spaghetti noodles without any long-range order. A factor that influences the degree of crystallinity is the molecular weight of a polymer. This variable measures the length of polymeric chains in a given material and it is particularly important because its change determines the final properties of plastics. The molecular weight of plastics is usually between 10,000 and 1,000,000. Thermoplastics with a high molecular weight are more difficult to form and mould (IAPD, 2009 and American Chemistry, 2010), i.e. they have a high crystallinity.

Some polymers are designed to never crystallize, while others are designed to always crystallize. For example, as a consequence of its highly regular chains that can easily be aligned, polyethylene is crystalline. However, there are also some plastics whose degree of crystalline disposition can be controlled by processing techniques, i.e. controlled polymerisation and moulding may result in higher crystallinity, while amorphous structures arise from both processing and quenching molten polymers.

Amorphous polymers are usually transparent and this characteristic is particularly important in food wrapping, plastic windows, headlight lenses, and contact lenses. Examples of amorphous plastics are polystyrene and PVC. Non-amorphous (i.e. crystalline) materials are translucent and opaque.

However, the colour is not the only characteristic that distinguishes different levels of crystallinity, as table 1.1 shows.

Table 1.1: Common characteristics of crystalline and amorphous plastics.

Higher Percentage of Crystalline	Higher Percent of Amorphous
- Higher heat resistance - Sharper melting point - More opaque - Greater shrinkage upon cooling - Reduced low temperature toughness - Higher dimensional stability - Lower creep	- Lower heat resistance - Gradual softening/melting point - More translucent/transparent - Lower shrinkage upon cooling -Greater low temperature toughness - Lower dimensional stability - Higher creep

Source: IAPD (2009)

Recalling the two opposite terms thermosets and thermoplastics, it is interesting to mention that science has developed so far, that today it is possible to construct a material to be thermoset or thermoplastic. As the main difference between the two types of plastics is the molecular structure (either linear or cross-linked), heat, chemical agents, irradiation, or a combination of these can initiate a process of cross-linking. In theory any kind of linear plastics can be transformed into cross-linked material in order to maximize properties. Generally cross-linked materials show better properties, such as improved resistance to heat, less creep and better chemical resistance than their linear counterpart. Nevertheless, a more complex process is necessary in order to use these to generate definite products.

Table 1.2. Examples of the various types of polymeric materials.

Linear Thermoplastics
PVC Nylon Acrylic Polycarbonate
Thermoplastics that can be cross-linked after processing
PEEK Polyamide-imide UHMW-PE
Thermosets
Phenolics Epoxies Melamines

Source: IAPD (2009)

Polymers' strengths

Polymers have very distinct characteristics. According to American Chemistry (2010), the following attributes are owned by most polymers and make them so popular for commercial means:

1. **Resistant to aggressive substances and other external influences**: despite the fact that some plastics can be easily solved by some solvents, other plastics provide safe and reliable resistance to aggressive chemical solvents, e.g. consider cleaning fluids, packaged in plastic or plastic tube in household's sewage system. Moreover, plastics are also extremely weather resistant and are therefore used to substitute materials that would degrade very easily when exposed to external phenomena.
2. **Thermal and electrical insulators**: electrical outlets and wiring are made or covered with polymeric materials, as well as pot and pan handles, insulated cups, coolers, and microwave cookware. The thermal underwear that many skiers wear is made of polypropylene and the fibrefill in winter jackets is often produced out of acrylic and polyester.
3. **Light in weight but with significant amount of strength**: some polymers float in water while others sink. But, compared to the density of stone, concrete, steel, copper, or aluminium, all plastics are lightweight materials. Concerning the strength of polymers, just consider the vast range of resistant products made out of polymers, i.e. from toys to the frame structure of space stations.
4. **Processing occurs in various ways**: there are many different ways of processing and moulding polymers that allow to generate a big variety of plastic products such as thin polymer fibres, heavy pipes, adhesive, paints, highly flexible and stretchy plastics, and foamed plastics as polystyrene, polyurethane, and polyethylene.
5. **Reproduction of an enormous range of characteristics and colours:** polymers have an enormous adaptability, e.g. they can reproduce a wide range of other materials, such as wood, porcelain, marble, cotton, silk, and wool-fibres. Moreover, mixing the right additives to polymers can enhance their properties and performance. Through manipulation of the molecular

structure scientists and engineers are becoming more successful at producing more useful materials. Furthermore, introducing various fillers, reinforcements, and additives into basic polymeric material, manufacturers and processors widely expand their products' possibilities.

6. **Preservation of the environment** (BPF, 2010): plastics help to save energy consumption in many ways. For example, plastics in cars save European motorists some six billion litres of fuel per year (BPF, 2010). These data follow the concept of saving fuel by decreasing weight. As a consequence, polluting emissions are reduced. The EuPC (2007) affirms that without plastics today's cars would be around 200-300 kg heavier. Plastics are also easy to shape and wind-cheating aerodynamic forms cut down fuel consumption as well. Special kinds of temperature insulating plastics, such as EPS of PEU produced through blowing agents, are also employed in modern house building. It is estimated that the energy used to produce the insulation material in first place is saved already after one year of use. The CO_2 reduction in the same period is estimated to be two to five times higher compared to CO_2 emissions caused in production (EuPC, 2007). Moreover, the long lifespan of plastic insulating materials, approximately 30 years, raises energy savings by 40 to 60 times, and CO_2 emission savings by 10 to 40 times compared to production needs. Another environmental sustainability example could be also the resistance of plastic pipes in the soil that offer an effective solution to the problem of leaking urban sewer pipe networks or of corrosive fluid carried through the ground. EuPC (2007) affirms that according to a study in the Netherlands done by TNO Science and Industry, the lifetime of PVC water pipe systems has been proven to be 100 years. This fact makes PVC pipes very efficient through time, avoiding a short-term periodical replacement. It also loosens control pressure on the whole pipe system.

   Moreover, plastics such as polymeric geo-membranes are also used as primary barriers in landfills to protect the environment by avoiding erosion and migration of leachate and gas as well as by hindering the intrusion of rainwater into landfills.

Plastics' feedstock

In this work the production processes of plastics are not going to be discussed. However, it is important to highlight the primary raw material of which plastics are produced: it can be petroleum (crude oil), natural gas, or coal. Petroleum is the most employed feedstock for the plastics industry. 4-5% of the global oil production is used for it (Stevens, 2001; FCIO, 2010). Some refer to plastics as a by-product or a waste product of fuel production. However, if all plastic products of our every-day life are considered, it becomes clear that our dependency on crude oil, natural gas, and coal is not only tied to energy issues. OPEC's cumulative oil production in 2008 amounted to 447.952 billion barrels (OPEC, 2008), i.e. approximately 71,22 * 10^{15} litres (1 barrel of oil = 42 U.S. gallons oil ≈ 159 litres oil). Assuming that 4-5% of it is used as plastics feedstock, the total amount of oil employed for that purpose would range between 22.397 and 17.918 billion barrels. Increasing oil prices and the uncertainty of the amount of oil resources left, is a challenge to the plastics industry (IMEA, 2009).

Types of plastics, additives, and bioplatics

The classification of plastics depends on its various chemical and physical characteristics. Today there is an enormous quantity of polymeric materials and more than 50 different unique families of plastics are in commercial use. Each family accounts for more than a dozen variations (IAPD, 2009). On the IDES site (IDES, 2010), a reference for technical information on plastics, the following families of plastic resin are listed. In total 62 are enumerated:

- Acetal
- Phenolic
- Polypropylene (PP)
- Acrylic
- Polyamide (Nylon)
- Polystyrene (PS)
- Acrylonitrile Butadiene Styrene (ABS)
- Polyarylate
- Polysulfone (PSU)
- Acrylonitrile Ethylene Styrene (AES)
- Polybenzimidazole (PBI)
- Polyurethane (PUR)
- Acrylonitrile Styrene (AS)
- Polybutadiene Rubber (PBR)
- Polyurethane Thermoset Elastomer (TSU)
- Acrylonitrile Styrene Acrylate (ASA)
- Polybutylene (PB)
- Polyvinyl Chloride (PVC)
- Alkyd
- Polycaprolactone (PCL)
- Proprietary
- Alphamethylstyrene (AMS)
- Polycarbonate (PC)
- Silicone
- Biodegradable Polymers (Biodeg Polymers)

- Polyester
- Styrene Acrylonitrile (SAN)
- Cellulose Acetate (CA)
- Polyether Imide (PEI)
- Styrene Acrylonitrile Silicone (SAS)
- Diallyl Phthalate (DAP)
- Polyetherketone (PEK)
- Styrene Maleic Anhydride (SMA)
- Dicyclopentadiene (DCPD)
- Polyethylene (PE)
- Styrenic + Vinyl + Acrylonitrile (SVA)
- Epoxy
- Polyethylene Naphthalate (PEN)
- Thermoplastic Elastomer (TPE)
- Fluoropolymer
- Polyimide (PI)
- Thermoplastic Polyurethane (TPU)
- Furan
- Polyketone (PK)
- Thermoplastic, Unspecified (TP, Unspecified)
- Ionomer
- Polylactic Acid (PLA)
- Thermoset (TS)
- Liquid Crystal Polymer (LCP)
- Polymethylpentene (PMP)
- Thermoset Elastomer (TSE)
- Maleic Anhydride Grafted Polymer (MAH-g)
- Polyolefin
- Unspecified
- Melamine
- Polyparaxylylene (PPX)
- Urea
- Methyl Cellulose (MC)
- Polyphenylene Ether (PPE)
- Vinyl Alcohol (VOH)
- Methyl Methacrylate (MM)
- Polyphenylene Sulfide (PPS)

Plastics are seldom used in their pure form. As stated before, mixing polymers with other materials, so-called *additives*, alters their characteristics.

Plastics = Virgin Polymers + Additives

The primary reasons for using additives are the following: enhancement of polymers' properties and performance, overall cost reduction (e.g. by increasing impact and flame resistance of products, which reduce the probability of having to replace them after short-time use), and improvement and controlling of processing characteristics. Additives may change the mechanical properties of polymers (i.e. strength, elongation, modulus, toughness) and also their thermal expansion, transparency, and thermal stability (Xanthos, 2010).

There are many different kinds of additives. These may include inorganic fillers (e.g. carbon or silica) to reinforce the plastic material, thermal stabilizers to allow the plastics to be processed at high temperatures, plasticizers to render the material pliable and flexible, blowing agents to produce foamed and expanded plastics, fire retardants to discourage ignition and burning, and UV stabilizers to prevent degradation when exposed to sunlight. Colorants, matting agents, opacifiers and lustre additives might also be used to enhance the appearance of a plastic product (Andrady and Neal, 2009). Other types of additives are process aids, lubrificants, antioxidants, and heat stabilisers. This rough enumeration shows that additives are highly necessary to improve the efficiency and longevity of plastics (BPF, 2010).

For example, plastics have become an important medium for raising standards of hygiene. An example is PVC that has become one of the most important plastics in medicine thanks to its flexibility, clarity and sealing properties. PVC is used in tubing, blood transfusion sets and disposable equipment. These applications were achieved by the help of additives that prevent plastic material from becoming hard and brittle at low temperatures, or soft and sticky at high temperatures.

Nevertheless, plastics and their additives do not have only positive aspects as plastic lobbies all over the world state. In fact, there is also another side of the coin. Many polemics regard plastics decomposition processes and noxious releases**.** When degrading or heated up, plastics release toxic substances. Many scientists agree with the fact that those substances can be considered hazardous for the environment and for human and animal health. There are many concerns raised, especially about substances with endocrine-disrupting potential. For example, a study (Loyo-Rosales et al., 2004) analyzed the content of Nonylphenol (NP) and Octylphenol (OP) in usual plastic bottles made of PET (polyethylene terephthalate), HDPE (high-density polyethylene) and PVC. The result was that HDPE and PVC showed a high level of NP, while OP was present in the water of all three types of bottles. NP is used as antioxidant and plasticizer, while OP is used as an antioxidant and stabilizer for plastic products. Both of these additives are toxic to human beings and other animals, especially for some water-dwelling organisms (UK Environment Agency, UK, 2010).

It is scientifically acknowledged that some compound present in plastic packaging have the capacity to migrate into food through the natural food chain. Many studies have addressed this phenomenon using specific examples of PET, PVC, and HDPE as well as the above-mentioned substances NP and OP (Loyo-Rosales et al., 2004; Eberhartinger, 1990; Guenther et al., 2002). However, there are also other plastic components that raise concerns mainly for their measurable presence in aquatic ecosystems and their endocrine disruptive toxicity and carcinogenity for humans (Oehlmann, 2008; Talsness, 2008). These are bisphenol A (BPA) and different kinds of phthalate (such as phthalates di-butyl phtalate (DBP), di-ethylhexyl phthalate (DEHP), disoldecyl phthalate (DIDP), and di-isononyl phthalate).

Concerning the decomposition of plastics, there have been some attempts to find efficient solutions for its biodegradability. Of all additives, there is one called “biodegradable plasticiser”. This was ideally meant to satisfy the demand for biodegradability that rose as a result of environmental and legislative pressure to reduce plastic packaging wastes. Biodegradable plastics may contain additives that cause degradation under conditions of ultra-violet light and oxygen, i.e. “photodegradable plastics”. Other additives create “oxo-degradable plastics”, for which degradation initiates under specific conditions of temperature and humidity (EuPC, 2008).

The desire for biodegradable polymers that are compatible with the environment was first realised by the introduction of “biodegradable plastics” into the market during the 1990s. However, many plastics were not able to biodegrade but rather only to disintegrate (Mohee et al., 2008). The difference between degradation and biodegradation consists in the fact that degradation stops at the fragmentation-stage of polymers. This occurs through the action of heat, moisture, sunlight and/or enzymes that shorten and weaken the polymer chains, breaking them apart and eventually leading to cross-linking that creates more intractable persistent residues. In the biodegradation process the polymeric fragments are further processed by microorganisms that consume them as food and as an energy source (Mohee et at., 2008). In order to avoid misconceptions, several standards in the area of degradable as well as biodegradable plastics have been developed. The following organizations have created standards: ASTM (American Society for Testing and Materials, USA), CEN (European Committee for Standardization, Europe), DEN (Deutsches Institut für Normung, Germany), JIS (Japanese Standardization Association, Japan), and the International Organization for Standardization (ISO). The definition of biodegradable plastic materials given by the ASTM (2003) is a material having the capability of undergoing decomposition into carbon dioxide, methane, water, inorganic compounds, or biomass predominantly by enzymatic action of microorganisms. The ASTM standard requires a decomposition rate of 60 to 90% of the plastic material within 60 to180 days in a composting environment. However, as Mohee et al. (2008) conclude: “the environmental degradability of plastics is a complex process that is influenced by the nature of plastics and the conditions to which they are exposed”, i.e. aerobic and anaerobic conditions.

In fact there are many different types of biodegradable plastics. A first classification can be done according to the materials that are used to produce the particular type of plastics: there are petroleum-based synthetic resins and bioplastics. Bioplastics are generally considered to be types of plastics derived from natural resins such as starch, cellulose from wood, vegetal oils, or sugars (EuPC, 2008). Starch from cereal plants and potatoes is the main feedstock used to produce bioplastics. It is harvested and turned into lactic acid, a monomer, by microorganisms. The lactic acid is then chemically treated in order to link the monomers to chains of polymers, which bond together form plastics called polylactide (PLA) (Salt, 2002). Another way of producing bioplastics is through the involvement of bacteria, which produce granules of a plastic called polyhydroxyalkanoate (PHA) inside their cells. The plastic is then harvested. Some scientific experiment involved stitching the genes of those bacteria into corn plants, which then manufacture PHA in their own cells (Salt, 2002). However, even if bioplastics are advertised as “natural plastics”, their starch content can vary between 5 and 90%. The rest of the content is synthetic material, additives, and plasticizers. For this reason, Davis and Song (2006) propose to change the name of biodegradable plastics from “starch-based polymers” into “starch-containing biodegradable polymers” in case the starch-content is lower than 50%. Therefore, besides not being always as biodegradable as expected, bioplastics are also not completely “bio”, i.e. produced out of purely natural products.

Moreover, PLA and PHA are economically not feasible yet and the trial to spread them on the market as a replacement of traditional petrochemical plastics has not yet succeeded. The European Renewable Resources & Material Association (ERRMA, 2010) estimates that nowadays there are 50,000 tonnes of “renewable polymers” manufactured in Europe each year and its growth is foreseen to make up 10% of the global market by 2020. If this is going to happen or not, has still to be seen. In part two the total amount of synthetic plastics produced in Europe will be shown and a better comparison can be made in order to understand the proportions of renewable plastics produced.

Another controversial issue regarding the production of bioplastics is their similarity to biofuels. As for biofuels, there is concern about the food crops being diverted to non-food applications. The counterargument to this concern is that one hectare of land can produce two to three tons of bioplastics. Additionally, European Bioplastics

(2010) proposes an integrated concept allowing biomass to be used for energy purposes and also for the production of other materials: the plan is to first create a product from biomass, and then to produce energy or fuel out of it. Despite these innovative ideas, the need for a well-managed and balanced use of agricultural land could turn into a fight between lobbyists from which consumers would not get any advantage in terms of food (EuPC, 2008; Packaging Gateway, 2007).
Another way of classifying bioplastics is their way of decomposing. There can be photo and oxodegradation, compost degradation, hydro-biodegradation, and bio-erodible plastics. It is true, that scientists seem to approve of bioplastics when it comes to biodegradation. According to Mohee and Unmar (2007) the usual biodegradation time required for bioplastics to be composted is one to six months. In their study they compared three kinds of plastics and found out that not all biodegradable plastics do effectively biodegrade. Moreover, the term “biodegradable” or “bioplastics” itself has a negative effect on the consumer’s attitude. In fact, since those terms are associated with environmental sustainability, the dumping of those “biodegradable” products is “more acceptable” and waste production, instead of being reduced at the source, increases even more, causing additional problems to the waste management.

To sum up, plastics are ubiquitous in our everyday life and a basic need for the modern way of living. However, plastics are also a matter of concern. One growing problem is the release of non-visible toxic substances from plastic material that spread throughout the environment through hidden means. The other problem is plastic waste and its biodegradability. Today the world is facing a big challenge in trying to find ways to reduce waste production and littering into the environment. The next part of the thesis is going to analyse the quantities of plastics produced and the disposal facilities employed for it, while the third part will concentrate on the presence of plastics in the environment as a consequence of littering or unorganized waste collection. However, only synthetic classical plastics will be taken into account, without considering bioplastics.

Part 2: Production, Consumption, and Waste Generation Patterns. Case Studies of Brazil, Europe, and the United States.

In this second part a quantitative analysis of plastics production, consumption, and generated waste for Brazil, Europe, and the US is going to be attempted. The purpose is to give an overview over streams of plastic materials in various stages of its life and from the perspective of developed versus developing countries. The data analyzed are going to be mostly from the year 2008, but also some earlier data will be used. Furthermore, in some parts variations of the above mentioned national areas will be looked at: in the paragraph concerning plastics production, the NAFTA countries[1] will be analysed instead of just the US. The third paragraph, concerning waste, will refer to the European zone, i.e. Europe of the 27 states (EU27) including Norway and Switzerland, rather than to the European Union (EU) only.

Retrieving the same typology of data for all the three geographical areas was not always an easy task. Moreover, while production and consumption data comprehend all types of plastic materials, the paragraph on plastics waste relates rather to municipal solid waste (MSW) than to waste generated by the industries.

i. Plastics Production

As already mentioned in part one, plastics consume 4-5% of the global crude oil production as feedstock. Another 4-5% of the global petroleum production can be accounted for the energy used in plastics production processes. Some people affirm that plastics are a side product of the oil refinery industry. When oil is cracked, naphtha is produced and this material constitutes the basics for producing synthetic plastics. Naphtha is then processed into primary plastics, mostly in the form of granulates called plastic pellets, which is then further elaborated into plastic products. Parts of these are final products, ready for final consumption, while other,

[1] An agreement between the North American states Canada, Mexico, and the US that is in force since January 1st, 1994 (USTR, 2010).

need a packaging and assembling operation before reaching the final consumer, e.g. plastic packaging and components.

However, Plastics Europe Market Research Group (PEMRG; Plastics Europe et al., 2009) states that there has been an average annual increase of 9% in the general global production and consumption of plastics since the 1950s. This has been driven by a track record of continuous innovation. As figure 2.1 shows, the total global production increased from 1.5 million tonnes in 1950 to 245 million tonnes in 2008. As a direct consequence of the current global financial crisis, this continued growth was reversed in 2008. All industry sectors were affected and also the plastics industry suffered a set back in 2008, receding to 2006 production levels. Previously, in 2007, it had reached a peak of 260 million tonnes.

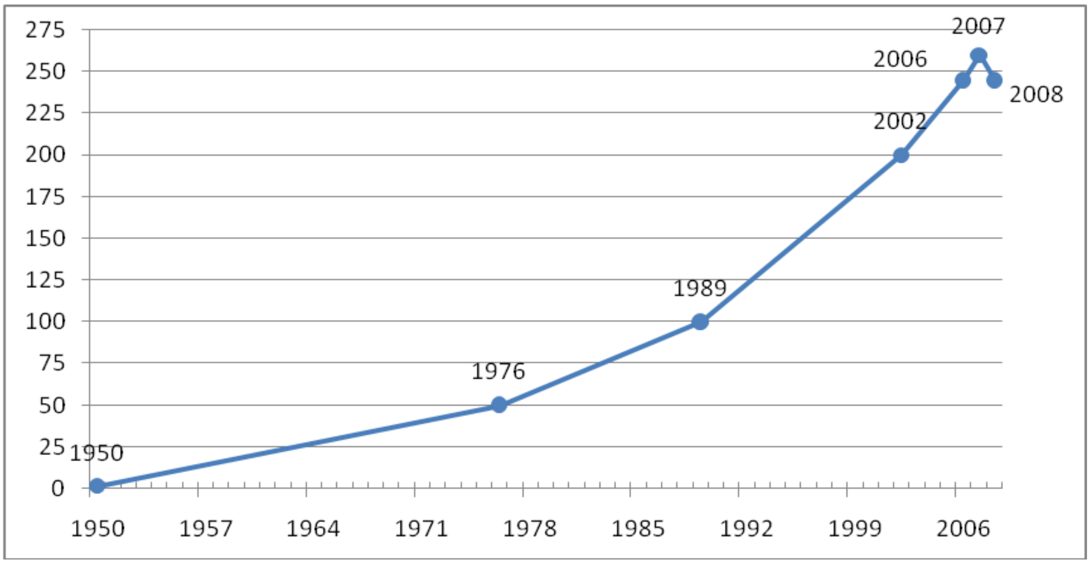

Figure 2.1: World plastics production 2050-2008. It includes thermoplastics, polyurethantes, thermosets, elastomers, adhesives, coatings and sealants, and PP-fibres. Not included are: PET-, PA-, and polyacryl-fibers.
Source: Plastics Europe Market Research Group (PERMG) in Plastics Europe, 2008.

PMRG (Plastics Europe et al., 2009) also found that the consumption of plastic materials on a per capita basis has grown to approximately 100 kg per year in NAFTA and Western Europe. These estimated potential to grow of these regions is of approximately 140 kg per capita by 2015.

To find plastics production data for developing countries is very difficult, due to a lack of accurate statistics. However, the biggest potential growth area will be the rapidly developing Asian region (excluding Japan), where the per capita consumption was of only 20 kg by 2008, but is expected to increase by approximately 16 kg by 2015 (Plastics Europe, 2009).

Also in Europe, the newer eastern Member States are expected to see the biggest percentage-increase, as their economy develops.

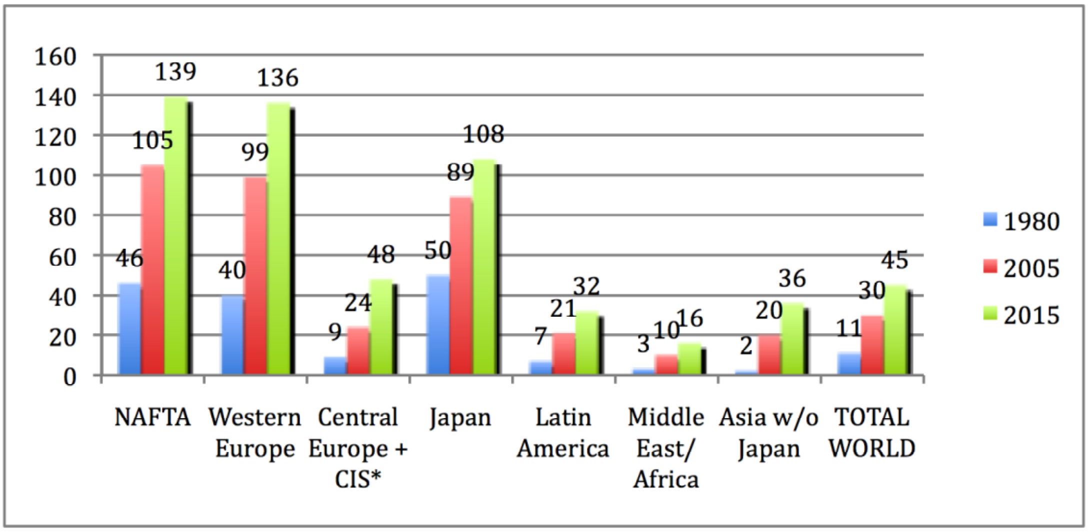

Figure 2.2: Annual plastics demand by converters in kg per capita per region for the years given: 1980, 2005, and 2010. Note: * Commonwealth of Independent States.
Source: Plastics Europe Market Research Group (PERMG) in Plastics Europe, 2008.

As it can be seen in figure 2.2, NAFTA states are the biggest demander for primary plastic products. Therefore, it can be deduced, that NAFTA states, followed by the West European countries, are also the biggest plastics producer.

In fact, according to the American Plastics Industry Trade Association (SPI, 2010), plastics industry is the third largest manufacturing industry in the US (SPI, 2010).

However, plastics production growth rates are going to increase mainly in Central Europe including the CIS states, Asia (excluding Japan), Latin America as well as the Middle East and Africa. Figure 2.3 shows the foreseen annual growth rate of plastics production in the different regions of the world between 2005 and 2015. Japan, NAFTA, and Western European countries are the regions with the lowest expected growth rates in plastic production for the near future.

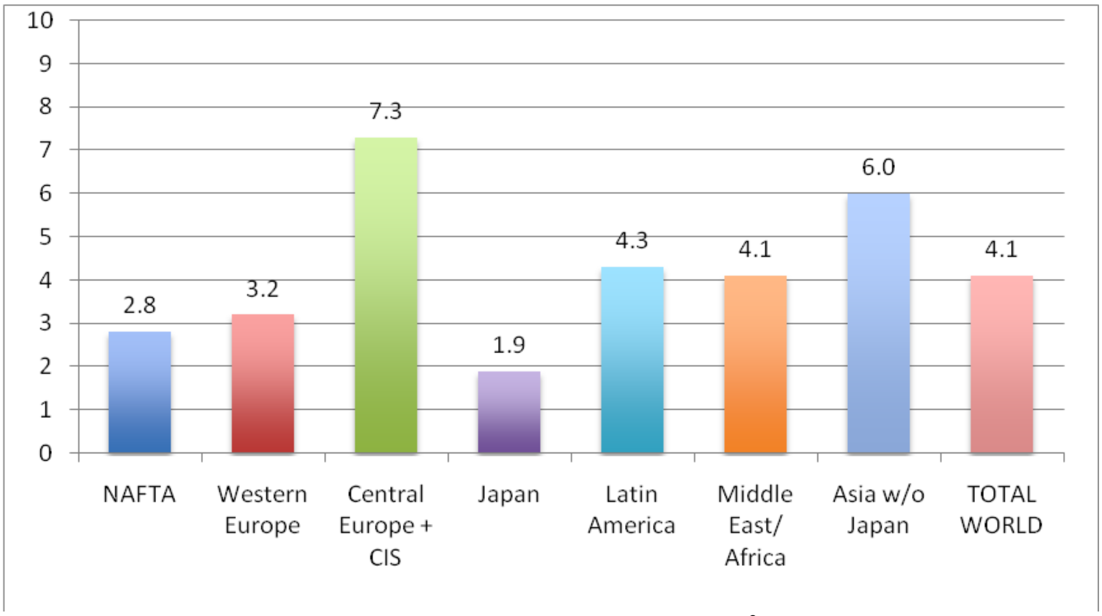

Figure 2.3: Compound annual growth rate in percentage 2005-2015[e] for plastics annual demand by converters in kg per capita per region. Notes: [e] according to the expected data for 2015.
Source: Plastics Europe Market Research Group (PERMG) in Plastics Europe, 2008.

The distribution of plastics production per country and region in the year 2008 looks as table 2.1 and figure 2.4 show. Considering the Europe zone, this is the region that in 2008 had the biggest production of plastics worldwide with an approximate total of 61 million tonnes. However, after NAFTA, also Asia (without China and Japan) and China constitute a significant part of plastics producers in the world.

Table 2.1: World plastics production 2008 by country and region (in percentage and million tonnes).

Country/Region	% 2008	Mt 2008	Charts
Europe zone*	25.0%	61.25 Mt	1.
NAFTA	23.0%	56.35 Mt	2.
Rest of Asia	16.5%	40.42 Mt	3.
China	15.0%	36.75 Mt	4.
Middle East. Africa	8.0%	19.60 Mt	5.
Japan	5.5%	13.48 Mt	6.
Latin America	4.0%	9.80 Mt	7.
CIS**	3.0%	7.35 Mt	8.
Total	**100.0%**	**245 Mt**	**-**

Notes: * meant as EU27, including Switzerland and Norway; ** Commonwealth of Independent States. Source: PERMG, 2008; own calculations.

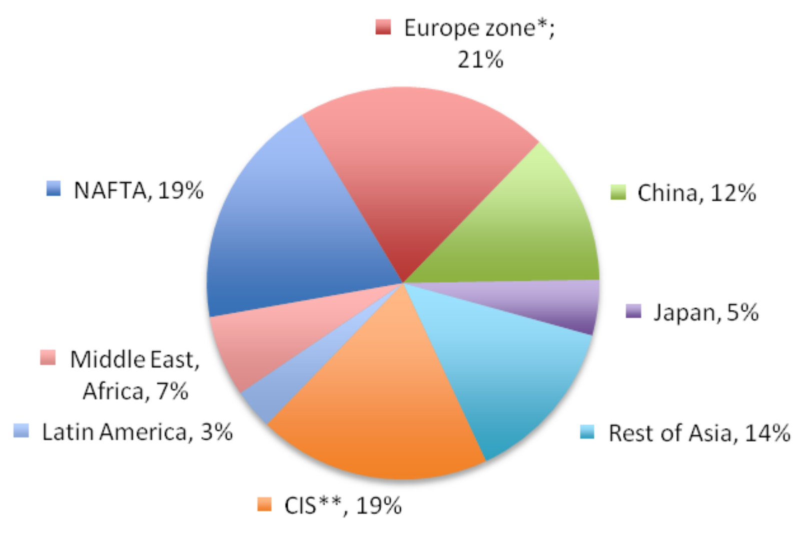

Figure 2.4: World plastics production 2008 by country and region. Notes: * meant as EU27, including Switzerland and Norway; ** Commonwealth of Independent States.
Source: Plastics Europe Market Research Group (PERMG) in Plastics Europe, 2008.

To take an example from a quickly developing Latin American country, the Brazilian absolute production number (5.194 million tonnes in 2008) is considerably smaller than the European one (61.25 million tonnes in 2008). However, on a percentage level, Brazil's increased its plastics production by about 33.6% between 2000 and 2009(Abiplast, 2009), while European plastic products grew by 22.5% between 2000 and 2008. Figure 2.5 below shows the Brazilian development. According to the Brazilian Association for the Plastics Industry, from 2007 to 2008 Brazil did not suffer any set back in the sector concerned, but even increased its plastics production, while Europe suffered a loss of around 7.7% (from 65 Mt in 2007 to 60 Mt in 2008; PEMRG, 2008; Plastics Europe, 2009).
The example of Brazil and the growth rate numbers given in figure 2.3 show that the sector of plastics production is important on a global scale and that it tends to grow fairly quickly also in developing countries.

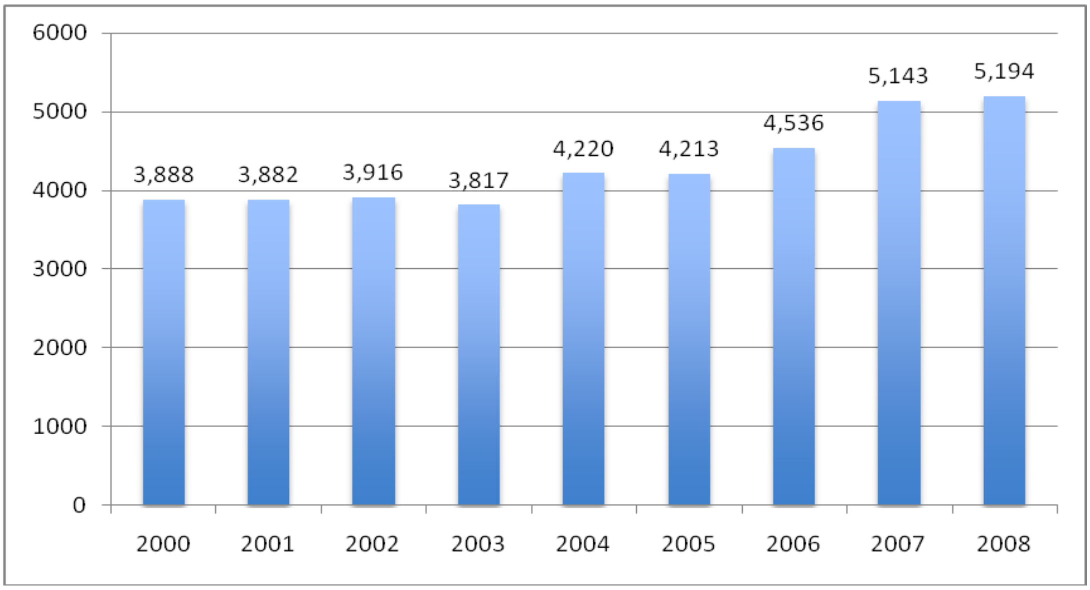

Figure 2.5: Production of plastic products in Brazil 2000-2009 (in thousands tonnes).
Source: Abiplast, 2009.

Concerning the share of types of plastics produced, the PERMG published a study (Plastics Europe, 2008) according to which, in 2007, thermoplastics were the most produced types of synthetic polymers with 65% of the total world production. The following figure (2.6) shows the proportions of thermoplastics compared to other types of plastics. It is to be kept in mind that thermoplastics are subdivided in two main groups such as standard plastics and engineering plastics. Most of the standard plastics are use for packaging and some for construction as well as the automotive sector (Plastic Europe, 2009).

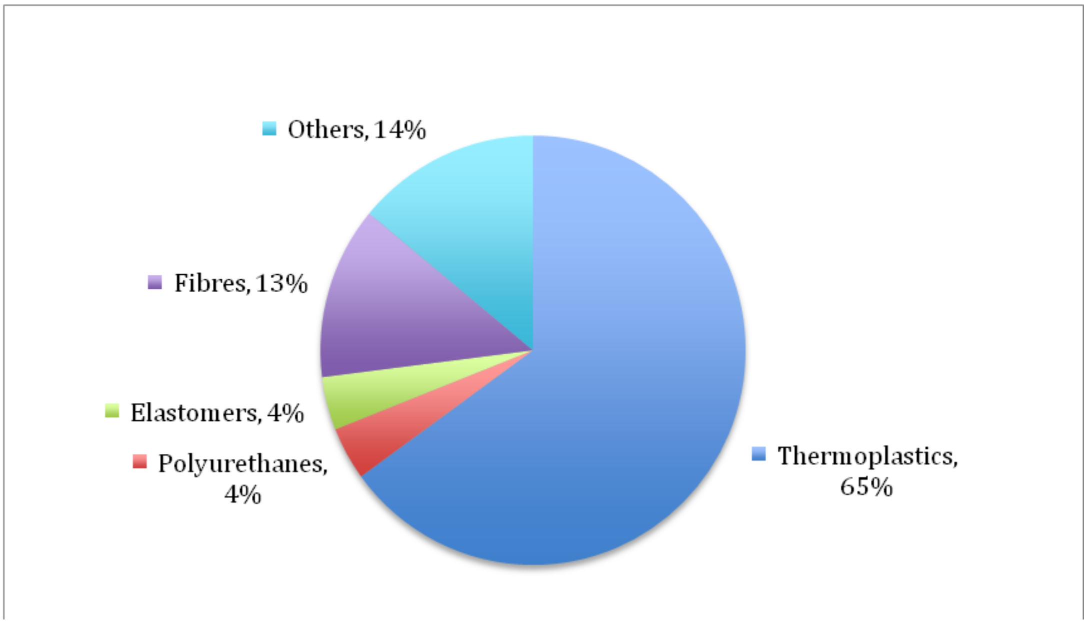

Figure 2.6: World synthetic polymer production 2007. Note: Thermoplastics: standard plastics (PET, PS, EPS, PVC, PP, HDPE, LDPE, LLDPE) and engineering plastics (e.g. ABS, PC, PBT, POM, PMMA, and others); Elastomers: synthetic Elastomers (SBR, IR, IIR, BR, NBR, CR, Others); Fibres: PA, polyester, acrylic, other synthetic fibres; Others: thermosets, adhesives, coatings, sealants.
Source: PEMRG, 2008.

Concerning plastic items produced on a global scale, a generalization is very difficult to make. As it has been stated already, there is infinite number of different plastic products being produced all over the world. An assessment of plastic flows in The Netherlands (Joosten, et al., 2000) classified plastic items produced on a national scale as follows:

- **Plastic building materials** (excluding plastic products of the other product categories used in building)
- **Plastic industrial components**
- **Plastic films and sheets, cellular**
- **Plastic films and sheets, reinforced**
- **Plastic films and sheets, others**
- **Plastic tubes**
- **Plastic rods and profiles**
- **Plastic floor covering**
- **Plastic furniture**
- **Plastic lighting**
- **Plastic packaging** (including durable plastic packaging, like pallets, crates, and containers, but excluding plastic products of the other product categories used as packaging material)
- **Refuse bags**
- **Adhesive tape**
- **Plastic office and school supplies**
- **Other plastic types** (plastic footwear and clothing, brushes, combs, tailor's dummies ect.)

However, given the heterogeneity of plastic products that are constantly generated, every institution and study makes its own classification according to its own needs. An example is the NACE code, created by the European Union in 1970. Since business and the industries are hard to describe, there may be plenty of possible misunderstandings. Therefore the NACE code was created in order to enhance communication and remove any doubt when it comes to information share. The code for manufacture of plastic products is NACE Code 25.2. This code sub-classifies the following categories:

- **Plastic plates, sheet, tubes, and profiles**
- **Plastic packing goods**
- **Builders' ware of plastics**
- **Other plastic products** (such as plastic tableware and kitchenware, as well as electrical insulating)

What can be definitely said is that there are some core industries that are primary consumers of plastics products. This issue is going to be discussed in the next paragraph on plastics consumption.

ii. Plastics Consumption

As microeconomic studies suggest, the offer of certain products and services directly depends on the consumers demand and therefore consumption determines production.

Plastics demand is very high for a very wide range of products. This trend established in western countries from the 1950s on, but nowadays it is also very spread in developing countries, depending on their level and pattern of development and income, as will be shown later in this paragraph. The market for plastic products is very animated, not only on a national scale, but in international trade patterns. According to SPI (2009), the US had a total amount of exports of 51,6 billion dollars in 2008. The top five export markets were its NAFTA partners (Canada with 22% share and Mexico with 21%), China with 8%, and Belgium and Japan with 4%. On the other hand, the top five markets from which the US imported plastic products in 2008 were Canada with 30%, China with 24%, Mexico and Germany with 4%, and

Japan with 6%. Plastics imports accounted for 38,6 billion dollars in 2008. By these data, it can be seen the plastic trade is quite significant among the "economic giants". The economy sectors that generally prove to have the highest demand for plastic products are the following[2]: packaging, building & construction (B&C), electrical & electronics (E&E), furniture & furnishings (F&F), automotive & transportation, agriculture, and institutions & households. In fact, packaging remains the biggest end-use for plastics in Europe and the US. The following figures show the numbers related to the consumption of plastic products by sector for EU27 and the US. There are some differences to take into account in these figures: while the European figure considers plastics in general, the US figure only treats the most common thermoplastics such as LDPE, LLDPE, HDPE, PP, PS, SBL, Nylon, and PVC (ACC, 2009). Moreover, the US figure also takes into account exports and consumer & institutional products, while the European doesn't.

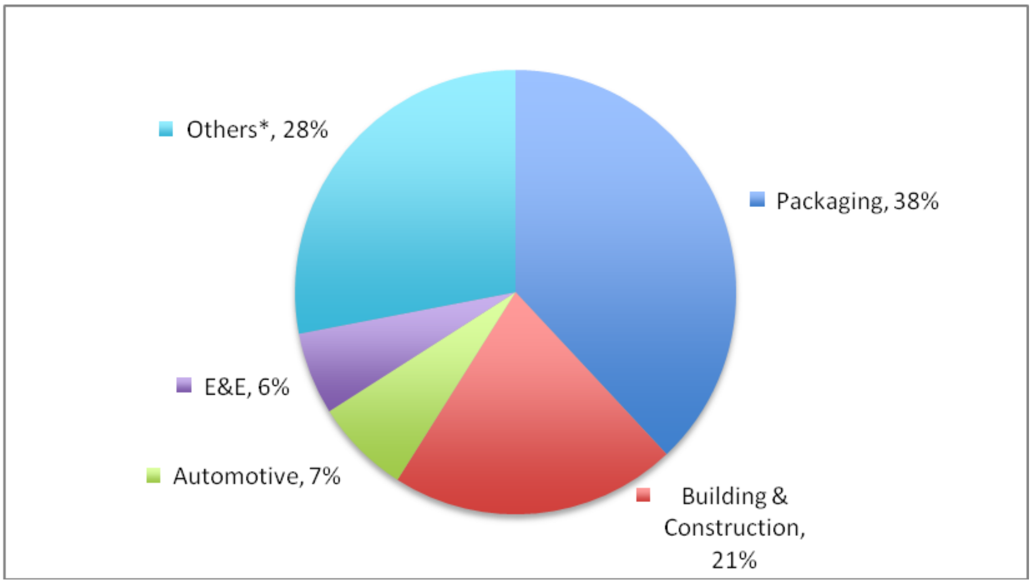

Figure 2.7: Plastics demand by converters in 2008: breakdown by end use segments in Europe zone. Note: * including medical and leisure products. Source: PEMRG, 2009.

Figures from the Association for Plastics Manufacturers in Europe (AMPE, 2006) for the year 2004 slightly differ from the percentage-shares of figure 2.7. Comparing the data of 2004 and 2008 there is the following evolution: building and construction +1%, packaging +1%, and automotive and E&E -0,5%. These differences are not very high and show a pretty stable demand for plastics. AMPE estimates that the

[2] Variation between countries and regions have to be considered.

total plastics demand from polymer converters in 2004 is of about 43.5 million tonnes for the European zone. AMPE also classifies plastics production into two use categories: short-service-life (lifetime < 2 years) accounts for 40% of the production and long-service-life (lifetime > 2 years) accounts for 60%.

Relating to the total plastics demand for the Europe zone, this is estimated at 54.5 million tonnes for the year 2008 (PEMRG, 2009).

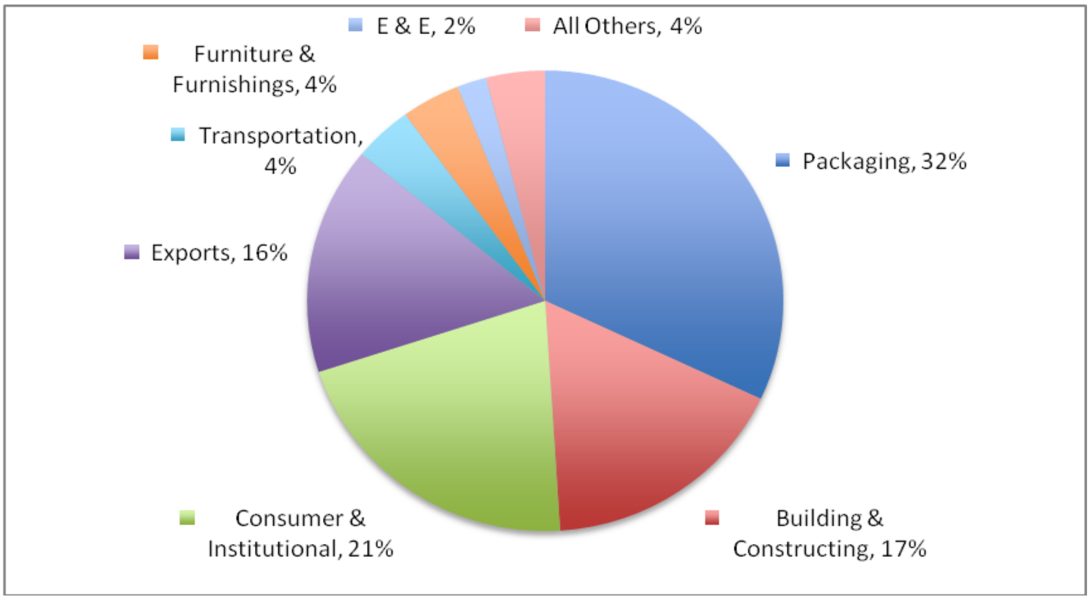

Figure 2.8: US Percentage Distribution of Thermoplastic Resins Sales & Captive Use by the Major Market, 2008. Source: ACC, 2009.

According to a study from the Instituto Mexicano de la Propriedad Industrial (IMPI; MOITI, 2007), plastics demand in the US was of 54.6 million tonnes in 2006 and the demand per capita for the same year was of 186 kg per inhabitant.

Comparing the data for NAFTA from figure 2.2 and table 2.2 the numbers differ. Figure 2.2 shows that annual plastics demand by converters in 2005 was of 105 kg per capita, while calculations from table 2.2 show a value for plastics demand in general of approximately 130 kg per capita for 2006. Still, it could be assumed that the volume of the actual demand and the demand by plastics converters might differ by the extra weight accounted for additives contained in final plastic products. Moreover, the two statistics date back different years (2005 and 2006).

Another remark has to be done on the total plastics world demand of table 2.2 (228 million tonnes in 2006) and the total global plastics production suggested by table 2.1 (245 million tonnes in 2006 and 2008). According to economic theories, demand

and offer should roughly equalize each other and here, this is not the case. However, since the data concerned are from different sources as well as from different relieving years, a certain degree of incongruence has to be taken into account.

Table 2.2: World Demand for Plastics 2006.

Country	Total demand (Mt/year)[a]	Demand per capita (kg/person/year)[a]	GDP/capita (in US $)[b]
Germany	16,0	194	35203
USA	54,6	186	44190
Canada	5,4	166	38951
Spain	5,8	144	27767
Italy	9,0	141	31790
France	7,8	129	35404
Japan	15,0	118	34188
Korea	7,6	107	18391
Mexico	4,5	43	8066
Brazil	7,0	38	5716
China	26,0	19	2001
Taiwan	5,3	15	15482
WORLD TOTAL	**228,0**	**n/a**	

Note/Sources: [a] IMPI from MOITI, 2007; [b] current prices, IMF, 2007; [c] estimated 2010 data, CIA, 2010.

Before introducing the Brazilian plastics demand data, a general graphic comparison between the gross domestic product (GDP) per capita and the plastics demand of the various countries of table 2.2 will be done in order to prove a correlation between the two variables.

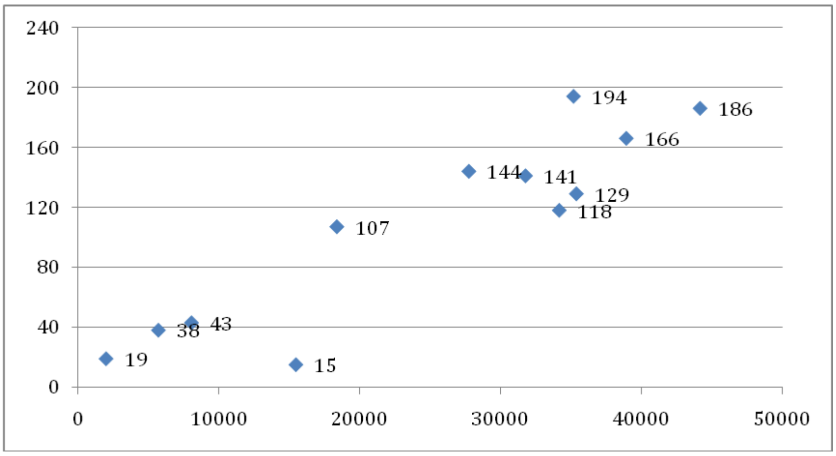

Figure 2.9: Correlation of GDP per capita and plastic demand for various countries.
Notes: x-axe: annual GDP/capita for the year 2006 according to table 2.2; y-axe: annual plastics demand in kg/ person; the values next to the points in the diagram show the demand in kg/person of plastics demand of the various countries in table 2.2.

In Figure 2.9 countries with higher income also prove to have higher plastics demand, while countries with lower income have much lower request for polymer consumption.

In order to complete the picture and take the example from developing countries, the following figures show Brazilian plastics consumption data that Abiplast published in 2009. Brazil consumed 5.3 million tonnes of plastics in the year 2009.

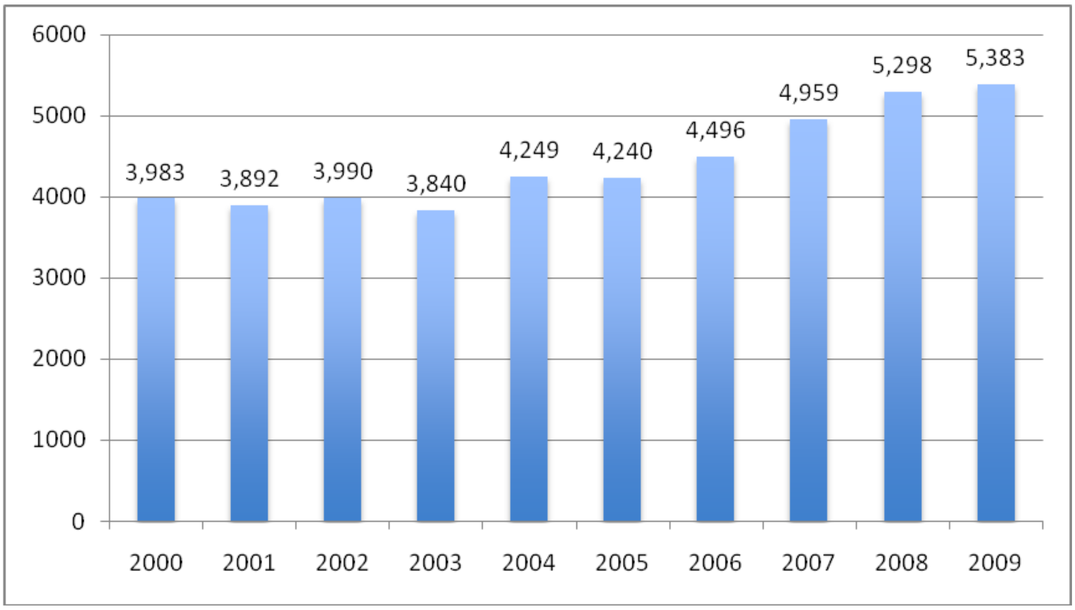

Figure 2.10: Brazilian consumption of plastic products 2000-2009 (in thousand tonnes).
Source: Abiplast, 2009.

As to what concerns the segmentation of the processed plastics market, the available Brazilian statistics are much more detailed than the previously reported European and US studies of end-use sectors of plastic products.

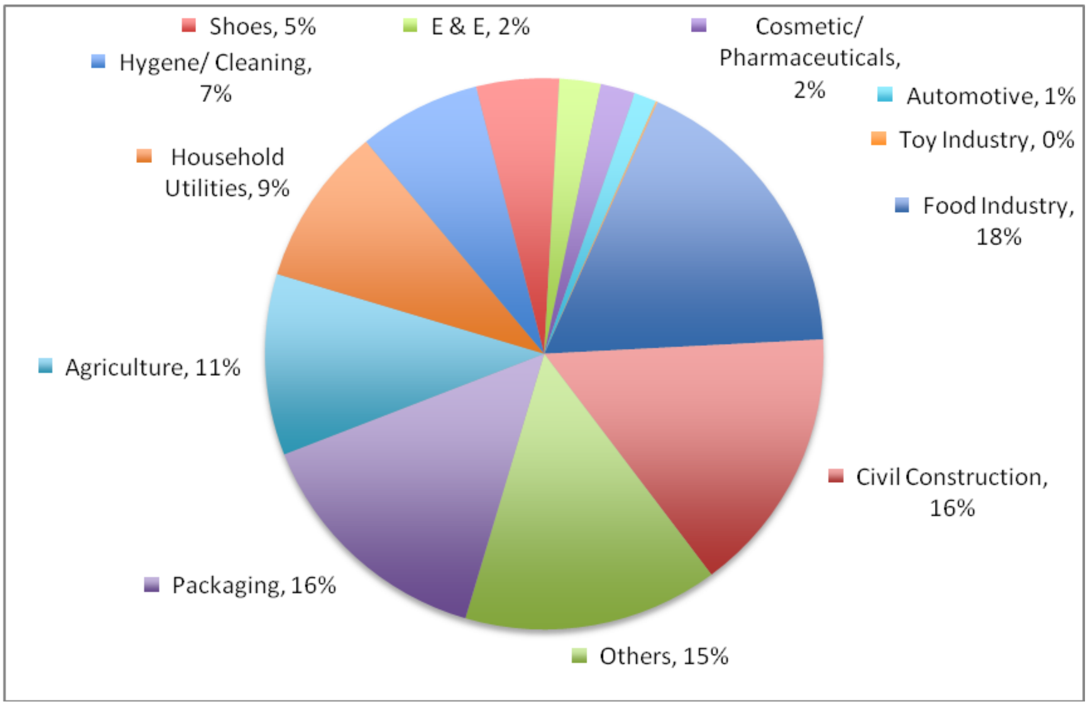

Figure 2.11: Segmentation of the Brazilian processed plastics market 2008. Source: Abiplast, 2009.

In comparison to the two regions mentioned before, packaging seems to have a much lower significance within the consumption shares. In fact, Abiplast gives a much narrower definition to the term “packaging” than the EU or the US. The Brazilian sector “packaging” considers bottles (PET), bowels, as well as tanks for chemical substances. However, packaging material in a more “western” sense is included in all other Brazilian consumption categories as well. For example, also the food industry, hygiene & cleaning, and cosmetics & pharmaceutics comprise packaging items such as containers, flacons, bottles, and plastic bags.

In conclusion, table 2.3 summarizes and completes the so far given data on plastics production and consumption for Brazil, the Europe zone, and the US. It has to be kept in mind that the comparison data of the various countries have been taken from different sources and that the percentages for the various sectors have been adapted according to an own subdivision of plastic employment by industry. Additionally, the US data report values for only thermoplastics, while the European and Brazilian data should comprehend also other types of synthetic resin.

However, the percentage-shares show that the sectored distribution of plastics production and consumption does not differ completely from one country/region to another in most of the cases. The Brazilian statistics include agricultural employment of plastics, while the European and the US' don't. Moreover, the export rates are slightly different from one country/region to another. It appears obvious that when talking about absolute numbers in million tonnes differences arise among the countries: the European region and the economic colossus USA have much higher production and consumption rates than Brazil as a development country that accounts for a weaker economy than the first two zones (it was not possible to find exact data about USA total plastics production). In addition, besides of looking at the correlation of economic factors, also the amount of population per country plays an important role. In fact, Brazil has the smallest population size between the three areas it was referred to. In table 2.4 the macroeconomic variables related to GDP and the population of the Europe zone, US, and Brazil are summarized.

Finally, it is interesting to note that Europe has a net export value of 10% of its total plastics production, while Brazil has a deficit of 4%, i.e. it imports more than what it exports. Since data for the US production were not found, no comparison can be done in this sense.

Table 2.3: Plastics distribution by sector data in the Europe zone, the US, and Brazil.

	Europe Zone[I]		USA[II]		Brazil[III]	
	(%)	Mt	(%)	Mt	(%)	Mt
Packaging	34%	20.2	32%	:	30%[a]	1.572
Building & Construction	19%	11.2	17%	:	15%	0.766
Automotive & Transports	6%	3.7	4%	:	1%	0.063
E & E	5%	3.2	2%	:	2%	0.117
Agriculture[d]	0%		-	:	10%	0.520
Households	0%		25%[b]	:	9%	0.457
Others	25%	14.9	4%	:	27%[c]	1.415
Exports	11%	6.8	16%	:	5%	0.28
TOTAL PRODUCTION	100%	**60.0**	100%	**:**	100%	**5.194**
Imports	1%	0.61	:	:	9%	0.469
TOTAL CONSUMPTION/ DEMAND	**90%**	**54.9**	**:**	**54.6[IV]**	**104%**	**5.383**

Note: [a] inclusive food industry; [b] inclusive furniture & furnishings; [c] inclusive hygene & cleaning, footwear, cosmetics & pharmaceutics, toys industry; [d] agricultural polymeric products are mainly films used for the protection of the soil and the crops, having also the capacity of hindering evaporation. Moreover, plastics are used as pipelines for irrigation systems, for greenhouses, and for bulk packaging; (:) data not available.
Source: own calculations besides: [I] 2008 data from European Plastics et al., 2009; [II] 2008 data for thermoplastics from ACC, 2009; [III] 2008 data from Abiplast, 2009; [IV] 2006 data from MOITI, 2007.

Table 2.4: Macroeconomic data and population of the Europe Zone, US, and Brazil. Data for the years 2007/ 2008.

Country	**Population (thousands[I])**	**GDP total (billion US $[II])**	**GDP per capita (US $[III])**
EU Zone*	509864	15412.7	41508
United States	303598	13741.6	45489
Brazil	191870	1833.6	9570

Note: * includes EU27, Switzerland, and Norway; [I] data from 2008; [II] data from 2007 at current prices and PPP; [III] data from 2007 at current prices and PPP.
Source: OECD, 2009.

On the basis of the above reported population numbers, it is possible to calculate that the Europe zone produces 117.7 kg plastics per inhabitant, while Brazil produces 27.0 kg per inhabitant. Regarding consumption data per capita per year, the Europe zone consumes 107.7 kg plastics, the US 186 kg, and Brazil 28.0 kg. This gives some clearer evidence of the difference between a developed and a developing country. However, to fully assess consumption patterns, more detailed and corresponding information would be required.

iii. Plastics Waste

General waste generation data

The definition of waste given by the Organization of Economic Cooperation and Development (OECD, 2008a) is:

„ [...] materials falling under waste regulations are materials that are not prime products for which the generator has at a given moment no further use for own purpose of production, transformation or consumption, and which he wants to dispose of. Waste may be generated during the extraction of raw materials, during the processing of raw materials to intermediate and final products, during the consumption of final products, and during any other human activity."

Main concerns relate to the potential impact from inappropriate waste management on human health and on ecosystems (soil and water contamination, air quality, land use and landscape). Despite achievements in waste recycling and relative decoupling of municipal waste generation from economic growth, important questions remain on the capacities of existing facilities for final treatment and disposal, the location and social acceptance of new facilities (e.g. NIMBY[3] for controlled landfill and incineration plants) and as to illegal shipments.

The main challenge is to strengthen measures for waste minimisation, especially for waste prevention and recycling, and to move further towards life cycle management of products and extended producer responsibility. This implies internalising the costs of waste management into prices of consumer goods and of waste management services; and ensuring greater cost-effectiveness and full public involvement in

[3] NIMBY is an acronym for "*not in my back yard*". The term is used pejoratively to describe opposition by residents to a proposal for a new development close to them. The term was coined in the 1980s by British politician Nicholas Ridley, who was Conservative Secretary of State for the Environment.

designing measures (OECD, 2008b).

According to the OCED (2008b), despite considerable progress, data on waste generation and disposal remain weak in many countries. There is a lack of appropriate waste flows and of related management practices, and their changes over time. Furthermore, the completeness of data sets and their international comparability is still subject of high negligence.

The OECD subdivides types of waste in the following core set indicators:

- municipal waste
- industrial waste
- hazardous waste
- nuclear waste.

Here, only figures concerning MSW will be analyzed. The previous two paragraphs on plastics production and consumption report data including both municipal and industrial plastic products without making a distinction between municipally or industrially used plastics. Rough evaluations could be done in order to subdivide plastics production of the different sectors according to the two waste indicators concerned. For example, plastic products manufactured for the automotive industry, the B&C, and partially for the E&E industry, could be put into the category of products for industrial use. However, such approximations would result into being highly imprecise, since the exact distribution values are not empirically and statistically given and data originate from different sources. Moreover, as data on hazardous waste generation, also statistics on industrial waste are difficult to retrieve. The main reason for this is the fact that this kind of information is only accessible to insiders of the relevant sector or company, or via purchase.

The American Environmental Protection Agency (EPA) published MSW data for the US: about 250 million tonnes of MSW were produced in the US in 2008. Among these, plastics comprise 12%, i.e. approximately 30 million tonnes. Out of these 30 million tonnes, the equivalent of 2.12 million tonnes were recovered, i.e. 7.1%.

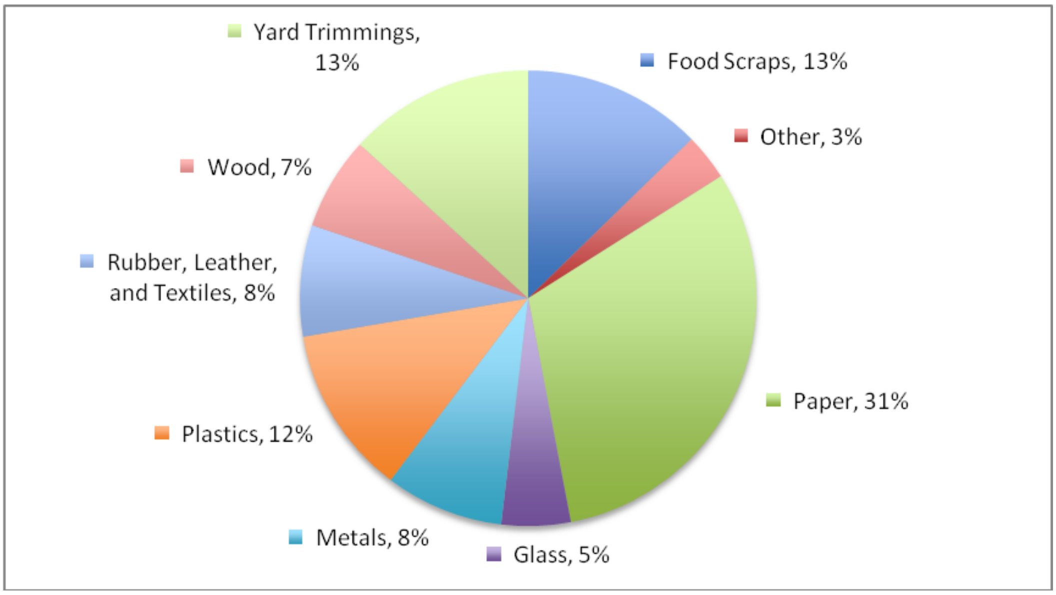

Figure 2.12: Total US MSW generation by material, 2008, including waste form residential, commercial, and institutional sources. Source: EPA, 2009a.

The breakdown into product categories of the waste generated in the US in 2008 is shown in figure 2.13. Containers and packaging make up the largest portion of MSW generated: 31%, i.e. 77 million tons. The second largest portion comes from nondurable goods, which amounts to 24%, i.e. 59 million tons. Yard trimmings make up the third largest segment, accounting for 13%, i.e. 33 million tons.

The generation and recovery of US materials from MSW are shown in table 2.5. The importance of this table relies in the fact that it shows data for plastics waste generation and recovery. It reveals that the recovery of containers and packaging waste has the highest value of the four product categories, i.e. about 44%. However plastics are not among the waste materials of this category that are being recovered the most, as they are not in other categories. Plastics recovery values are definitely lower than the total recovery level of US MSW. In general, more than 13% of plastic containers and packaging are recovered, mostly from soft drinks, milk, and water bottles. Plastic bottles were the most recovered plastic products. Recovery of HDPE natural (white translucent) bottles was estimated at about 29%. PET bottles and jars were recovered at 27% (EPA, 2009b).

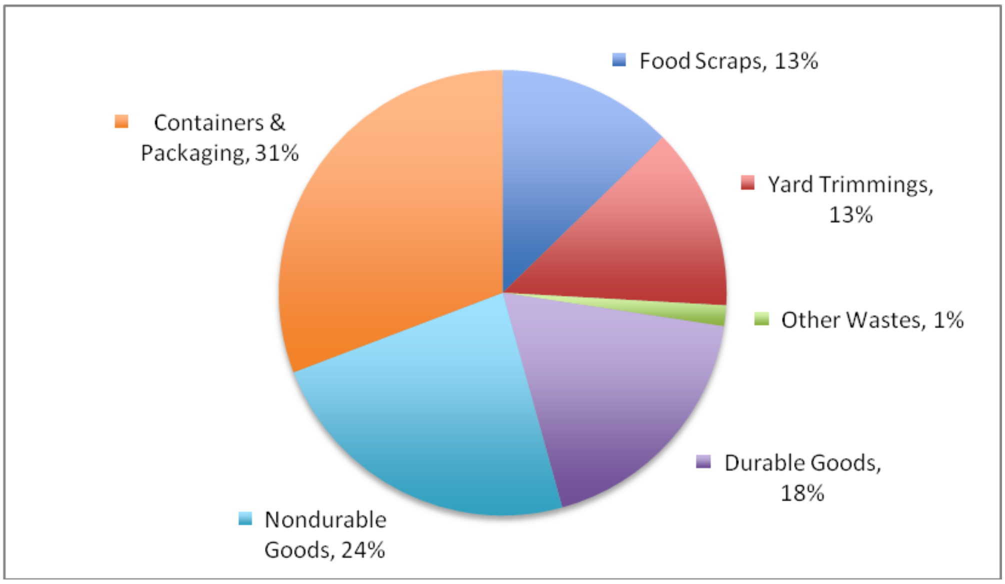

Figure 2.13: Total US MSW generation by category, 2008. Source: Source: EPA, 2009a.

Table 2.5: US generation and recovery of products in MSW, 2008 (in million tonnes).

Products	**Weight Generated (Mt)**	**Weight Recovered (Mt)**	**Recovery as % of Generation**
Durable Goods			
Steel	13.13	3.68	28.00%
Plastics	10.52	0.39	3.70%
All Other [a]	22.02	3.86	17.5%
Total Durable Goods	45.67	7.93	17.40%
Nondurable Goods*			
Paper & Paperboard	39.12	17.86	45.70%
Plastics	6.52	Negligible	Negligible
All Other [b]	13.07	1.45	11.09%
Total Nondurable Goods	58.71	19.31	32.90%
Containers & Packaging			
Paper & Paperboards	38.29	25.08	65.50%
Plastics	13.01	1.73	13.20%
All Other [c]	25.46	6.72	26.39%
Total Containers & Packaging	76.76	33.53	43.70%
Other Wastes [d]	68.47	22.1	32.30%
Total Plastics Data [e]	30.05	2.12	7.05%
Total MSW	**249.61**	**82.87**	**33.20%**

Note: * nondurable products are considered those that last less than three years; [a] including aluminium, other non-ferrous metals, glass, rubber & leather, wood, and textiles; [b] including rubber & leather and textiles; [c] including steel, aluminium, glass, and wood; [d] including food and other organic materials, yard trimmings, and miscellaneous inorganic wastes; [e] as legible from the table data. Source: Source: EPA, 2009a.

It hast to be noted, that the term "recovery" does not necessarily mean "recycling", as it could also be intended as material landing in incinerator facilities with eventual heat or energy recovery.

Figure 2.14 shows how US plastics in MSW are distributed among different product categories in the year 2008. Differently than the European definition given in the previous paragraph on consumption, the US differentiation between durable and nondurable goods lies in the definition: durable goods last more than 3 years, whereas nondurables are goods last up to 3 years.

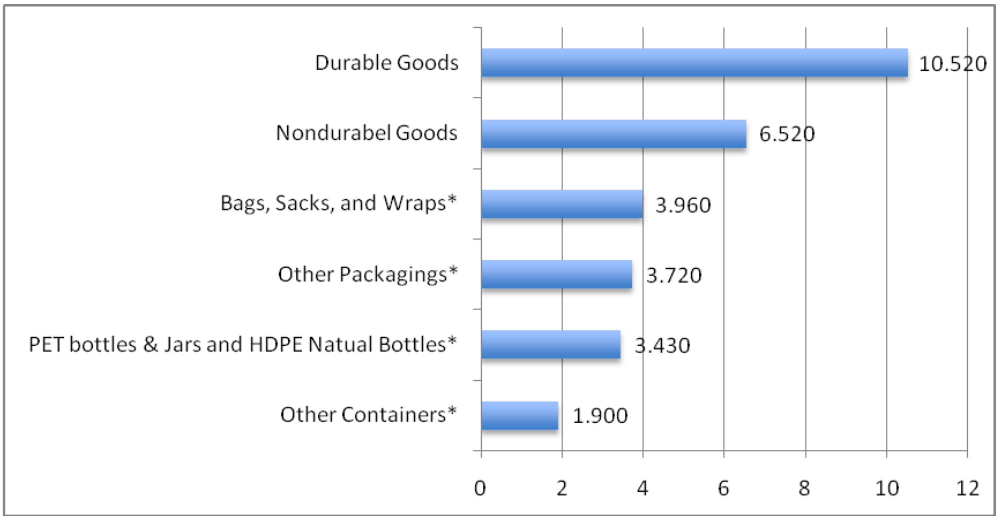

Figure 2.14: US plastic products generated in MSW, 2008 (in thousands tonnes).
Notes: * within the category "Plastic Containers & Packaging". Source: EPA, 2009b.

However, although detailed US MSW data are relatively easy to find, since posted on the EPA website (*http://www.epa.gov/epawaste/nonhaz/municipal/msw99.htm*), this was not the same for US industrial waste figures. Even the OCED reports no data on industrial waste generation in its Waste Compendium 2006-2008 (OECD, 2008a). It is interesting to notice that the statistics of EPA and OECD for the same year regarding MSW in the US are differing: EPA (2009b) reports MSW values of 249.610 million tonnes, whereas OECD (2009b) reports only 222.860 million tonnes. Nevertheless, the plastics component of MSW coincides with the two sources, namely 12%.

To what concerns the other two reference regions/countries that were considered up to now, Europe and Brazil, the following data will illustrate more about their MSW rates.

Starting with European data, Eurostat provides statistics about MSW generation regarding the Europe zone. Figure 2.15 shows the development of MSW generated per capita and year trough the time since the late 1990s. The bulk of this waste stream is from households, though similar wastes from sources such as commerce, offices and public institutions are included. For areas not covered by a municipal waste system estimations were made. Each inhabitant of the European region generated in average 585 kg waste in 2008, i.e. 1.6 kg a day. For the same region, the OECD reports 1.84 kg waste per person for the year 2006. Figure 2.18 that will follow in the next pages shows the data from a study of 2009 (Troschinetz and Mihelcic), which assessed the EU MSW consumption at 1.51 kg per person and per day. Despite differences, the dissimilarities between Eurostat statistics and the other sources are insignificantly small.

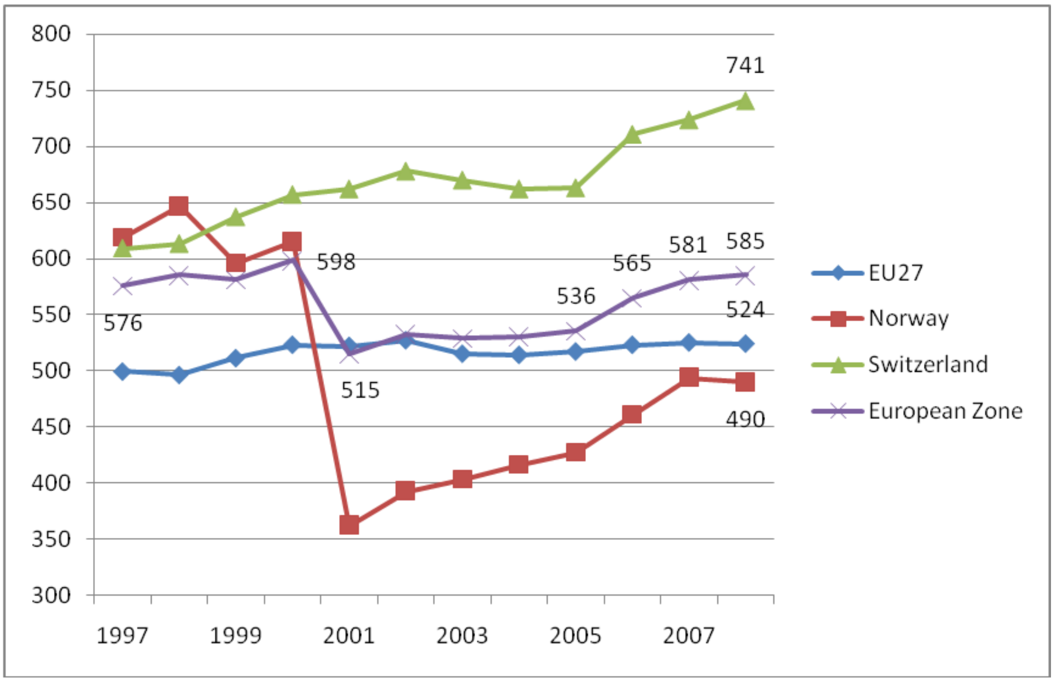

Figure 2.15: Amount of municipal waste generated in Europe zone in kg per person per year, 1997-2008. Source: Eurostat.

Eurostat also gives some figures concerning the production of non-hazardous waste generated by European households and economic activities according to the classification system NACE. Plastics waste was probably generated in the sectors of manufacturing, i.e. industries, construction, households, other economic activities, and other NACE branches. All these sectors together account for 67% of total non-hazardous waste production in the Europe zone. However, the plastic content is not given.

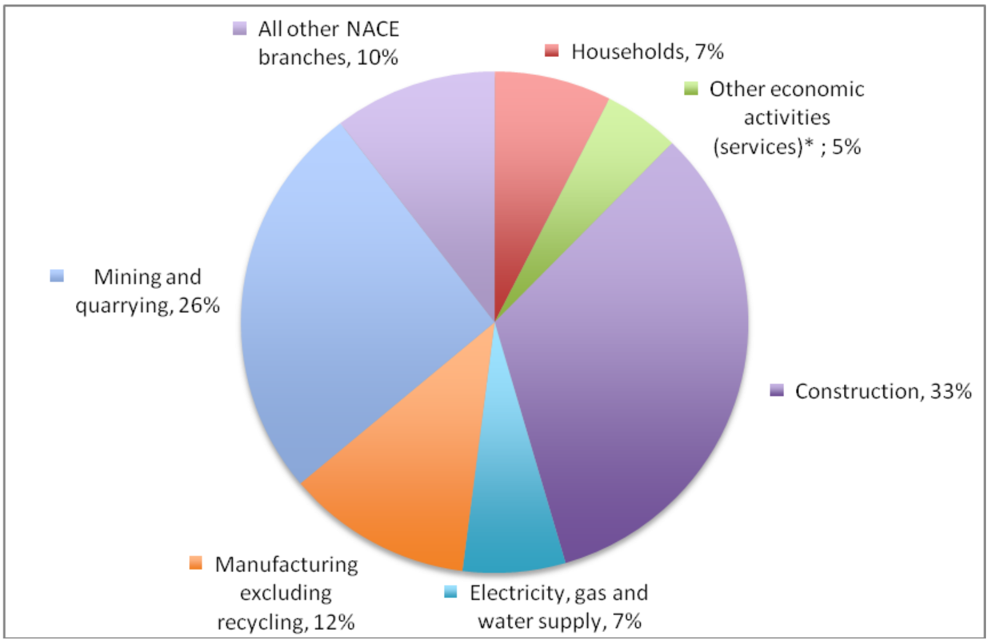

Figure 2.16: Total amount of non-hazardous waste generated by households and businesses by economic activity according to NACE Rev. 1.1. in 2008. The total amount of non-hazardous waste for EU27 and Norway (Swiss data non available) is of 2.872 million tonnes. Notes: * excluding 'wholesale of waste and scrap' and 'sewage and refuse disposal, sanitation and similar activities. Source: Eurostat.

A study of 1999 (Tuker et al.) estimated that the plastic waste supply by category would be as table 2.6 proposes. Nonetheless, it has to be kept in mind that these estimations consider pure resin and not plastics end products. In any case, in the last column of the table the percentage distribution of plastics waste in form of pure resins can be seen.

Table 2.6: Overview of plastic waste supply by category (in kilo-tonnes pure resin).

Year	1995	2000 (e)	2005 (e)	2010 (e)	% distribution for 2010
Waste type					
Agriculture	286	305	320	337	1%
Building	817	1077	1433	1742	6%
Households & Other	3390	4274	5127	5995	21%
Packaging (Households & Distribution)	8777	11065	13273	15521	55%
Industry	658	848	1061	1263	5%
Automotive	856	1087	1374	1633	6%
E&E	793	1036	1305	1561	6%
Total EU	**15577**	**19692**	**23893**	**28051**	**100%**

Note: (e) estimated values. Source: Turker et al., 1999.

Assuming that the estimation of the 1999 study is approximately right, it is possible to take the shares from the various sectors and create a figure showing the distribution of generated plastics waste by sector, given in percentages (figure 2.17).

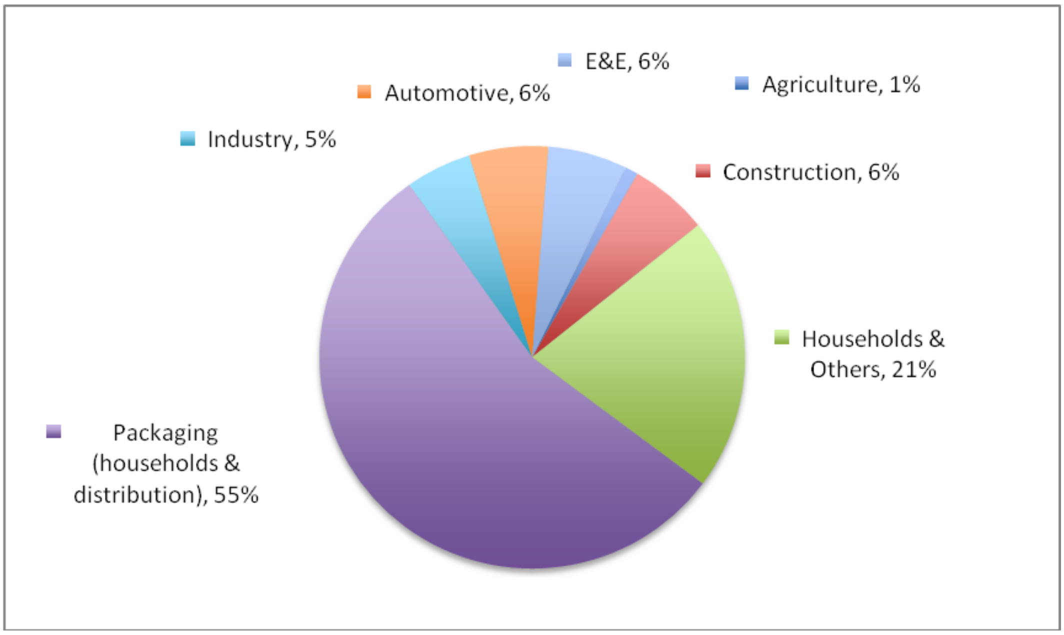

Figure 2.17: European plastics waste distribution among industry sectors in percentages.
Source: table 2.6.

Combining the percentage values of table 2.6 with the AMPE (2006) estimated post-user waste value of 19.1 million tonnes for the year 2004 and 21.5 million tonnes for 2006 (Aguado et al., 2007), the following plastics waste result:

Table 2.7: Absolute numbers in million tonnes and percentages of European plastic waste generated per sector.

Sector/ Waste type	% distribution[a]	Absolute distribution 2004 (Mt) [b]	Absolute distribution 2006 (Mt) [c]
Agriculture	1%	0.191	0.215
Building	6%	1.146	1.29
Households & Other	21%	4.011	4.515
Packaging (Households & Distribution)	55%	10.505	11.825
Industry	5%	0.955	1.075
Automotive	6%	1.146	1.29
E&E	6%	1.146	1.29
Total EU	**100%**	**19.1**	**21.5**

Sources/Notes: [a] data from table 2.6; [b] data for the year 2004 from AMPE (2006); [c] data for the year 2006 from Aguado et al. (2007).

Finally, from 2004 to 2006 there has been an increase of total plastics waste of approximately 13% in the European zone.

Passing over to development countries, a study on sustainable recycling of MSW in developing countries (Troschinetz and Mihelcic, 2009) states that the typical average MSW generated by developing countries is of 0.3 to 1.44 kg per person per day. Touristic regions produce even more waste, such as the Maldives that has the highest MSW generation rate. The study also affirms that typical developing countries generate the least amount of MSW, i.e. 0.3 kg per person per day, while developed countries typically generate 1.43 to 2.08 kg per person per day. Factors like GDP and developmental status can highly influence the MSW generation rates. The relationship between MSW generation and income varies with respect to the developmental stage of nation. As a country develops, its waste generation increases, while weak correlation exists between income and waste generation for middle and upper-income countries where waste generation actually decreases in wealthiest countries (Medina, 1997).

Waste generation in developing countries is affected by various factors, namely: the lifestyle, associated with certain incomes that can influence the consumption rates and pattern; the number of people living in a household since it has been shown that the higher the number of people living within a household, the lower waste generation rates (Bolaane and Ali, 20004); socio-economic development and degree of industrialization that influence the income patterns; climate and seasonal changes impact waste generation by having an effect on the amount of organic material generated as a waste product of preparing fresh foods in the season or climates that allow such preparations.

The following figure 2.18 shows how MSW generation pattern differ among 23 case studies.

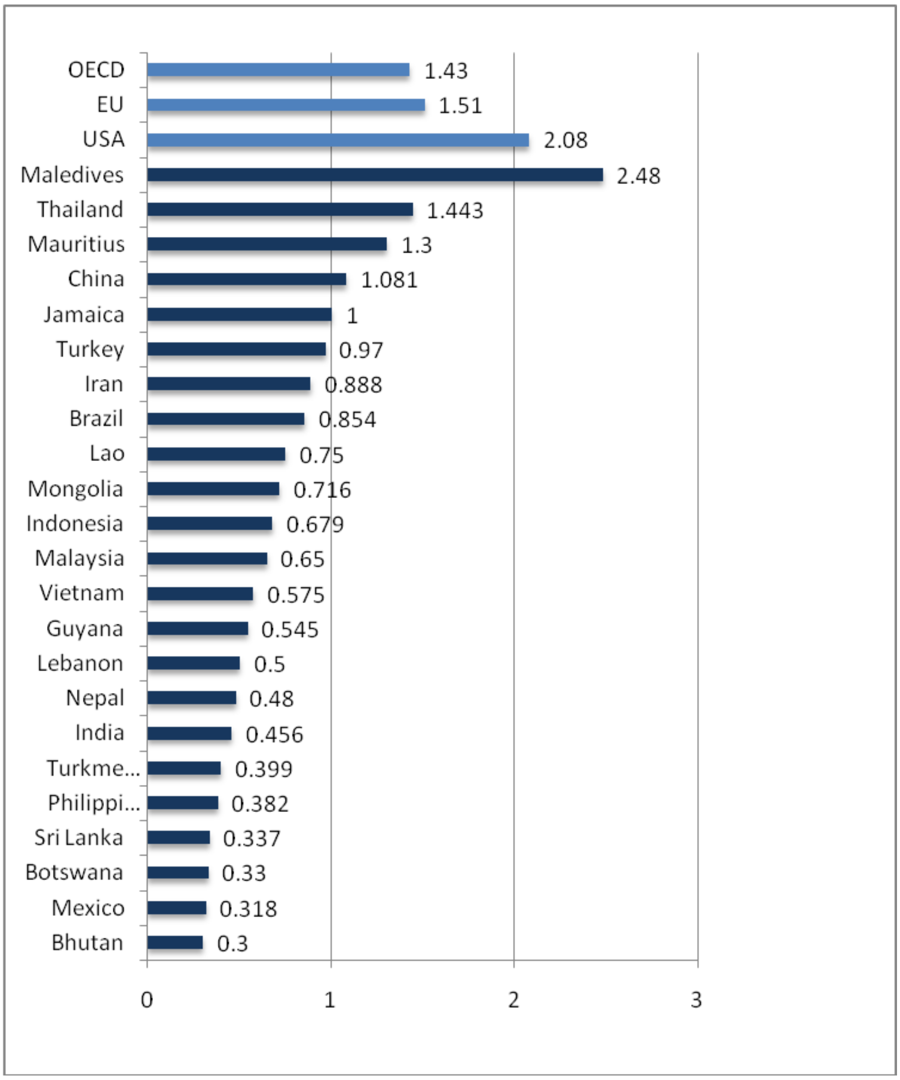

Figure 2.18: Municipal solid waste generation rates (kg/person/day) for 23 developing countries (lighter blue) compared to rates of developed countries (dark blue).
Source: Troschinetz and Mihelcic (2009).

Moreover, at least 55% of MSW in developing countries is organic and moist material (Troschinetz and Mihelocic, 2009; Blight and Mbande, 1996). In their study, Troschinetz and Mihelocic assess that the MSW composition is plastic material only at an 11 to 12% level. The same percentage is attributed to the US, while Europe has a household waste share of plastics of approximately 8%, number that is confirmed by the transformation of the households waste data of figure 2.16 into absolute numbers (i.e. 214 million tonnes) and these related to the total plastic waste amount of 19,1 million tonnes (AMPE, 2006).

Regarding Brazil, the OECD statistics (2009) report 58 million tonnes of MSW in Brazil for the year 2000 (latest available data). If taken this information and related it to the Brazilian population census (i.e. 191.87 million people; OECD, 2009) for the same year, the result is 0.828 kg MSW per person per day. This number differs by a negligible amount from the one reported in figure 2.18 (0.854 kg per person per day). Nevertheless, a Brazilian official survey (IBGE, 2002) on MSW production per capita and day of the year 2000 reports even lower data, i.e. an average number of 0.74 kg with average municipal values ranging from 1.29 kg per person per day in bigger *municipios* (> 1 million inhabitants) to approximately 0.42 kg per person per day in smaller ones (< 10'000 inhabitants).

A survey of 2008 (CEREM, 2008) to quantify the different materials in MSW in 32 *municipios* in Brazil has determined that in average 22% were constituted by plastic materials. It has to be beard in mind that the waste collection system in Brazil is very different from the one in developed countries. Very often only bigger cities have a real working waste collecting system and this is applied only to the wealthier parts of the city, while poorer quarters have to deal with the garbage on their own. Moreover, there are no real waste collecting systems in the countryside and the waste management is often left to the population. For this reasons, the average plastics composition of MSW has definitely to be lower than 22%, considering also rates from the European zone (7.21%; own calculations) and the US (12%; see table 2.5). To what concerns industrial waste, no real official data are available for it (Oliveria and Rosa, 2003).

Another official survey from the State of Sao Paulo published in 2001 (IBAM, 2001) states that the plastics share in Brazilian waste is in average of 3%. This data however, dates back 10 years and plastics waste generation might have been increasing ever since. With a high probability such a low number for plastics content in Brazilian waste means that it results from average estimations for the whole country, including rural areas. However, this percentage data seems to be more realistic than the previous one. Table 2.8 shows all the estimated components of Brazilian waste.

Table 2.8: Brazilian waste composition in percentage.

Material	%
Glass	3%
Metal	4%
Plastics	3%
Paper	25%
Other*	65%

Note: * organic waste, hospital waste, and other materials difficult to recycle (oils, lubrificants, pesticides, paints, an). Source: IBAM, 2001.

Types of disposal

As soon as products and materials reach the end of their life, they enter into a specific system of waste management. There are various waste management methods that differ for developed and developing countries, for urban and rural areas, and for residential and industrial waste producers. The responsibility for the implementation of waste management systems in terms of collection, transports and technology differs from country to country but it is often in the hands of the local authorities. There is also an upcoming trend for the involvement of private companies in the management of waste disposal. The main aim of waste management systems is the reduction of effects on health, the environment, or aesthetics. However, for various reasons waste management systems cannot cover the whole territory and cannot monitor all the population of a country. There are some restrictions to their efficiency for which municipal waste collecting systems cannot be ubiquitous. For example, developing countries generally lack of organization and planning of waste management due to insufficient information about regulations as a consequence also of financial restrictions. The disposal is often random and uncontrolled. Large quantities of waste remain uncollected (Al-Khatib et al., 2007). According to Al-Khatib et al., problems result from poverty, lack of education, and opportunity. Problems are also partially due to adherence to customs that "do not easily fit into the modern world". In the past years, developed countries have established always more sophisticated and regulated programs for the disposal of solid waste, while developing countries have generally continued to use rudimentary methods such as open dumping.

Since waste management systems cannot be ubiquitous, they might also fail in their purpose and the consequence is waste landing into natural environments and having hazardous effects on the surrounding nature, biodiversity, and human beings.

In this section different disposal techniques and applications are going to be analyzed quantitatively and proportionally for the three areas Brazil, the Europe zone, and the US.

Various ways to dispose waste are going to be mentioned including the problematic of plastics waste. The disposal typologies will mainly be:

- Landfilling
- Incineration
- Recovery and recycling
- Littering and dumping into natural environments as well as uncontrolled open air burning.

There are also other ways to dispose final waste such as composting or shipping into countries with weaker or no waste disposal regulations. This version of disposing waste may be legal or frequently illegal. This practice however, rather than of being applied for plastics refuses, it is used for hazardous, particular toxic, and nuclear waste, as well as for electronic waste. On the other side, composting is the controlled decomposition of organic matter through biological processes, resulting in nutrient-rich “humus” (Narayana, 2009). Referred to plastics, some scholars (Davis and Song, 2006) believe that bioplastics and biodegradable synthetic polymers are particularly suitable for composting techniques. However, this theory is neglecting the toxic substances coming from additives and plasticisers freed through the decomposition of such “biodegradable” plastics. Biodegradable natural and synthetic plastics are not going to be considered here.

The responsibility for disposing industrial waste lies usually in the hands of the industrial companies themselves. Data related to this activity are, like for the general waste production, very difficult and almost impossible to retrieve. For obvious reasons MSW-monitoring results much easier and transparent. MSW data are more complete and are going to be used in the following analysis.

Starting with the European zone, AMPE (2006) estimated that 53% of post-user plastics were disposed in the year 2004, while 47% were recovered. It also affirms that from 1996 to 2004 plastics recovery has more than doubled (+130%). To remind what has already been explained, the use of the term "recovery" includes various recovery techniques, i.e. incineration with usable energy or heat production, and the various recycling technologies. As defined before, the plastics waste stream of the Europe zone was of 21,5 million tonnes in the year 2006. Aguado et al. (2007) states that in 2006 61% of this stream has been disposed in landfills, 23% incinerated with energy recovery and 16% recycled. According to these data, the total recovered plastic material for the year 2006 is of approximately 39%. As usual incongruence comes up. In this case, the incongruence is of strange nature: since the establishment of the 1999 Landfill Directive (Europa, 2010) on a European Union level, European countries have committed to reduce their landfill use by implementing alternative measures such as increasing recycling rates. Therefore a decrease in energy recovery rates seems to be relatively unlikely. However, it has to be kept in mind that AMPE is a pro-plastic organization and its data tend to be polished. However, the growing use of landfill facilities could also be in line with the AMPE data since in 2006 it states as well that landfilling, although having stabilized, has still the tendency to slightly increase (AMPE, 2006), but should further reduce its growth rate as countries continue to develop their waste recovery infrastructure.

Recycling can be subdivided into mechanical and feedstock recycling. The feedstock recycling typology absorbs just 1.6% of the plastics waste (Aguado et al., 2007). Nevertheless AMPE (2006) estimates that from 1996 to 2004 this kind of plastics recover has increased by +36%. Feedstock recycling is the transformation of polymers into hydrocarbon chemicals for the production of new polymers, refined chemicals, or fuels. Mechanical recycling on the other hand is the selection of similar types of polymeric residue and their transformation into plastics pellets or directly into secondary plastic materials. Among further recycling techniques, there is also a process called "chemical recycling" that is continuously being improved in Europe. Chemical recycling is the application of selective solvents for the extraction of polymers of interest, for example separating PVC from other types of plastics.

Interesting to mention is that in order to fulfil the 1999 European Landfill Directive, there has been a growth of export of waste for recycling within the European continent (AMPE, 2006).

Regarding the application of energy recovery facilities in Europe, AMPE (2006) affirms that some countries have very few facilities such as the new Member States and also some others like Finland, Greece, Ireland, and the UK. To the contrary, in countries such as Austria, Denmark, Netherlands, and Switzerland an approximate energy recovery rate of 70% of plastics waste is achieved. As well, in some countries many cement-kilns use pre-treated waste plastics as alternative fuel (in 2004: Germany about 50,000 tonnes and Italy about 25,000 tonnes).

Passing over to the disposal analysis on US waste, table 2.5 shows that out of 30 million tonnes plastics waste stream only 7.05% are recovered. In terms of general waste, it has been estimated that 80% of US waste is recyclable, but just the actual recycling rate is just at 33% (Environmentalists, 2010). The recycling numbers for both general and plastics waste are very low, especially compared to the European zone. Table 2.9 shows the different ways of MSW disposal in the US.

Table 2.9: Generation, materials recovery, composting, incineration with energy recovery, and discards of MSW in the US, 1960 to 2008 (in million tonnes and percentage share for the year 2008).

Activity	1960	1970	1980	1990	2000	2003	2005	2007	2008	% 2008
Generation	88.1	121.1	151.6	205.2	239.1	242.2	249.7	254.6	249.6	100%
Recovery for recycling	5.6	8	14.5	29	52.9	55.6	58.6	62.5	60.8	24.4%
Recovery for composting [a]	negl.	negl.	negl.	4.2	16.5	19.1	20.6	21.7	22.1	8.9%
Total materials recovery	55	8	14.5	33.2	69.4	74.7	79.2	84.2	82.9	33.2%
Incineration with energy recovery [b]	0	0.4	2.7	29.7	33.7	33.1	31.6	32	31.6	12.7%
Discards to landfill. other disposal [c]	82.5	112.7	134.4	142.3	136	134.4	138.9	138.4	135.1	54.1%

Notes: [a] composting of yard trimmings, food scraps, and other MSW organic material; does not include backyard composting; [b] includes combustion of MSW in mass burn or refuse-derived fuel form, and combustion with energy recovery of source separated materials in MSW (e.g. wood pallets, tire-derived fuel); [c] discards after recovery minus combustions with energy recovery; discards include combustion without energy recovery; (negl.) negligible. Source: EPA, 2009a.

From table 2.9 it is possible to see the development of waste disposal techniques in the US. While in the 1960s landfilling was the main procedure implemented that accounted for 93.6% of the total MSW produced, since the 1990s recovery techniques have gained more and more terrain.

To what concerns plastics waste in MSW, it is assumed that the polymer waste values in table 2.5 report information about synthetic polymers that are therefore not going to be composted like eventually bioplastics are. As a consequence, plastics are not included in the 8.9% rate of recovery for composting. Plastics, however, are included in the incineration and in the landfill discard percentages. Recalculating the shares of plastics without the composting rate results in the following table 2.10:

Table 2.10: Distribution of MSW and plastics waste techniques in the USA in 2008 (in percentage).

Activity	**% MSW**	**% Plastics Waste**
Recovery for recycling	24.40%	7.05%
Recovery for composting [a]	8.90%	0%
Total materials recycling recovery	33.20%	7.05%
Incineration with energy recovery [b]	12.70%	17.70%
Discards to landfill. other disposal [c]	54.10%	75.30%
Total	100%	100%

Notes: as in table 2.9. Source: according to own calculations.

From the new calculations it results that plastics waste is discarded into landfills with a rate of 75.3%, while the rate of incineration with energy recovery is of 17.7%.

Brazil, with a population growth of estimated 1.2% for the year 2009 (CIA, 2010), is not one of the developing countries with the strongest growth rate (i.e Burundi reaches 3.69%, Somalia 2.82%, Bolivia 1.77%, Colombia 1.22%, and in comparison Argentina 1.05%). However, the big country faces considerable problems in the management of MSW. 86% of the Brazilian population is concentrated in urban areas and the annual urbanization growth rate estimated for the period between 2005 and 2010 is of 1.8%. According to the CIA (2010), Brazil has 26% of population living under the poverty line (data from 2008), i.e. approximately 50 million people. Most of these people live in slums, so called *favelas*, illegal settlements built on squatted land generally to be found on the border of big cities. The access to *favelas* is limited due to their labyrinth structure of uncontrolled construction and due to high delinquency rates and riskiness. In these quarters waste management on an organized basis does not exist. The waste disposal option used in these cases is open dumping or *lixão* (plural: *lixões*), as it is called in Portuguese. It is estimated that 1 billion people living in slums alone all over the world produce 620,000 tonnes of solid waste per day, i.e. 226 million tonnes per year (Barton et al., 2008).

Regarding quantities of MSW produced in Brazil, all literature refers to the National Survey on Basic Sanitary Services in Brazil (IBGE, 2002). According to estimations for the year 2000 the solid domiciliary waste production of all Brazilian *municipios* amounts of about 125,281 thousand tonnes per day and the public generated waste is of 36,546 tonnes per day. This makes a total of MSW that reaches 161,872 tonnes per day. Multiplied by 365 days this would approximately result in 59 million tonnes of waste per year. This number is quite similar to the number previously given (58 million tonnes, sourced OECD, 2009).

According to the IBGE (2002) survey, in 2000 49% of the waste was landfilled: 47% was adequately disposed into sanitary landfills and 22.3% into controlled landfills. 30.5% of the generated waste discarded into *lixões*. Additionally though, it is specified that only 8.4% of all 5,507 *municipios* actually weights its collected waste. Moreover, just 32.2% of the municipalities owe landfilling facilities (13.8% sanitary and 18.4% controlled landfills) and 63.6% of all *municipios* uses *lixão*-sites. The remaining percentages are not specified.

In the analysis of the IBGE (2002) incineration, composting, and recycling technologies are not reported. This, despite a study in 2008 (Troschinetz et al., 2009) that reports of a Brazilian MSW overall recovery rate of 41%. Plastics beverage bottles recovery accounts for 20%. Table 2.11 shows this data:

Table 2.11: MSW recovery in Brazil.

	% share	Notes
Total MSW	41%	
Paper	30%	
Plastics	20%	Plastic beverage bottles only.
Glass	20%	Containers only.
Metal	49%	Aluminium cans only.

Source: Troschinetz et al., 2009.

These high recycling rates are adjudicated to the presence of scavengers' activity. Scavengers, so-called *catadores* in Brazil, are citizens with low to no-income that collect materials either dispersed throughout the city or concentrated on dumpsites. In Brazil (IBGM, 2002) 24,500 *catadores*, of which 22% has an age of minor 14 years, were estimated for the year 2000. Scavengers are on one side an important part of the informal recycling sector in developing countries, but their poor work and living conditions put their health and safety under big risks. At the end of the 1980s Bartone (1988) estimated that 2% of the third world population survives by recovering materials from waste.

Another more recent study on waste disposal technologies applied in Brazil dates back to 2005. This study contains the following table:

Table 2.12: Brazilian distribution of waste disposal technologies.

Waste disposal	t/day[a]	%[b]	% disposal of solid waste[c]	
Open ditch	48.322	21.2%	Sewage	
Wetland open ditch	233	0.1%		
Covered ditch	84576	37.0%		
Sanitary landfill	82640	36.2%	86.6%	Solid waste (100%)
Composting	6550	2.9%	6.9%	
Sorting plants	2265	1.0%	2.4%	
Incineration	1032	0.5%	1.2%	
Random places	1230	0.5%	1.2%	
Others	1566	0.7%	1.7%	
TOTAL	**228413**	**100%**		

Source: [a,b] Bizzo, 2005; [c] own calculations;.

Although this study does not consider controlled landfilling procedures, it is in agreement with the IBGE (2002) data that put landfilling on first place within waste disposal techniques. It could be assumed that Bizzo united the categories of controlled and sanitary landfills into one, i.e. sanitary landfill only. Bizzo also considers composting and incineration plants, which seem to find a very low application level in Brazil. Interesting as well is that Bizzo considers also random disposal.

Regarding the recycling issue, Bizzo presents a table as follows.

Table 2.13: Brazilian recycling data 2005.

Material	Recycled %	Mt/year
White paper	33.0%	2,000
Cardboard	79.0%	3,500
Plastics	16.5%	200
Aluminium cans	95.7%	121
Steel cans	47.0%	330
Glass	45.0%	400
Tyres	23.0%	25
PET	48.0%	173
Aseptic longlife package	22.0%	35
Acid lead batteries	80.0%	70

Source: Bizzo, 2005.

Comparing the plastics recycling data of table 2.13 to table 2.11, there is not a big deviance between 16.5% and 20% recycling rate, considering that table 2.11 considers only plastic beverage bottles. PET, however, has a very high recovery rate of estimated 48%.

Finally, let's take the value of 16.5% plastics recycling in Brazil and insert it in table 2.12. Assuming that plastics waste is equally distributed in the MSW mass, the percentage rates of plastics disposal can be found on the basis of the calculated disposal distribution of solid waste. Table 2.14 shows the results:

Table 2.14: Brazilian distribution of waste disposal technologies including an estimation of plastics distribution per disposal facility.

<table>
<tr><th>Waste disposal</th><th>t/day[a]</th><th>%[b]</th><th colspan="2">% disposal of solid waste[c]</th><th colspan="2">% disposal of plastics[c]</th></tr>
<tr><td>Sanitary landfill</td><td>82640</td><td>36.2%</td><td>86.6%</td><td rowspan="6">Solid waste (100%)</td><td>72.3%</td><td rowspan="7">Estimated Plastics content (100%)</td></tr>
<tr><td>Composting</td><td>6550</td><td>2.9%</td><td>6.9%</td><td>5.8%</td></tr>
<tr><td>Sorting plants</td><td>2265</td><td>1.0%</td><td>2.4%</td><td>2.0%</td></tr>
<tr><td>Incineration</td><td>1032</td><td>0.5%</td><td>1.2%</td><td>1.0%</td></tr>
<tr><td>Random places</td><td>1230</td><td>0.5%</td><td>1.2%</td><td>1.0%</td></tr>
<tr><td>Others</td><td>1566</td><td>0.7%</td><td>1.7%</td><td>1.4%</td></tr>
<tr><td>Plastics recycling</td><td colspan="5">16.5%[d]</td></tr>
<tr><td>TOTAL</td><td>228413</td><td>100%</td><td colspan="4"></td></tr>
</table>

Source: [a,b,d] Bizzo, 2005; [c] own calculations;.

iv. Let's make the point.

From table 2.15 below that summarizes the second part of the results, it is possible to read various facts:

1. The Europe zone is the biggest polymer producer and accounts for 25% of the world production. However, the US as a single country has very high production rates. To the contrary, Brazil shares only 2.1% of the global plastics market.
2. European and American consumption/demand values are very close. The year of reference is not the same (2006 and 2008), but due to the financial crisis data should not have changed considerably. Brazil's plastics consumption is almost 11 times lower than the one in the Europe zone and the US. However, Brazilian imports overshoot its exports and the country consumes more plastics than it produces. To the contrary, the other two areas cover their plastics demand. According to the calculations done, the Europe zone manages to export about 10% of its total production, while the US only 3%. Plastics demand per capita is the highest in the US, while Brazil proves to have very low values, i.e. almost 4 times less than the European zone and about 6.6 times less than the US.
3. In line with the consumption patterns, the US has the highest plastics content in total MSW, i.e. 12%, while the Europe zone generates only 7.21% plastics waste. Brazil has the lowest plastics share in it MSW of just 3%.
4. Thanks to landfilling with energy recovery, the European zone is the strongest in terms of plastics waste recovery. However, Brazil and the Europe zone are on the same footing to what concerns recycling values. The first one, thanks to informal recycling activity, the other because of higher efficiency in its waste management system.

   The US makes a big use of sanitary landfill technologies. Also Brazil uses landfilling a lot, but most of the times not sanitary but simply "controlled" landfilling or, even most of the times, open dump-sites (*lixões*) are employed (see data on number of *municipos* using the different kind of facilities).

Table 2.15: Sum up table for part III.2. Plastics production, consumption, and waste.

World[0] TOTAL PLASTICS PRODUCTION: 245 Mt						
	USA		Europe zone		Brazil[a]	
	Absolute numbers	%	Absolute numbers	%	Absolute numbers	%
Population (thousands)[b]	303,598		509,864		191,870	
PRODUCTION						
Total Plastics production (Mt & share in world production)	56.35[c]	23%	61[d]	25%	5.194	2.1%
CONSUMPTION/DEMAND						
Total consumption/demand	54.6[e]		54.9[f]		5.383	
Plastics demand (kg/p/y)	186[e]		107.7		28.055	
Plastic demand (kg/p/d)	0.510		0.295		0.077	
Plastics imports	5.196[g]	9%	0.61	1%	0.469	9%
Plastics exports	6.956[g]	12%	6.71[h]	11%	0.280	5%
Plastics net exports[j]	1.75[g]	3%	6.1	10%	-0.189	-4%
WASTE PRODUCTION						
MSW tot (Mt)	249.610[i]		298.270[j]		59.080[k]	
MSW (kg/p/year)[l]	822.173		585		307.917	
MSW (kg/p/day)[l]	2.253		1.6		0.844	
Plastics in MSW (Mt)	30.000[m]	12%	21.5[n]	7.21%	1.7724	3%[o]
WASTE DISPOSAL						
P recovered (Mt)	120.968	24.80%	8.385	39%[q]	0.346	19.50%[r]
Recycling	2.130	7.10%[p]	3.44	16.0%[q]	0.292	16.5%[s]
Sanitary landfill	22.590	75.30%[p]	13.115	61%[q]	1.281	72.3%[t]
Controlled landfill	:	:	:	:		
Composting	:	:	:	:	0.103	5.8%[t]
Sorting plants	:	:	:	:	0.035	2.0%[t]
Incineration with or w/o energy recovery	5.310	17.70%[r]	4.945	23%	0.018	1.0%[t]
Littering	?		?		0.018	1.0%[t]
Others					0.025	1.4%[t]

Sources and notes: [o] 2008 data; source: Plastics Europe et al., 2009; [a] all Brazilian data for production and consumption originate from Abiplast, 2009; [b] OECD, 2009; [c] data for NAFTA; source: PERMG, 2008; [d] source: PERMG, 2008; [e] 2006 data; source: MOITI, 2007; [f] source: PMRG, 2009; [g] own calculations starting from monetary values of import and export previously given in this part of the results chapter and assuming that the net export corresponds to 13 billion $ (US exports: 51,5 billion $; US imports: 38,6 billion $; SPI, 2009); [h] source: Plastics Europe et al., 2009; [i] source: EPA, 2008; [j] own calculations (pop*MSW kpy/1Mio); 2008 data MSW kg/person/year taken form Eurostat, 2008; [k] 2000 data; source: IBGM, 2002; [l] same sources as MSW total; [m] source: EPA, 2009a; [n] 2006 data; source: Aguado et al., 2007; [o] 2000 data; source: IBAM, 2001; [p] source: EPA, 2009a; [q] source: Aguado et al., 2007; [r] including incineration with energy recovery, sorting plants, and recycling; [s] source: Bizzo, 2005; [t] see table 2.14.

Last but not least, the littering activty as a „way of disposing" waste, including plastic material, is an often neglected problematic. Sources on this matter were neither found in the official literature, nor in public data of the two developed-country areas. Both the Europe zone and the US officially assume that all their waste is being disposed in apposite facilities without considering dumping activities in open nature. Highly underestimated is the fact of how much garbage can be carried across continents through lakes, rivers, and streams straight into the world's ocean (Ocean Conservancy, 2010).

Interesing is though, that Bizzo (2005) mentiones littering in his table on types of disposal for Brazilian MSW. Here it has been calculated that according to Bizzo's numbers, 1% of plastics waste lands into nature. In fact, the reality looks slightly differnt: the use of *lixões* is a big source of spreading trash into the environment. Wind erosion, precipitation, and anthropogenic influences and activities can lead to dispersion into natural areas.

Problems in estimating the amount of trash and plastics littered into the environment arise from difficulties in determining how much garbage is really produced and dispersed. The data used up to now are official data obtained mostly through weighting (besides for some cases in which the numbers were estimated, e.g. Brazil) garbage being disposed in the relevant facilities. Therefore, the obvious reality is that not all the waste produced is being registered.

The next paragraph will show an approximate graphic estimation of plastic material flows for the three countries analyzed.

v. Plastics MFAs for Brazil, Europe, and the US

General explications on how to read the MFAs

In the following pages three MFAs for the areas that have been analyzed up to now will be shown. All the three report flux data in **kg per capita and year**. The data used the one reported in the previous paragraphs and range between the **years 2006 and 2008**.

The first MFA reports the plastics flow analysis for Europe, the second one for the US, and the third one concerns Brazil. The **sequence of the MFAs** was chosen according to the complexity of the diagrams. The European, due to the simple data on plastics consumption found, is the least complex of the three, while Brazil, with its multitude of consumption sectors and disposal techniques, is the most complex of all.

All the three MFAs report the same **process colours**, varying according to the process typology. The actual production and export processes are marked in yellow, while the consumption processes are of orange colour. The waste collection processes are in lighter grey and the processes concerning the disposal facilities applied are coloured in dark grey. Finally, the littering process has an explicative red colour apt to signalize the environmental and other dangers that it poses, as specified in part three.

Concerning the **fluxes**, the arrows in dark red indicate all those flows for which precise values are unknown. To the contrary, the green arrows that change their thickness according to the flow mass they are representing show all those flows for which data were found.

Results of the MFAs

Despite of the different absolute values for the three areas concerned that were already discussed in the previous paragraphs, the three MFAs show that most of the plastics produced and imported into each area flows into the packaging sector, followed by the household & institutions and the B&C sector. For the case of the Europe zone and Brazil, much of the plastics produced go into the indefinite sector "others".

The plastic wastes arising and flowing into the MSW collection system, again, packaging materials are on the first place, followed by household wastes. This however, is the case for the Europe zone and the US, since no data regarding the distribution of plastic materials per sector into MSW are given.
From the MSW collection process, it is easy to see that most of the plastic wastes land into sanitary landfills and for the case of Brazil on open-air dumping places. The other disposal techniques represent in all three countries a graphically relative small share in the waste disposal system.
Industrial plastic waste data are marked with a question mark, as well as littering values that are termed "Losses #". For these, no data are available in this study.

Fact is, that among all the garbage being littered into nature, plastics are the most long-living material: they can be found after years, and even if their process of degradation already started. Plastics cannot be overlooked. The third and last part will introduce this problematic.

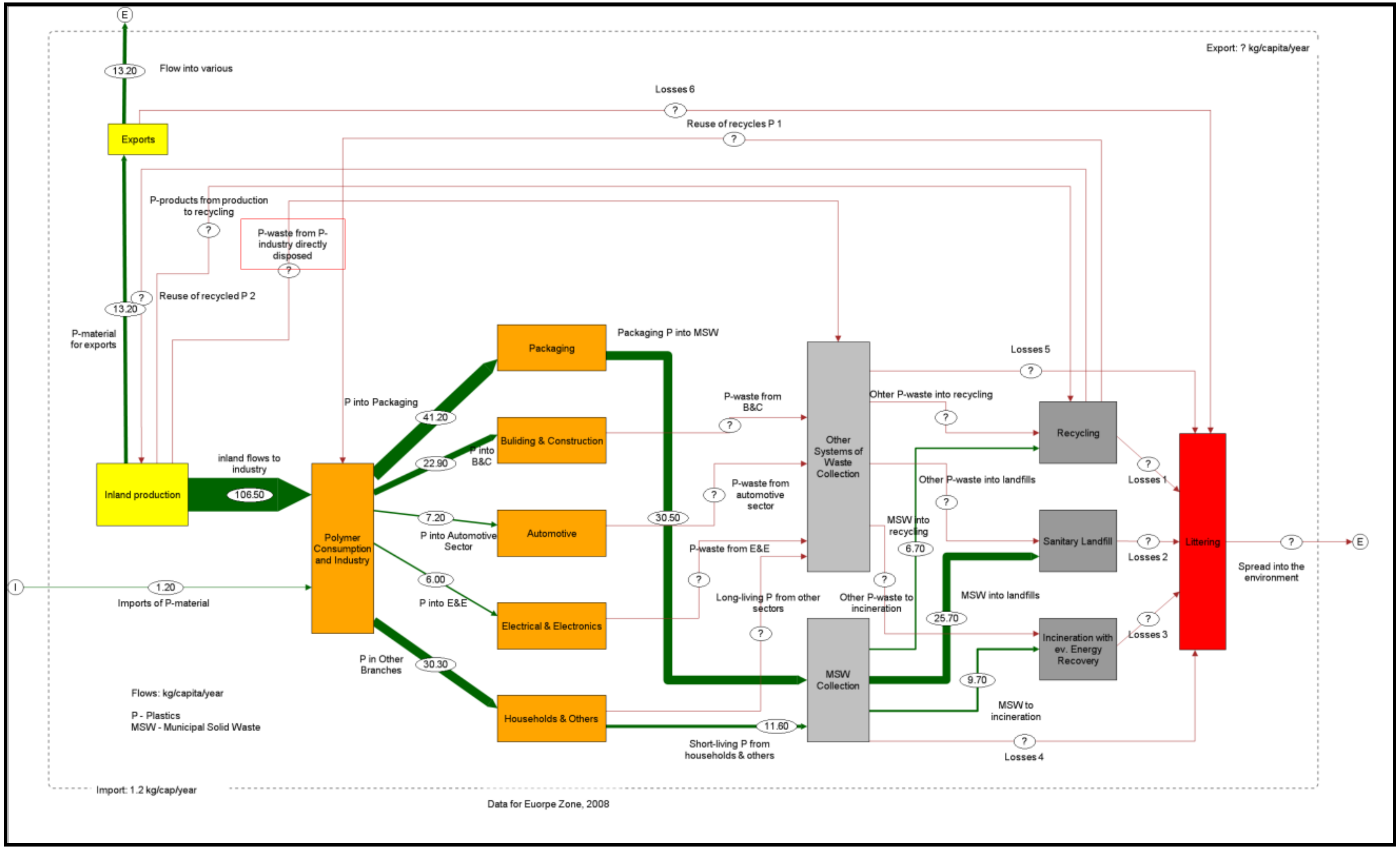

Figure 2.19: Plastics MFA for the Europe Zone.

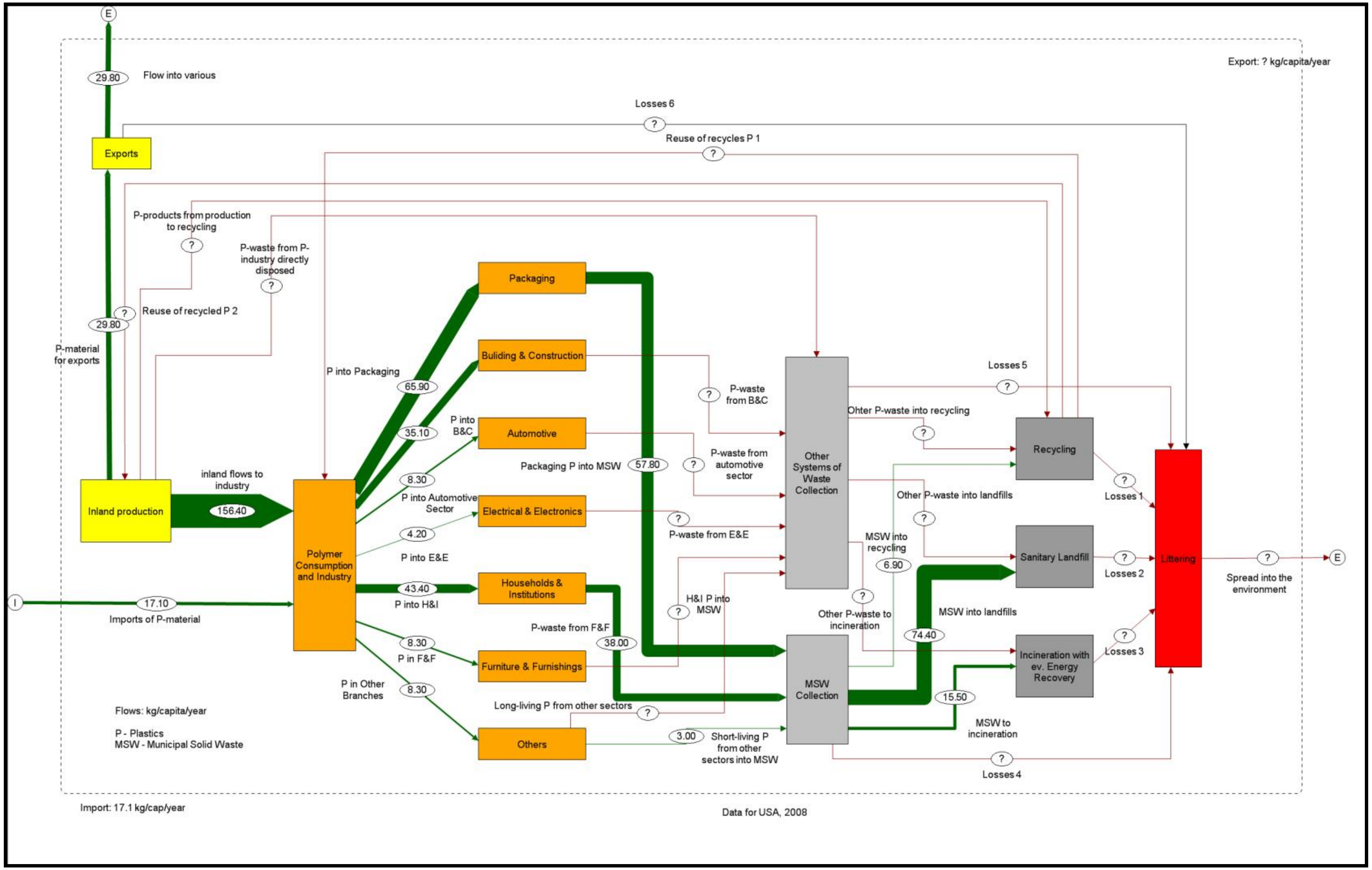

Figure 2.20: Plastics MFA for the US.

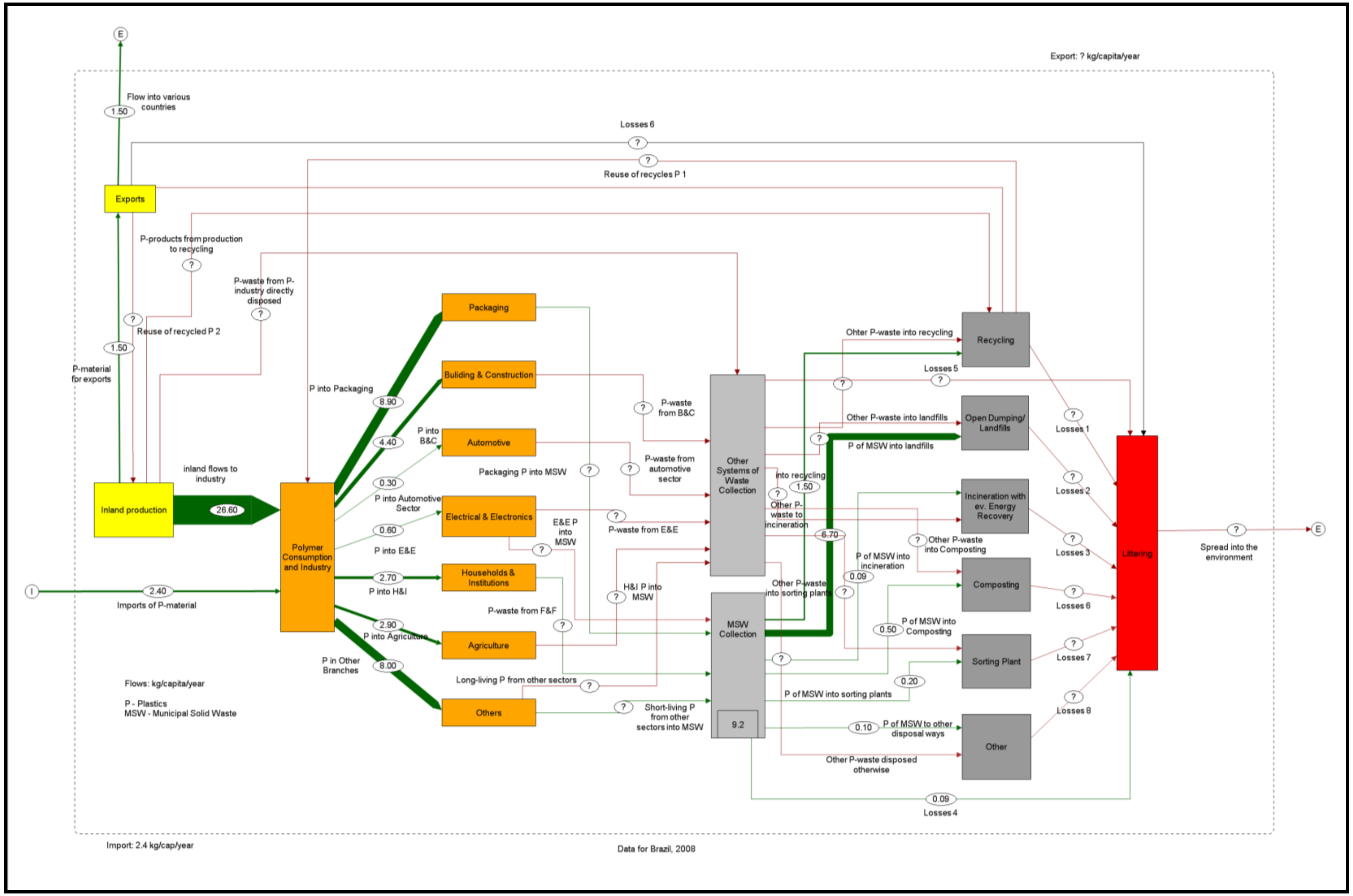

Figure 2.21: Plastics MFA for Brazil.

Part 3: Plastic Litter: Accumulation, Dangers, and International Action.

"Polymers, like diamonds, are forever."

Many changes have occurred on our planet's surface during the last 50 years, but one of the most instantly observable is the ubiquity and abundance of plastic debris. Despite wide recognition of the problem also on an international scale, plastic debris is one of those phenomena of anthropogenic source whose impacts on natural systems that are still growing. Even if the littering process would be stopped completely right now, the problem of persisting plastic items in the environment would last for decades and even for centuries (in case of its side-effects, i.e. release of toxic substances) (Barnes et al., 2009).

Plastics have a high durability that ensures their persistence through time wherever they are situated, either in natural environments or in landfills (Barnes et al., 2009). As it was seen before, plastics waste can be pre-consumer plastics waste and post-consumer plastics waste. Pre-consumer wastes arise by the production of plastics that do not meet the quality expectancies in the first place and therefore have to be dumped. Post-consumer plastic wastes arise from households (MSW), commercial and large industries, agriculture, and construction & demolition. As it was mentioned in chapter two, most of the plastic waste generated is disposed in more or less appropriate facilities, depending on the part of the world concerned. Here, it is assumed that a big part of plastics waste that is not being disposed adequately lands into the sea and oceans through rivers, water flows, currents, wind erosion, and deliberate and non-deliberate human activity. An argument for this assumption is that scientists all over the world talk about littered plastic waste in connection with marine debris. Almost all the literature on littered plastic wastes is to be found within sources on marine debris.

Researchers (Ryan et al., 2009; Barnes et alt., 2009) traditionally identify sources of marine debris in two categories: the first one is land-based such as run-off from rivers, waste water systems, wind blown litter, and recreational litter left on beaches. The second source for marine debris is marine-based and is produced by ships and platforms that dump rubbish into the sea. In general, marine-based polluters might be: fishing, merchant, military, and research vessels as well as recreational boats and cruise ships, offshore petroleum platforms and its utility vessels (UNEP, 2009). UNEP's guidelines to use market-based instruments to address the problem of marine litter (UNEP, 2009) state that land-based debris may start on streets, public parks, parking lots, and other similar surfaces. The debris is then washed, blown, or discharged into nearby waterways by rain, snowmelt, and wind. Sources include inappropriate or illegal dumping of domestic and industrial rubbish, as well as public littering, inadequately covered waste containers and waste container vehicles. Other sources of littered debris can be poorly managed waste dumps (such as, but not only, those in developing countries), manufacturing sites, sewage treatment and combined sewer overflows, beachgoers, fishermen, and shore based solid waste disposal and processing facilities. It has been estimated that about four-fifths (80%) of marine trash comes from land (Ocean Conservancy, 2010; Weiss et al., 2006; Leous and Parry, 2005; GESAMP, 1991). However, in both cases, whether land-based or ocean-based, disposal or loss may have been deliberate (whether legal or illegal) or accidental (Andrady, 2003).

Concerning marine-based sources, especially in developing countries it is frequently the case that the absence of garbage reception facilities in most ports, associated with a lack of inspection and fines for faulty ships, are one of the reasons for growing marine debris originated from ships and vessels (Santos et al., 2005).

From the share of marine debris coming from land sources, it is possible to see that there is a tight connection between littered plastic wastes and marine debris. Considering the generally used subdivision of littered waste material found in the seas, it is important to say that the literature subdivides it into macro (> 20 mm), meso (2-20 mm), and micro-debris (< 2 mm) (Ryan et al., 2009; Barnes et al., 2009). Despite other sources that give different sizes to macro, meso, and micro-debris (Andrady, 2003), for this work the above mentioned values will be considered. Barnes et al. (2009) and Moore (2008) estimate that 40 (for Barnes and 60 for Moore) to 80% of macro and meso marine debris found is plastic. Some set the amount of floating marine plastic litter at 90% (Weiss et al., 2006). Concrete observations in Brazil have shown that on the Costa dos Coqueiros, Bahia, 70% of the garbage found on the beaches was plastic material (Rodrigues Santos et al., 2005). In general, much of the plastic marine debris found is packaging and food wrappers, beverage bottles and bottle caps, carrier and trash bags, toys, light stick for fishing, cigar and cigarette filters, cigarette lighteners, and even footwear. For example, in 2002 a ship heading from Los Angeles to Tacoma, Washington, disgorged 33,000 Nike basketball shoes as its container fell over board during stormy seas weather (Weiss et al., 2006). There is also a high quantity of micro-marine debris, such as virgin plastic pellets and small plastic fragments (Ivar do Sul et al., 2009). Moreover, many studies certify of light-stick found along coasts. Light-sticks are small glowing plastic containers used for industrial fishing methods. The light-sticks are attached to the branch lines above hooks in order to attract fish (Witzell, 1999; Pinho et al., 2008). According to a study on Hawaiian swordfish longline fisheries, average longlines reach a length of 74.5 km, containing 397 light-sticks (i.e. one every 187 meters) (Bigelow et al., 2006).

Since 1986 Ocean Conservancy (2010) organizes each year “the world’s largest volunteer effort for the ocean and waterways” by cleaning up coastal areas on an international basis. In 2009, more than 6000 sites in 108 countries all over the world were cleaned up by almost half a million volunteers during one day. The resulting top ten statistics of items found are the following:

Table 3.1: Top ten marine debris items found in the Ocean Conservancy International Coastal Clean-up day 2009.

Rank	Debris item	Number of debris item	Percentage of total debris items
1	Cigarettes/cigarette filters	2,189,252	21%
2	Bags (plastic)	1,126,774	11%
3	Food wrappers/ containers	943,233	9%
4	Caps, lids	912,246	9%
5	Beverage bottles (plastic)	883,737	9%
6	Cups, plates, forks, knives, spoons	512,517	5%
7	Beverage bottles (glass)	459,531	4%
8	Beverage cans	457,631	4%
9	Straws, stirrers	412,940	4%
10	Bags (paper)	331,476	3%
Top ten total debris items		**8,229,337**	**80%**
Total debris items worldwide		**10,239,538**	**100%**

Source: Ocean Conservancy, 2010.

Other items found were six-pack holders (43,257 items; 0.04% of the total), toys (101,543; 1%), derelict fishing gears (around 201,739 items including light sticks, traps, ropes, and nets; 2%), and medical or personal hygiene articles (104,850 items including condoms, diapers, syringes, and tampons or tampon applicators; 1%).

It has also to be said, that 75% of all debris items were collected from coastal areas, whereas 25% from inland waterways. About the same share can be applied to people working on the ocean's coast and in inland areas.

This study proves the immense quantities of trash that can be collected in one day, and that trash can be also found on inland waterways, i.e. that trash is actually present to a big extent in inland water flows. Despite the big importance of such a global clean-up action and despite the big number of items collected as well as the efforts invested, it must be noted that clean-up operations generally focus on larger items along strandlines and not on micro-debris.

Other steadier monitoring programs of marine debris have been set up all over the world, but many authors have noted the difficulty in comparing data among studies. This difficulty is largely owing to differences in sampling protocols and types of data recorded (Ryan et al., 2009). Moreover, monitoring programs are time and resource consuming and cannot be implemented all over the world on a regular basis.

However, in 2005 it was estimated that 13,000 pieces of plastic litter float on every square mile of the oceans (UNEP, 2005).

The US Academy of Science estimated that the total worldwide input of marine litter into the oceans is of approximately 6.4 million tonnes per year (UNEP, 2005). According to some other calculations 8 million items of marine litter have been estimated to enter oceans and seas every day.

The distribution of general marine and plastic debris over the world seas is very patchy for a variety of reasons, including local wind, current conditions, coastline geography and the points of entry into the system such as urban areas and trade routes (Barnes, 2009). As the US National Academy of Science (2008) states, marine debris, especially plastic debris, is now ubiquitous in the oceans and along coasts. It is found in the middle of the oceans, on remote uninhabited tropical atolls (Barnes, 2009), and on Arctic and Sub-arctic islands. Even the deep sea is afflicted by it as for example shopping bags suspended and floating at water depth of 2000 m (Gregory, 2009). There are some plastics material and especially other kind of materials such as glass and metals that are sunk at the bottom of the seas.

Moreover, there are great marine debris patches situated in the middle of the open sea, floating like gigantic islands. One example is the Great Pacific Garbage Patch, situated about 1000 miles (i.e. about 1600 km) northeast from Hawaii. Some estimate that its size doubles double every 10 years and that nowadays it has twice the size of Texas (i.e. 1,392,482 km^2, which corresponds approximately to 16.6 times the size of Austria) (Howhaw, 2009). The Great Pacific Patch is generated by the clockwise moving currents of the Pacific Ocean (gyre) that traps debris in a particular region of the ocean. According to Moore et al. (2001) the weight of plastic debris in that area is in average of 5114 g/km^2. This is quite a lot considering that for example one 1.5 l plastic water bottle weights 42 g[4]. However, according to Ocean Conservancy (2010) the Pacific Garbage Patch is not visible in aerial photographs or satellite images. The accumulation of trash there is similar to a "chunky soup" rather than a solid island of garbage on which ones could walk.

Further four major gyres in the world's seas are situated in the South Pacific, the North Atlantic, the South Atlantic, and the South Indian Sea. These are areas where garbage gathers driven by the sea and atmospheric currents. For example, the North Pacific subtropical gyre is caused by large volumes of air moving from the tropics toward the North and South poles and creating a central part of the gyre where currents are calm and marine debris accumulates (Leous and Parry, 2005).

With reference to the longevity of plastics in the sea, scientists (Ryan et al., 2009) affirm that the decomposition rate of plastic debris is much slower in water than on land. Anthony L. Andrady, a polymer chemist at the Research Triangle Institute in North Carolina who studies marine debris, gives the reasons for this: "Seawater keeps plastics cool while algae, barnacles, and other marine growth block ultraviolet rays. Every little piece of plastic manufactured in the past 50 years that made it into the ocean is still out there somewhere, because there is no effective mechanism to break it down" (Weiss et al., 2006). Therefore plastics are harder to decompose in the sea than on land and this resistance is due to colder temperatures and lower impact with sunlight, since the sea acts as an efficient sink heat sink and absorbs infrared radiation in the sunlight (Andrady, 2003). Moreover, storms, atmospheric phenomena, and salinity do not contribute much to plastics degradation in the seas. It is estimated that plastics' longevity at sea ranges from hundred to thousands of years

[4] According to own measurements.

(Barnes et al, 2009). According to Ocean Conservancy (2010), the estimated decomposition rates of common marine debris items are as table 3.3 shows, considering that the timelines of each product depends on the product's composition and on environmental conditions.

Table 3.2: Estimated decomposition rates of common marine debris items.

Plastic debris item	Possible plastic material [a]	Life-time in the seas
Photodegradable beverage holders	:	Up to 6 months
Plastic grocery bags	PE-HD, PE-LD, PE-LLD, PP	1 to 20 years
Foamed plastic cups	PS, EPS	Up to 50 years
Plastic beverage holders	PE-HD, PET, PS, PP	Up to 400 years
Disposable diapers	Superabsorbent polymers (SAP)	Up to 450 years
Plastic bottles	PE-HD, PET, PS, PVC-P, EPS, PP	Up to 450 years
Monofilament fishing line	Nylon, polyvinylidene fluorid (PVDF), PE	Up to 600 years

[a] estimated from Conference to the Parties to the Basel Convention, 2002.
Source: Ocean Conservancy, 2010, c-more, 1993.

What can be seen is that plastics lifetime has to be multiplied several fold if considered as marine debris.

Carcasses of animals found might also prove the lifetime of floating debris. An example is the plastics swallowed by an albatross that was found dead in 2005, had originated from a World War II seaplane shot down 60 years before, some 9600 km away (Weiss et al., 2006).

As Ryan et al. (2009) state, the characteristics that make plastics so useful, also make inappropriately handled waste plastics become a significant environmental threat. Recalling the enumeration of advantages of plastic materials in part one, at least three of them are a threat to marine environment: light weight, resistance to external influences, and its ability to reproduce an enormous range of characteristics and colours. The risks tied to these characteristics and that plastics debris poses to marine life and marine activities are of various natures and not always tied to environmental protection matters. Almost all the literature sources on marine debris found, list or just mention the threats of plastic debris in particular. According to a classification of possible impacts of marine debris on its surrounding environment of the UNEP & IOC (2009), there are environmental, social, economic, and public health impacts arising from marine debris.

Starting with the environmental impacts, there is first of all *entanglement*. Entanglement of marine life is mostly due to fishing nets and ropes, plastic bags, monofilament lines, six-pack rings, and packing strapping bands (Greenpeace, 2006). Plastics entangle and kill marine life by drowning, strangulation, dragging, and reduction of feeding efficiency. This threat has been increasing since the 1950s, when natural and easily degradable ropes and cordages used in marine activities were replaced by nylon and other synthetic materials. The most affected animals are turtles, sea mammals (such as seals, dolphins and other whales), birds, fish, and crustaceous (Gregory, 2009). Moreover, there is the danger of *ghost fishing*: this is a form of continued catching of marine life through *ghost nets* as for example gillnets, traps, cages, pots, seines, and trawls, even if the item was already abandoned or lost. The National Academy of Sciences (2008) reports that in the Golf of Mexico annual losses of blue crab fisheries range from at least 20 to 100%.

Entanglement may be tied to high temporarily suffering and struggling of those animals affected. Furthermore it might pose significant threat to species or stocks. This, however, is dependant from their structure of the species or population (e.g. population growth rates). An example of critically endangered specie is the Hawaiian monk seal that with 1250 individuals remaining sees its population recovery hampered by the frequent entanglement of its juvenile exemplars (US National Academy of Science, 2008).

Another environmental harm caused by plastics is *ingestion.* The ability to reproduce an enormous range of characteristics and colours of polymers let them look like valuable food to marine life. For example, plastic bags can be taken as jelly fishes and plastic pellets as fish eggs from hungry sea animals (i.e. birds, turtles, and fishes). Ingestion may cause internal and external wounds, suppurating skin lesions, ulcerating sores, blockage of the digesting tract with consequent satiation, and starvation, as well as general debilitation leading to death (Gregory, 2009). Additionally, microplastics have the capacity to adsorb persistent organic polluters (POPs), i.e. toxic hydrophobic organic contaminants such as polychlorinated biphenyls (PBCs), dichlorodiphenyl-dichloroethylene (DDE), and nonylphenols as well as endocrine substances that, once ingested, can be transferred to the animal tissues and eventually enter into the food web, even from the basis of the food chain. The result may be the contamination of a large amount of living species, including human beings (National Academy of Sciences, 2008; Moore, 2008; Gregory, 2009). For example, small multi-coloured plastic debris (< 1 mm) is also ingested by crustacean species like krill (Moore, 2008), which are situated at the very base of the global food chain. Another problem with ingestion is the fact that once ingurgitated, the polymeric material is not removed from the world, but to the contrary, after the death of the animal concerned, it enters again into the external environment (see albatross example above).

Smothering: plastics can also damage and smother reefs, sea grasses, and mangroves, as soon as they possibly sink to the sea floor due to sediments settings. Moore (2008) states that much of the materials sinking consist of thin packaging film and have the potential to inhibit gas exchange, possibly interfering with CO_2 sequestration.

Moreover, plastics debris might damage by filling up and destroying nursery habitat where new life would otherwise emerge (UNEP, 2001).

Pelagic plastics can also form a stable substratum for colonization by marine microorganisms like bacteria, crustose organisms, tubeworms, coralline algae, and molluscs (Gregory, 2009). Due to its longevity and quantities present at sea, plastics are a much more effective mean for dispersion of these organisms, than ship hulls or ballast water (Barnes, 2005).

Passing to the social and economic impacts of plastics debris, loss of aesthetics is the most important to mention in the case of polymer-trash. For coastal communities relying on the income generated by seaside businesses, indirect costs of littered beaches can be very high (Sheavly and Register, 2007). Other economic losses are tied to the entanglement of keels and propellers of vessels, costs of cleaning up, and losses to fishery and aquaculture operations. To what concerns public safety, marine debris could consist in being hazardous to swimmers and divers that may risk cuts, abrasions, and stick (puncture) injuries, as well as assumption of leaching poisonous chemicals (UNEP & IOC, 2009) and contamination through bacteria, and infectious diseases (consider syringes found during the International Coastal Clean-up mentioned before).

What could be done in order to mitigate and prevent the impacts that marine and plastics debris? First of all a valid educational basis has to be created. This should include not only the general public, but also specific user groups such as plastics industries, all the stakeholders involved in plastics distribution, and waste management workers. Also recreational boaters, and commercial fishermen should be educated in this sense (Sheavly and Register, 2007; Ryan et al., 2009). Sheavly and Register (2007) affirm that every piece of debris and litter found in our waterways for sure involved at some point a person who made an improper decision. A critical and successful education involves also the complete understanding of the matter and the risk tied to it. This might be achieved by involving all the relevant stakeholders such as national, regional, and local authorities, various organizations (NGOs, consumer, civic, international/national, religious, and nonprofits), businesses (ranging from the touristic to the commercial ones), and the industries. Another mean to prevent, reduce and control marine debris is the right implementation and tightening of national and international legislation. There are several international agreements on waste, which are not necessarily only concerning marine debris. The Basel Convention of 1989 on the Control of Transboundary Movements of Hazardous Wastes and their Disposal is one example for it. It is a multilateral environmental agreement negotiated by the United Nations (UN) between more than 160 ratifying nations and regulating the import and export of hazardous waste. It establishes legal obligations to ensure the environmentally sound management of wastes, including plastics. There are also a multitude of bilateral or further multilateral agreements between countries concerning proper waste disposals. The European Union, for example, set up the Landfill Directive of 1999 to prevent or reduce as far as possible negative effects on the environment from the landfilling of waste, by introducing stringent technical requirements for waste and landfills (EC Environment, 2010).

With regard to international legislation on marine debris, the International Maritime Organization (IMO) set up through the London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, also known as London Convention 1972, that established international regulations restricting the disposal of wastes from aircraft, platforms, and at-sea vessels (Leous and Parry, 2005). In 1973 UN delegates, in cooperation with the IMO, began to work on MARPOL, the most comprehensive agreement to date that regulated the discharge oil as well as solid waste into the sea. Annex V of MARPOL restricts at-sea disposal of trash and banned at-sea disposal of plastics. It further requires adequate waste disposal facilities in the ports to receive waste from ships and vessels. The last important international agreement on marine debris is UNCLOS (United Nation Convention on the Law of the Sea), signed in 1982 and in force since 1994. UNCLOS recognizes that oceans are an "exhaustible and finite resource" (UNCLOS, 2010) and distinguishes it from prior agreements by addressing regulating requirements also for land-based sources of marine pollution.

Another program run under UN supervision is the UNEP Regional Seas Program launched in 1974. It addresses the accelerating degradation of the world's oceans and coastal areas "by engaging neighbouring countries in comprehensive and specific actions to protect their shared marine environment" (UNEP Seas, 2010).

However, according to scientists (Barnes et al., 2009) international regulations are not strict enough and the expected reductions of ocean-based marine debris did not occur.

The management, prevention, and reduction of problems rising from marine debris both land and marine-sourced are difficult to address. There is an increasing trend on spreading information concerning this problematic, but further efforts will have to be undertaken in order to face the issue.

IV. Conclusion

The 20th century was the century of plastics' development and growth. Today the research field in polymeric studies is almost saturated. Their molecular structure is very well known and the process of creating various types of plastics with the help of different kinds of additives is a highly controlled procedure within the chemical industry.

Plastics production is highly dependent on the petroleum industry: 4 to 5% of the global natural oil production goes into plastics industry without counting the oil needs for the gain of energy for the actual production process. This is one of the reasons why alternatives that imply the use of renewable resources are being investigated. However, this relatively new and "more bio" alternatives comprehend a very small and insignificant part of the plastics market, i.e. approximately 0.02% of the global plastics production. Moreover, the (bio)degradation rates and sustainability for those alternative plastics highly depend on the way they are produced, as well as on the additives contained in it. Either way, polymers from renewables (i.e. mostly starch from crops) or fossil resources, might encounter some problems in future due to a global plastics demand increase of 4.1% since the 1950s, with peaking rates in central Europe, CIS, and Asia (without Japan) ranging from 6 to 7.3% for the next five years. It is possible to affirm that due to the constantly growing demand, prices of the necessary raw materials will keep increasing as well. However, this problem seems to be of less concern to the general public than the need for fossil and bio fuels. This, despite the fact that plastics production is constantly increasing and these particular versatile materials are more and more successfully applied in many different fields of human activity, ranging from household items, to industry needs, to building and construction products. However, the consumer sector with the highest plastics need is packaging, followed by households, and building & construction. The study and the subsequent MFAs drafted of it for the three areas Brazil, Europe, and the US, do support this statement.

Although developing countries show much lower plastics' demand rates than developed countries, their demand is predicted to strongly increase due to technological and eventual economic improvements, and also because of their population growth. Brazil has currently an approximate demand for plastics products per person and day of 80 grams, while the Europe zone has a demand, which is almost four times higher. The US has even higher demand rates with more than half a kg plastics request per day per head. Each US citizen is estimated to consume 186 kg per year, while Brazilians only account for 28 kg a year. This, without taking into account that more than 50 million people in Brazil live under the poverty line and are therefore consuming proportionally much less plastics than the richer part of the population. According to calculations done in this study, there is a strong correlation between national income per capita and plastic demand. It was found, that the lower the GDP per capita, the lower the demand for plastic materials: while China, with an annual GDP per capita equal to 2001 US dollars, has a need of plastics of 19 kg per person per year, Germany, with 35,000 US dollars GDP per capita, has an annual demand of 194 kg plastics per person.

As a consequence of increasing plastics consumption in developed countries and in the growing economies of developing countries, currently a more urgent problem than the eventual future difficulty of finding raw materials for plastics production is plastics waste management. As very long-living materials, plastics take a long time to degrade and especially to decompose completely without leaving any residues. This might be a minor problem in technologically advanced countries with incineration facilities (e.g. some European countries such as Austria) that are even reliant on plastics as for their high calorific values that are necessary for a more efficient combustion of waste material. In comparison between Brazil, Europe, and the US, the Europe zone has the highest incineration rate (23%) and Brazil the lowest (1%). However, the problem of plastic wastes persists as in the case of landfilling infrastructure, the cheapest (in short, but not long term) and most used technique for most countries. Also in the three countries compared in this study, landfilling is the most applied solution. However, while Europe and the US make use of sanitary landfills, Brazil uses mostly uncontrolled dumping sites, which pose particular problems because of specific not degrading materials such as plastics or other toxic substances. While only 61% of the European MSW is being landfilled, the US and Brazil landfill more than 72% of their waste on landfills and, in the case of the South American country, open dump areas. Recovered plastic materials show to have a

39% rate in Europe, 25% in the US, and 20% in Brazil. However, “recovered” means either recycling or incinerating with energy recovery. While the US’ incinerates 18% of its MSW plastic wastes, Europe incinerates 23%, but recycles like Brazil approximately 16% of it. Europe and Brazil are therefore big recyclers compared to the US, but both for different reasons: the one for an efficient official MSW collection system, the other because of an efficient scavengers system.

Regarding the plight of persisting plastic waste, the problem consists in the eventual release of environmentally toxic substances and/or its erosion through various means into natural areas. Consequently, those wastes may be carried through water stream systems to the seas, the ultimate sink of littered plastics. Scientists and the international community concerned with the preservation of the (marine) environment view the increase of plastic marine debris with growing consternation. Monitoring programs all over the world and international conventions show the general acknowledgement that something has to be done against marine plastic debris. Although most of the international agreements fighting this plight were created for marine-generated waste, action should be taken at land-based sources, since it was acknowledged that approximately 80% of marine debris and especially plastics marine debris originates from land-based activities.

Finally, in order to give a better idea on plastics’ life cycle, local and national authorities as well as plastic lobbies should face the truth and investigate the rates of run-off and littering activities of plastics waste. It is undeniable that plastic materials constitute one of the bricks of the modern world, but awareness of the consequences of its littering should be enhanced and educational activities should be supported by the responsible authorities. Further, these educational activities should be based on solid and uniform studies on the plastics life cycle, not only on a national basis, but also from a wider angle, i.e. a global view.

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List of Abbreviations

ABS	Acrylonitrile Butadiene Styrene
AES	Acrylonitrile Ethylene Styrene
AMPE	Association for Plastics Manufacturers in Europe
AMS	Alphamethylstyrene
AS	Acrylonitrile Styrene
ASA	Acrylonitrile Styrene Acrylate
ASTM	American Society for Testing and Materials (US)
B&C	Building & Construction
Biodeg Polymers	Biodegradable Polymers
BPA	Bisphenol A
CA	Cellulose Acetate
CEN	European Committee for Standardization
CIA	Central Intelligence Agency
CO_2	Carbon Di-oxyde
DAP	Diallyl Phthalate
DBP	Di-butyl Phthalate
DCPD	Dicyclopentadiene
DDE	Dichlororodiphenyl-dichloroethylene
DEHP	Di-ethylhexyl Phthalate
DEN	Deutsches Institut für Normung
DIDP	Disoldecyl Phthalate
E&E	Electrical & Electronics
EPA	US Environmental Protection Agency
EPS	Expanded Polystyrene
ERRMA	European Renewable Resources & Material Association
EU	European Union
Eu PC	European Plastic Converters
EU27	European Union of the 27 States
Europe zone	European Union of the 27 States, Norway, and Switzerland
F&F	Furniture & Furnishings
HDPE	High Density Polyethylene
IMO	International Maritime Organization

IMPI	Instituto Mexicano de la Propriedad Industrial
ISO	International Organization for Standardization
JIS	Japanese Standardization Association
LCP	Liquid Crystal Polymer
LDPE	Low Density Polyethylene
LLDPE	Linear Low Density Polyethylene
MAH-g	Maleic Anhydride Grafted Polymer
MC	Methyl Cellulose
MFA	Material Flow Analysis
MM	Methyl Methacrylate
MSW	Municipal Solid Waste
NAFTA	North Atlantic Free Trade Agreement
NGO	Non Governmental Organization
NP	Nonylphenol
OECD	Organization for the Economic Cooperation and Development
OP	Ocylphenol
PA	Polyamide
PB	Polybutylene
PBC	Biphenyls
PBI	Polybenzimidazole
PBR	Polybutadiene Rubber
PC	Polycarbonate
PCL	Polycaprolactone
PE	Polyethylene
PEK	Polyetherketone
PEMRG	Plastics Europe Market Research Group
PEN	Polyethylene Naphthalate
PET	Polyethylene Terephthalate
PEU	Polyurethane Foam
PHA	Polyhydroxyalkanoate
PI	Polyimide
PK	Polyketone
PLA	Polylactic Acid
PMMA	Polymethyl Methacrylate
PMP	Polymethylpentene
POM	Polyoxzmethylene

POP	Persistent Organic Polluters
PP	Polypropylene
PPE	Polyphenylene Ether
PPS	Polyphenylene Sulfide
PPX	Polyparaxylylene
PS	Polystyrene
PSU	Polysulfone
PUR	Polyurethane
PVC	Polyvinyl Chloride
SAN	Styrene Acrylonitrile
SAS	Styrene Acrylonitrile Silicone
SMA	Styrene Maleic Anhydride
SPI	Society of Plastic Industry
SVA	Styrenic + Vinyl + Acrylonitrile
TDPA	Totally Degradable Plastic Additive
TPE	Thermoplastic Elastomer
TPU	Thermoplastic Polyurethane
TS	Thermoset
TSE	Thermoset Elastomer
TSU	Polyurethane Thermoset Elastomer
UK	United Kingdom
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNEP	United Nations Environmental Program
US	United States of America
UV	Ultra Violet Light
VOH	Vinyl Alcohol