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Why is there plastic packaging in the natural environment?

Understanding the roots of our individual plastic waste management behaviours

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Highlights

- Intention to discard waste is at the heart of the understanding of plastic pollution.
- A cost-benefit balance modulates our individual plastic waste management behaviours.
- Underestimation of plastic impacts is one explanation for individual mismanagement of waste.
- Landfilling can be linked to the persistence of old waste management behaviour.
- The study of waste reuse behaviour could be a source of innovation to improve waste management.

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Abstract

Plastic waste is now a classic contaminant of the natural environment and the origins of the contamination need to be well understood. The transition from a useful object to a waste product is a fundamental moment that, from the point of view of the scientific literature, remains poorly understood. This review therefore aims to highlight some factors controlling this intentionality, but also those that influence individual waste management behaviours. For this purpose, an original approach involving the study of the amount of knowledge within different disciplinary fields of research has been employed. The results underline that the low direct impact of the consequences on their users of the discarding of plastic packaging seems to be an important reason for individual mismanagement. Furthermore, the modern individual behaviours of the discarding of plastics are often deeply rooted in the past of the populations. Policies to reduce waste disposal come up against strong individual behavioural constraints that limit the proper management of plastic waste. Thus, incivilities, difficulty in enforcing sanctions, or public opposition to changes in waste management are all factors that contribute to the maintenance waste discarding behaviour. The reuse behaviour of objects that have become useless is also historically attested, but has tended to disappear with the rise of the consumer society. This type of behaviour, whose valorisation is a way of reducing plastic waste abandonment behaviour, remains, however, less scientifically studied than other ways such as recycling.

Keywords

Plastic waste, waste management behaviours, waste management history, environment

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1. Introduction

1.1. The rise of plastic packaging

Over the millennia, ceramic, glass, wood, wicker and textiles have been the main materials used for containing and trading organic products and materials until the recent invention of plastics which marked the dawning of a new era (Fig. 1) (Bevan, 2014). Different properties explain the rise of plastics after the Second World War such as their extremely large physico-chemical properties that enable it to be applied to a wide range of applications at a cost that is often lower than traditional alternatives (e.g. metal, glass, ceramic). Plastics are also very simple to process, making easy to manufacture them in a wide range of objects. Thus, from the 1950s onwards, food packaging and containers, which had previously been made with traditional materials, were increasingly made from plastic materials, thus allowing better preservation of foodstuffs (Risch, 2009). At the same time, the world population increased sharply from 2.5 billion to 7.6 billion between 1950 and 2017 (United Nations, 2017). These populations also moved, migrating from the countryside to the cities where they tended to concentrate (Cheng and Urpelainen, 2015). Thus, between 1950 and 2019, the world population living in urban areas increased from 30% (751 million inhabitants) to 55% (4.2 billion inhabitants) (United Nations, 2018). These populations have increasingly easy access to consumer society, implying an increasing accessibility to consumer goods and services (Paek and Pan, 2004). These three factors (i.e. replacement of traditional manufacturing materials by plastic, increase and concentration of populations, and access to a consumer society) are widely responsible for the increasing use of plastic materials in packaging.

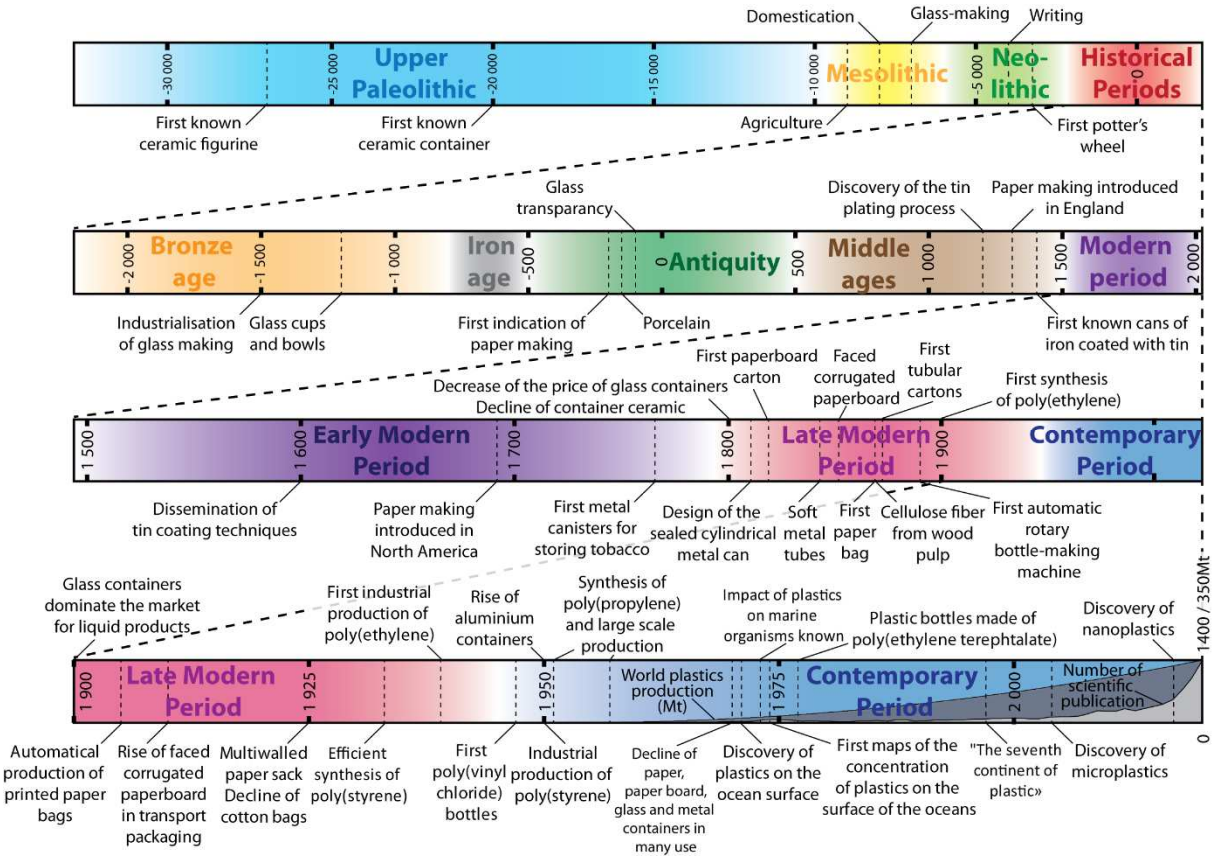

Fig. 1. Time lines of packaging history (data from Berger, 2003; Risch, 2009). The first ceramics used to preserve food were dated to the Upper Palaeolithic Period and were widely used for this purpose until the 19th century, after which their use gradually declined. The use of glass is also ancient since the first traces of its industrialisation can be found as early as the Bronze Age in Egypt. From this period, manufacturing techniques were constantly improving, but it was not until the 19th century that the reduction in the cost of manufacturing glass containers made glass containers accessible to a larger part of the population. It was also in the 19th century that cardboard packaging and paper bags were invented. Finally, the first metal cans were developed at the beginning of the 19th century. These new kinds of packaging, which made it possible to preserve food efficiently and facilitate its transport, experienced a major increase in demand until the beginning of the second half of the 20th century. Plastic materials then began to be mass marketed, passing from 1.7 Mt in 1950 to 348 Mt in 2017 (PlasticsEurope, 2018, 2013, 2012). Their physico-chemical properties made it possible, among

other things, to replace glass bottles, paper bags and cardboard. In the end, food packaging will extensively be made of plastic materials. As early as the 1970s, the presence and impacts of plastic waste were observed in the natural environment and from this period, continuous scientific research on plastic pollution began. Nevertheless, it was not until the end of the 2000s that this topic became fully important (Data: Scopus database; Key words: 'plastic' and 'pollution').

1.2. Voluntary abandonment of plastic waste: a source of plastics pollution

First discussed in the 1980s, the amount of knowledge about the sources of plastic waste in the environment has continuously increased since then (Li et al., 2016; Pruter, 1987). These sources are originally divided into two categories: those of accidental origin and those resulting from voluntary human actions. While accidental sources may sometimes be identified as they occur, the individual behaviour of the discarding of plastic waste, although closer to our daily lives, is much more dispersed in the scientific literature. Thus, the transition from 'object' to 'waste' is poorly understood, despite the fact that it is one of the fundamental sources of plastic pollution. According to the United Nations, waste can be defined as 'materials that are not prime products […] for which the generator has no further use in terms of his/her own purposes of production, transformation or consumption, and of which he/she wants to dispose' (Department for Economic and Social Information and Policy Analysis, 1997). Similarly, the European Union defines waste as 'any substance or object which the holder discards or intends or is required to discard' (European Union, 2008). In these two cases, the intention to discard an object is a central idea to define the waste, perhaps even more than the action itself.

1.3. From plastic waste to pollution

Approximately 50% of plastic objects made are intended for single use and only 20% to 25% for long-term use (Geyer et al., 2017; Hopewell et al., 2009). Thus, as the use of plastic materials

has increased, the quantities of waste generated have also increased: of the 8,300 million tonnes of plastic produced worldwide between 1950 and 2015, 4,900 million tonnes were discarded (Geyer et al., 2017). Despite the potential for recovery, about 50% of the plastics produced are of too little value for their recovery to be economically viable. Finally, less than 2% of the plastic waste produced since the 1950s has been recycled, less than 6% incinerated and the vast majority (about 92%) has been landfilled or disposed of in the natural environment (Fig. 2) (Geyer et al., 2017). However, plastic waste is not limited to continents since approximately 4.8 to 12.7 million tonnes of plastic ends up in the oceans each year (Agamuthu et al., 2019). However, unlike natural organic material such as wood, plastic materials degrade very slowly in the environment. Thus, it is likely that a few decades to a few centuries will be necessary for plastics to degrade if the environment is favourable in terms of physical, chemical and biological conditions. As a result, plastics tend to accumulate in the environment and are not harmless to it (Ballerini et al., 2018; Brandon et al., 2019). This implies implementing the necessary means to reduce their impact, but also to be able to understand the reasons why human beings do not manage their plastic waste properly.

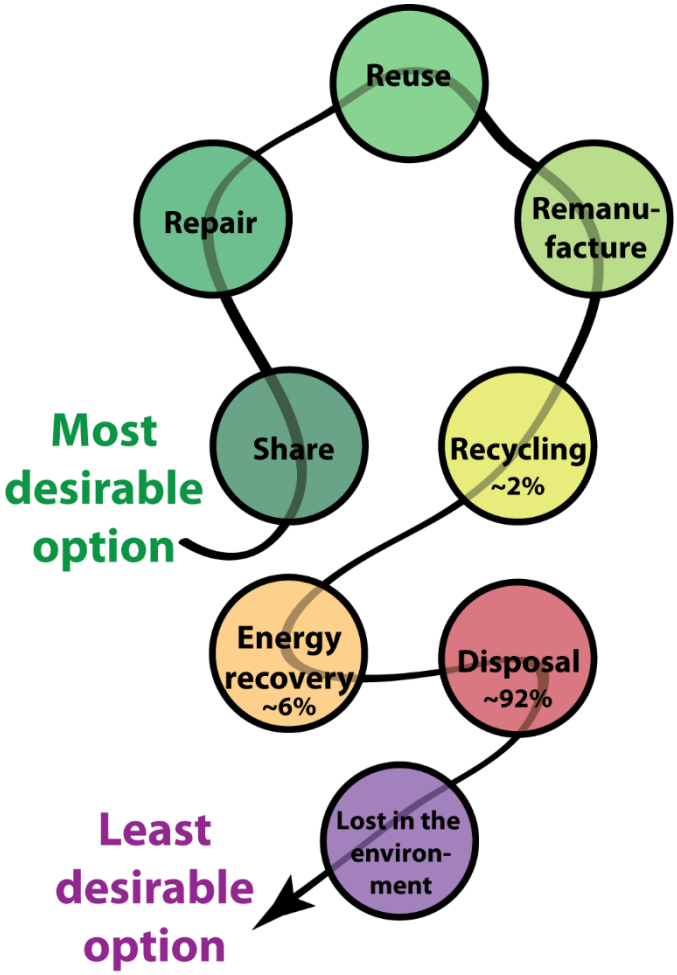

Fig. 2. Waste management hierarchy (modified after Davies, 2016 and Geyer et al., 2017).

1.4. Objectives

The objective of this article is therefore to synthesise scientific knowledge on some of the factors that control this intention to dispose our plastic objects, and on those that influence the way we dispose of our waste. Thus, the objective of the first part of the article is to explain why our perception of the risks associated with plastic waste discarded in our environment modulates the way we manage our plastic waste. The second part aims to present more specifically the origins of landfilling and the limits of the means conventionally implemented to fight against this type of practice. The objective of the third part is to present the case of reuse behaviour, and why this type of behaviour constitutes an underestimated way to fight against

plastic pollution. Finally, we introduce a synthesis, summarising the main elements highlighted by this publication.

This article will also propose an original approach by introducing and illustrating the main elements highlighted by examples from different fields such as ethology, archaeology and history.

2. A cost-benefit balance that modulates our individual plastic waste management behaviours

2.1. Risk avoidance mechanisms: general cases

The risk of infection by parasites is a significant threat to many living organisms and behaviours allowing to avoid this risk is often a first line of defence (Buck et al., 2018; Hart, 1990). Humans generally avoid objects that they believe to be contaminated by potential parasites, and tend to eliminate waste that can harbour or feed parasitic organisms (Curtis, 2014). Disgust is an emotion that is considered as one of these strategies for avoiding pathogens (Buck et al., 2018). It can be induced by different stimuli from senses such as sight, taste and smell (Buck et al., 2018; Hart, 1990). This emotion is a powerful way for the body to avoid a situation presenting a risk of contamination by parasites (Buck et al., 2018; Hart, 1990; Weinstein et al., 2018). This can be illustrated by shell middens (i.e. large accumulations of shellfish observed on the coasts around the entire world), which is interpreted by archaeologists as a desire to remove the organic remains whose decomposition can be a source of bad smells from living areas (Barton, 2002). Avoidance strategies originate both from innate reflexes, and also in learning from cultural origins or through the experience acquired by the organism (Curtis, 2007). The development of avoidance strategies acquired at a personal or societal level can be illustrated by the example of the major epidemics of the Middle Ages. Thus, waste, particularly organic waste, had a negative impact on the quality of life of people living in the Middle Ages. It is for example the case of organic residues that infiltrated the soil and contaminated drinking water

resources (Leguay, 1999). These poor health conditions probably favoured the spread of the Black Death, which ravaged Europe from 1347 to 1351 (Tammemagi, 1999). At the end of these epidemics, the link between heaps of waste and diseases appears in many testimonies (Leguay, 1999). Similarly, it appears from that period that the neighbourhoods the most exposed to waste are more often and more severely affected by disease. The origins of epidemics were unknown at the time and the attributions were often multiple, but the senses, particularly taste and smell, took on an increasingly important role in the perception of the danger posed by waste from this period (Leguay, 1999).

Avoidance behaviours are modulated by a cost-benefit balance (Weinstein et al., 2018). Thus, if the maintenance of a healthy community and a healthy environment is an important motivation for individuals to properly manage their waste, the perceived cost to the individual must be acceptable in relation to the perceived benefit (Davies, 2016; Weinstein et al., 2018).

2.2. Out of sight, out of mind?

Of all the waste generated every day, plastic materials are probably not the most disgusting. These materials are recent on the evolutionary time scale (PlasticsEurope, 2015) and are therefore not the subject of innate avoidance behaviour on the part of living beings, as shown by the numerous cases of plastic waste ingestion described in the scientific literature (Boerger et al., 2010; Colabuono et al., 2009; Fossi et al., 2016; Nicolau et al., 2016). In addition, most plastic materials can be considered relatively inert on a time scale of a few months to a few years (Hamid, 2000; Hamid and Amin, 1995). Thus, plastic materials do not follow the same degradation processes, such as putrefaction processes for example, which are observable for other biological materials and for which we have an instinctive aversion. Their ageing in our environment does not cause any particular odours for human beings either. Smell, which plays such an important role in the processes of disgust, has no role here. Although specific bacterial communities are known to develop on the surface of plastics, no associated risk has ever been

shown (Amaral-Zettler et al., 2015; Dussud et al., 2018; Frère et al., 2018; Zettler et al., 2013). Thus, in the first approach plastic materials do not seem likely to activate avoidance mechanisms likely to initiate particular plastic waste management behaviours.

However, while the direct consequences of plastics waste mismanagement for the individual are modest, the consequences for the environment and ecosystems are greater. For example, the ingestion of nano- and microplastics by planktonic organisms affects a wide range of functions such as reproduction, growth or feeding behaviour (Besseling et al., 2014; Cole et al., 2015). The ingestion of plastics has an energy cost for organisms that can result in reduced growth, reproduction and health of the organism (Sussarellu et al., 2016; Watts et al., 2015). However, while the ingestion of plastic can be observed by an informed fisherman, when cleaning his catch for example, these kinds of impacts can only be highlighted by scientific means. In addition to direct impacts during ingestion, it should also be noted that plastics interact with additives and micropollutants in the natural environment. Some additives pose significant risks to the environment and health such as DEHP, an endocrine disruptor commonly used as plasticisers in PVC, and which desorbs during the plastic ageing process (Doyle et al., 2013; Jeddi et al., 2015; Kedzierski et al., 2018; Manikkam et al., 2013). Plastics also adsorb micropollutants in water such as metals (Boucher et al., 2016; Brennecke et al., 2016; Holmes et al., 2014, 2012), endocrine disruptors (Fossi et al., 2014, 2012) or persistent organic pollutants (Bakir et al., 2012; Lee et al., 2013; Rios et al., 2007). The ingestion by living organisms of contaminated plastics could therefore constitute an additional pathway for these pollutants, although this type of transfer is probably very secondary to micropollutant transfers occurring between an ingested prey and its predator (Galafassi et al., 2019; Rist et al., 2018). Most of these risks associated with plastic waste are unknown to the general public. Thus, while plastic waste has a clear impact on the marine environment and ecosystems (Wright et al., 2013). These impacts are not very sensitive from a human point of view and, even if they can

be intellectualised, they are still far removed from the everyday life of users of plastic. This is undoubtedly a key to understand plastic pollution (Science Advice for Policy by European Academies, 2019): by not understanding the impact of plastic waste on the natural environment and by not feeling its impact, users restrict their management efforts to a minimum. This type of psychological limitation was also identified in studies on factors limiting behavioural change in the context of climate change (Dietz et al., 2007; Gifford, 2011; van der Linden et al., 2015).

2.3. Two particular cases?

While it is likely that the avoidance mechanisms, which normally play an important role in our individual waste management, may not be conducive to the proper management of plastic waste, two particular cases are worth mentioning.

In Europe, nearly 40% of the demand for plastic materials comes from the packaging industry (PlasticsEurope, 2018). Most of the plastic materials used in packaging are impermeable to fluids (e.g. blood, fats, drinks) present in food. Nevertheless, traces of these foods can generally be observed only on the surface of the plastic material. Thus, expanded (EPS) and extruded (XPS) poly(styrene) are very often used for food packaging because of their excellent insulating properties, impact resistance and light weight. These materials also have good impermeability to biological fluids despite their very porous structure. The presence of food residues on their surface leads to the necessary management of these wastes to avoid the appearance of odours related to maceration of organic residues. This is the case, for example, for fish trays where organic residues can quickly generate unpleasant odours. This immediate management is also important to avoid the appearance of species attracted by organic residues such as flies, or to limit handling once parasites have contaminated the packaging. Thus, the classic behaviour is to quickly manage this packaging waste in a confined space or at least to keep this packaging waste away from living spaces. Thus, people are more sensitive to health risks, as well as to waste odour issues, than to maintaining a preserved natural environment (Tadesse et al., 2008).

In the case of plastic waste that has been in contact with food, avoidance mechanisms are therefore likely to be involved in waste management behaviours, however, in an indirect way.

Plastic waste on beaches or in exceptional natural sites illustrates a second potential example of waste avoidance behaviour (Kaseva and Moirana, 2009). The environmental quality of a beach is often a major concern for tourists (Santos et al., 2005). Apart from affecting the recreational capacities of the environment, most of the plastic waste observed in the natural environment does not pose a direct threat to human beings. However, this waste is perceived as 'disgusting' by some users, while others at the same time do not pay attention to it. It seems that certain cultural or experiential aspects of each individual contribute to the perception of these wastes and make the intensity of the experienced discomfort vary from one person to another. In addition, this type of behaviour has economic consequences since the presence of a considerable amount of waste on beaches can result in avoidance behaviours: summer visitors tend to avoid or no longer return to beaches contaminated by plastic waste (Free et al., 2014; Retama et al., 2016; Stolte et al., 2015).

3. Uncontrolled landfilling

3.1. A behaviour deeply rooted in time

In the epidemic context of the end of the 15th century in Europe, hygienic trends appear and lead to waste management measures being taken (Leguay, 1999). Thus, in the cities of 12th, 13th and 14th century England, household or commercial waste piles were not allowed for more than a few days in the city (Schofield, 2002). In France, a city like Amiens had a waste disposal service and the regulations required that this waste must be disposed of outside the city before sunrise (Leguay, 1999). Waste is often exported out of the city, and is either dumped into rivers or transported to areas of natural or artificial depressions (e.g. wells) (Bertolini, 2002).

If in the Middle Ages the export of waste from the cities and its abandonment in the natural environment was considered an adequate management measure, nowadays this type of management is to be proscribed. However, similar mismanagement behaviours are still observed even in the most developed countries. In France, for example, local political actors consider that this type of waste mismanagement has been constant or even increasing over the last ten years or so (ADEME and ECOGEOS, 2019). Packaging waste is often observed in the terrestrial environment in a diffuse manner, but with a high frequency. Packaging waste is often abandoned along roadsides, or near voluntary waste drop-off receptacles. While it can also be abandoned in natural environments, this type of waste is more frequently observed in urban areas and are mainly discarded by the inhabitants of the territory or surrounding areas. They are therefore most of the time abandoned in the immediate vicinity of the place of use.

3.2. Resistance of populations to good waste management practices

3.2.1. Incivility

Incivility is the main reason evoked by local actors to explain uncontrolled landfilling (ADEME & ECOGEOS, 2019). Public archives of the Middle Ages testify to complaints against individual selfishness and denounce the laxity of law enforcement officials (Leguay, 1999). These complaints were particularly numerous during the 15th century, when the sharp increase in urban populations, as well as epidemics, probably contributed to an awareness of the risks associated with dumping waste on the streets (Leguay, 1999). The lack of awareness among populations of the impact that waste disposal has on the environment and ecosystems is known to be a source of reluctance to change practices. Thus, in Ethiopia, environmental security is a secondary concern for its population (Tadesse et al., 2008). Furthermore, in the particular case of packaging waste, it is often even less of a concern to local authorities than other wastes. In France, the involvement of the police and the judiciary is therefore often less than for other wastes (e.g. asbestos) (ADEME, 2007). The release of waste into the environment may be partly

308 due to a lack of knowledge among the population about the impact of this waste on the
309 environment and its ecosystems (Pettipas et al., 2016). In the case of plastic waste, it has been
310 shown that awareness-raising actions on the theme of plastic pollution, as well as the
311 identification of human behaviour that has a negative impact on the environment, can facilitate
312 behavioural changes (Mcnicholas & Cotton, 2019). More generally, prevention actions ranging
313 in communication actions and the setting up of collection systems are generally developed by
314 local actors. However, these actions are judged to be moderately effective by those working in
315 the field (ADEME & ECOGEOS, 2019).

316 #### 3.2.2. Sanctions

317 The texts of the Middle Ages also highlight the struggle for the authorities to impose the policies
318 necessary to preserve public health. Indifference, hostility of residents disturbed in their habits
319 or forced to take responsibility for keeping clean roads often limits the impact of the decisions
320 taken (Leguay, 1999). Sanctions have often been proposed to impose virtuous waste
321 management behaviours on populations. However, waste regulations appear in the archives of
322 many European cities, but were rarely enforced by residents. Active policies involving
323 sanitation measures, the relocation of polluting activities, the cleaning of watercourses and the
324 development of cleaning and street state management services seem to be more successful
325 (Leguay, 1999). Thus, while in the Middle Ages repressive policies appeared, they generally
326 remained ineffective (Leguay, 1999). Nowadays, the lack of sanctions that could encourage
327 good behaviour is commonly cited by local authorities as a major limit to good practice
328 (ADEME and ECOGEOS, 2019). According to this report, in France sanctions are often
329 initiated by local authorities and sometimes by national entities. They most frequently consist
330 of a reminder of the law, the establishment of infringements and the lodging of a complaint.
331 The contraventions, disciplinary sanctions and reports to higher authorities are much rarer.
332 However, these sanctions face many difficulties. First of all, the identification of the responsible

is difficult and requires significant resources (e.g. video surveillance), whereas it is considered by those working in the field as one of the most effective means of reducing this type of pollution. In fact, complaints are often dismissed for lack of a responsible person. Furthermore, sanctions, where they can be applied, are often considered to be too lenient and not very dissuasive. These procedures are also often complex and difficult for local authorities to carry out. Moreover, the procedures are often very long, which limits their effectiveness. Thus, these authorities often lack of resources not only to implement these procedures, but also to enforce these sanctions. The final limitations are organisational: the distribution of competences and powers can be complex to allocate and implement by the different actors involved.

3.2.3. Impacts of collection facilities on uncontrolled landfills

The possibilities for collecting plastic waste have an influence on the discharge of waste into the natural environment or the creation of uncontrolled landfills (ADEME and ECOGEOS, 2019). These include the cost of proper waste management, the distance to waste management centres and public opposition to the establishment of waste management infrastructure.

The problem of waste management costs can be identified in certain texts of the European Middle Ages. For example, waste management initiatives suffer from financial problems, as illustrated by documents from this period describing the difficulties of raising taxes and financing cleaning services in cities. (Leguay, 1999). The question of the cost of waste management was a clear limiting factor to its proper management, and it is still an important issue. Consequently, the most common solution used by populations is to discard waste in natural depressions, rivers, near roads or on land with a low market value (Tadesse et al., 2008). Then, it is often local actors who bear the costs of managing and cleaning up abandoned waste. In the case of beaches frequented by tourists, to limit the economic impact on tourism-dependent economic activities that this kind of behaviour has, clean-ups are generally organised by volunteers or local authorities. The costs of cleaning actions can sometimes be compensated

when the perpetrators of the pollution are identified. However, as they are difficult to identify, the final cost often lies with the local population and, if it does not have the human and financial means, then the pollution is not eliminated properly. At the global level, the amount of waste management infrastructure is often too small in relation to needs, in particular because of the costs involved in good waste management.

The extensive use of pottery such as amphoras has sometimes led to significant accumulations of waste. For example, Monte Testaccio in Rome is entirely made of 30 and 50 million amphora broken between the first century BC and the third century AD and forming an artificial hill of 600,000 m3 (Havlíček and Morcinek, 2016). Modern landfilling is a continuous practice of collective waste disposal practises in specific areas and currently the most common and economical solution of waste management (Geyer et al., 2017). In modern times, and more particularly between 1960 and 2002, the mass of household waste collected increased threefold in line with the gradual increase in the population, but also because of the increase in plastic consumption, as well as the best waste collection methods (Miller, 2009). At the same time, waste regulations were becoming increasingly stringent, leading to a gradual decrease in the number of landfills from about 8,000 in 1988 to 1,654 in 2005 (Miller, 2009). A similar observation can be made in some European countries such as France, where between 1990 and 2013, the amount of household waste storage centres decreased from 500 to around 220 (Haeusler et al., 2017). This reduction in the number of sites may in some cases have led to the exclusion of part of the population, particularly rural populations, from landfilling sites, which are not very efficient from the point of view of good waste management, but have very low management costs. In some cases, this may have encouraged the return of uncontrolled landfills. In general, the reluctance to pay for efficient waste management is also one of the major points to explain the existence of some uncontrolled landfills (ADEME and ECOGEOS, 2019).

Reluctance to develop waste management infrastructure can also be observed in some particular context. Waste collection, for example, implies the existence of containers that must be as close as possible to the areas where waste is generated. If the effort to reach the containers is too great, waste is often dumped outside the collection areas. Populations may also oppose the establishment of a collection area, if it is considered too close to residential areas (Tadesse et al., 2008). Thus, sanitary risks, unpleasant smells and inconveniences associated with the presence of this waste are cited by Ethiopian populations to explain the reluctance of using collection facilities. Thus, in this context, the cost-benefit balance is unfavourable to good waste management.

4. Reuse: a (lost) cultural legacy

The question of the management of packaging and food container waste is a long-standing issue. In this context, the reuse of materials was most widely used before final disposal.

4.1. Management of ceramic packaging waste in the past

If ceramic techniques appeared as early as the Palaeolithic period, it was not until the diffusion of Neolithic pottery that ceramic-based waste appeared in archaeological records (Fig. 2) (Rice, 1999; Vandiver et al., 1989; Wu et al., 2012). With them, the first non-degradable packaging waste appears. As early as the 19th century, the Italian geologist Antonio Stoppani proposed considering ceramic fragments as one of the possible markers of the ‘Anthropozoic’ era due to the high amount of ceramic he found in soils (Stoppani, 1873; Turpin and Federighi, 2012). However, despite their durability, the length of time of their use is sometimes relatively similar to that of a comparable modern packaging. Thus, the duration of the use of an amphora during the Roman Empire is in the order of a few months to a year, comparable to that of modern plastic bottles (Geyer et al., 2017; Peña, 2007). Their relative fragility exposes them to the risk of breakage and since the generated debris were generally quickly disposed of (Bertolini, 2002).

These breakages are often reused to make a floor or wall, or crushed for the manufacture of new building materials or to fill a topographic depression (Bertolini, 2002; Peña, 2007).

4.2. The transition to the consumer society

Waste management choices can be related to different demographic factors such as the level of education, house size, or age of the individual (Tadesse et al., 2008). To the extent that these parameters change over time, the associated behaviours also change. Thus, behaviours involving the reuse of functioning objects and the discarding of damaged and useless objects into the natural environment are deeply rooted in the generations born before the arrival of the consumer society (Yukalang et al., 2018). For those born afterwards, reuse behaviours decrease while those involving the discharge of waste into the environment persist, especially when waste management infrastructure is weak or difficult to access (Tadesse et al., 2008). Considering an object that is perfectly functional to be waste, or that could easily be diverted from its original use, seems to be a major step backwards when compared to the practices observed in the history of mankind. Many reasons can explain why a still functional plastic object is considered as waste. Examples include a low market value or the perception of this object, considered cumbersome or unnecessary at a given time. This is the case, for example whose actual duration of use (*i.e.* a few weeks to a few months) is no longer correlated to the potential duration of use of the object (*i.e.* a few years to a few decades) (Geyer et al., 2017).

4.3. Reuse behaviour: an under-exploited source of innovation to improve plastic waste management?

In developing countries, object reuse is the main management behaviour far ahead of reducing consumption or recycling (Innocent Sinthumule and Helen Mkumbuzi, 2019; United Nations Development Programme, 2018). This is due in particular to the fact that waste is more easily perceived as having a value and can therefore be a source of income (Yukalang et al., 2018).

However, despite the predominance of this type of behaviour, scientific knowledge about it is comparatively lower than that of recycling (Barr et al., 2005; Corral-Verdugo, 2003; Kaplan et al., 2018). For example, whether it is for articles on recycling or reuse, in both cases, about 70% of these publications were made by countries with a very high Human Development Index (HDI) [0.8-1.0], but which account for about 20% of the world's population (UNDP, 2019; United Nations, 2019) (Fig. 3). Countries with a high HDI ([0.7-0.8]) account for about 20% of the publications. Nevertheless, this result is skewed by the fact that China published between 65 and 70% of these publications. The share of scientific publications from countries with HDI below 0.7 is less than 5% for a population of about 3 billion people (about 42% of the world's population). Thus, global scientific research on these behaviours is therefore mainly carried out by the richest countries and probably reflects their needs (recycling rather than reuse). This imbalance leads to a profound lack of knowledge about one of the most important practices involved in the reduction of plastic pollution. Thus, one of the main modes of waste management is poorly documented from the scientific point of view, whilst this type of information could contribute to the development of relevant solutions contributing to the fight against plastic pollution.

Fig. 3. Although reuse behaviours are very common in many countries (Innocent Sinthumule and Helen Mkumbuzi, 2019; United Nations Development Programme, 2018), scientific publications including the terms 'recycling' and 'behaviour' in their titles are 4 to 5 times more

numerous than titles including the terms ‘reuse’ and ‘behaviour’ (data from the SCOPUS database for the period 1985-2019, search carried out on 21 January 2020).

5. Synthesis and conclusions

5.1. The weight of the consequences

The use of plastics takes place in a particular context in the history of mankind: that of the consumer society. Thus, the extensive use of plastics combined with a marginal rate of reuse and recycling has generated significant quantities of plastic waste. Some of them are the result of voluntary disposal, while the other has an accidental origin. The intention and manner of disposing of waste are therefore at the heart of the understanding of plastic pollution. Necessity and uselessness are two elements often put forward to explain the disposal of waste. This necessity to discard waste has much to do with the importance of human beings avoiding risks of injury and infection. To this end, communities developed laws that make it easier to maintain a good quality living environment. Thus, in an epidemic context, hygienic trends emerge or become stronger, and this sometimes leads to specific waste management measures. In the absence of an objective measurement of the risks associated with waste, the senses play a fundamental role in the perception of this risk. These senses can lead to disgust, a feeling that plays a very important protective role, especially against pathogens. This feeling is rooted both in innate reflexes, in our culture, but also in our learning. In the case of plastic waste, the associated risks are new, little known by people and the consequences are not very sensitive in everyday life. Thus, the studies carried out on the impact of plastic waste and microplastics show that if they have consequences on humans, these are mostly indirect and therefore not very obvious from an individual point of view. The underestimation of the social and environmental impact of plastic waste disposal is a part of the explanation for this poor management behaviour. Thus, the dumping of plastic in the natural environment too often remains an act whose consequences are considered harmless.

It also means that the perception of plastics pollution can provide positive feedback on our waste management behaviour. A complex balance must therefore exist between the perceived level of pollution and the way we manage plastics waste. A better understanding of the mechanisms of this balance may help to identify new approaches to address plastics pollution.

5.2. Behavioural issues

It is also possible to see the discarding of plastic waste in the natural environment as the persistence of ancient waste management behaviours. In developing countries, a shift has taken place in the chemical composition of everyday objects with the replacement of traditional materials by plastic materials. At the same time, persistence in the habits of waste management (being discarded on the periphery of urbanised areas or directly in the natural environment) is observed and illustrated by the dumping of plastics in the environment, even in the most developed countries.

Where they exist, management efforts may be limited by a combination internal or external user factors. Internal factors may include selfishness, indifference to the consequences, or hostility to actions that will disrupt user habits or force users to take responsibility. For example, measures aimed at installing infrastructure for the collection, landfilling, incineration or recycling of plastic waste may be the subject of 'not in my backyard' behaviours. The availability of these waste collection points and waste treatment sites is, however, a major lever for reducing uncontrolled dumping of plastics. At the same time, repressive policies to fight against poor waste management behaviour are not very efficient as they are often difficult to make effective. Active policies including, for example, awareness-raising among the population, seem more efficient, but have a cost that is sometimes difficult to justify, especially in the poorest countries.

5.3. Ways to reduce waste abandonment

Various emerging ways would make it possible to reduce these individual behaviours. One potential path consists of delaying as long as possible the moment when a plastic object is considered useless by its owner. To do this, several lines of thought can be proposed. First of all, facilitate the conversion of the object for another use. This must be considered as soon as the industrialist thinks about the design of the object. The idea is to identify how an object whose initial use is very limited in time (e.g. <1 year), but durable enough to serve for several years, can be diverted from its initial use for other functions. Next, it is necessary to replace single-use objects such as cutlery or plastic bags with objects designed to withstand several dozen or several hundred phases of use. Banning certain single-use plastic objects is now quite common in many countries around the world. It is also necessary to promote the reuse of the material by avoiding, for example, overly complex formulations and additives that are dangerous for humans and the environment. Finally, it is necessary to restore the value of plastics (e.g. taxation of the plastics that have the greatest impact on man and the environment). Increasing the value of plastic waste and turning it into a source of economic income is an interesting way of encouraging more virtuous behaviour.

It is also important to be able to identify the authors of waste abandonment. For many stakeholders, this issue is an important barrier in the fight against illegal dumping of plastic waste. A reflection should therefore be conducted on the issue of individual traceability of plastic waste in order to identify its last owner. A data file associating the owner and an individual barcode present on the plastic packaging could, in accordance with state legislation, be a relatively simple way for field actors to identify the last owner of a waste.

The factors that control our individual plastic waste management behaviours are numerous and others would benefit from further research. One example is the impact of public policies on our plastic packaging management behaviours. It would also be very interesting having a more global vision of the cultural elements that promote or discourage virtuous waste management

behaviours. The acquisition of new scientific knowledge on the issue of plastic pollution is fundamental to determine the most relevant solutions. However, if the dynamics are well underway in the 'hard' sciences, the contributions of the humanities and social sciences remain comparatively marginal on this theme. An important investment in favour of the humanities and social sciences applied to the problem of plastic pollution therefore appears indispensable.

Garbage archaeology applies the principle of the study of the rubbish testimonies (Rathje and Murphy, 2001). In this sense, garbage is a legacy and a study topic for the knowledge of the way of life of our ancestors. Our descendants will have to face a daunting legacy and will seek the reasons why we were unable to find strategies to effectively solve the problem of plastic end of life.

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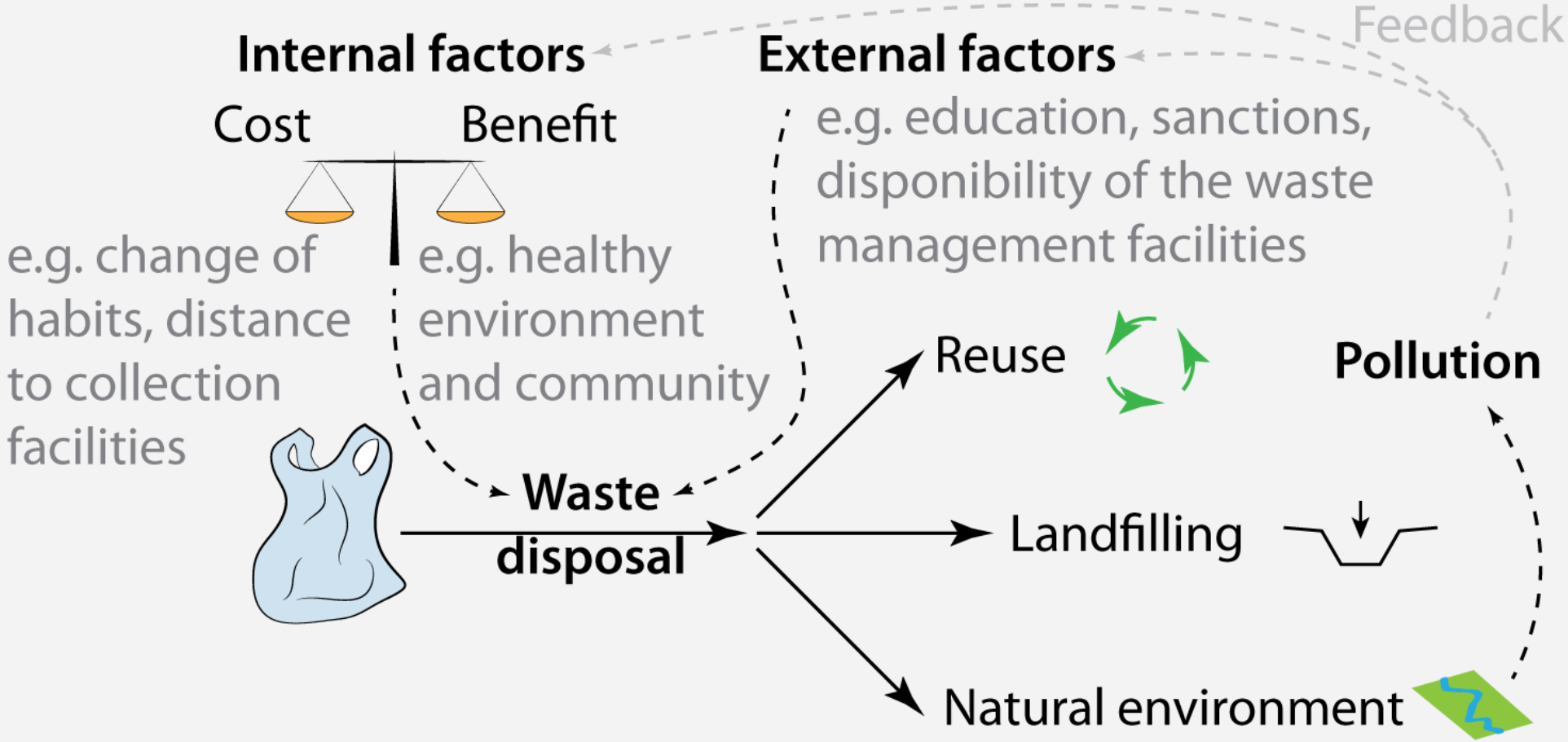
Feedback
Internal factors
External factors
Cost
Benefit
e.g. education, sanctions, disponibility of the waste management facilities
e.g. change of habits, distance to collection facilities
e.g. healthy environment and community
Reuse
Pollution
Waste disposal
Landfilling
Natural environment