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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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1 **Why is there plastic packaging in the natural environment?**

2 **Understanding the roots of our individual plastic waste management behaviours**

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12 **Highlights**

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

20

21

22

23 **Abstract**

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

41 **Keywords**

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

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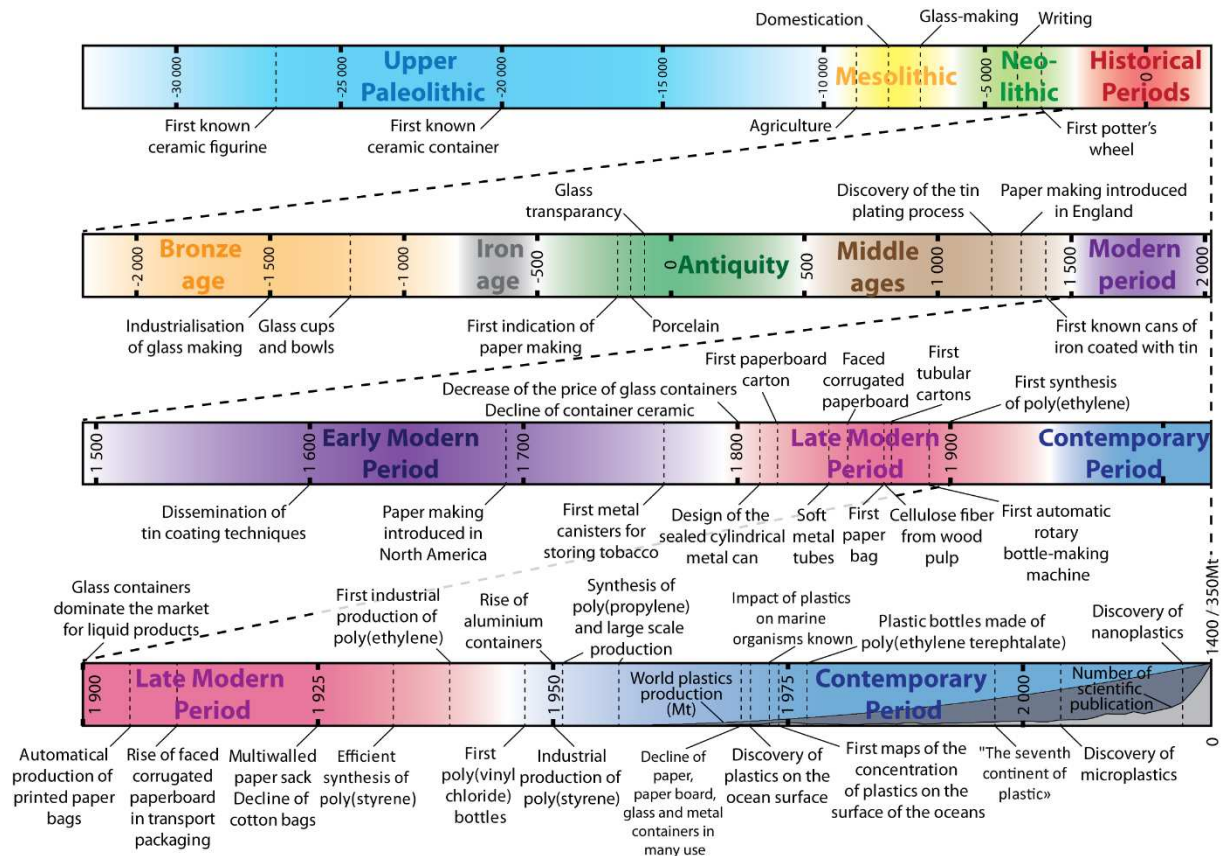
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76 1. Introduction

77 1.1. The rise of plastic packaging

78 Over the millennia, ceramic, glass, wood, wicker and textiles have been the main materials used
79 for containing and trading organic products and materials until the recent invention of plastics
80 which marked the dawning of a new era (Fig. 1) (Bevan, 2014). Different properties explain
81 the rise of plastics after the Second World War such as their extremely large physico-chemical
82 properties that enable it to be applied to a wide range of applications at a cost that is often lower
83 than traditional alternatives (e.g. metal, glass, ceramic). Plastics are also very simple to process,
84 making easy to manufacture them in a wide range of objects. Thus, from the 1950s onwards,
85 food packaging and containers, which had previously been made with traditional materials,
86 were increasingly made from plastic materials, thus allowing better preservation of foodstuffs
87 (Risch, 2009). At the same time, the world population increased sharply from 2.5 billion to 7.6
88 billion between 1950 and 2017 (United Nations, 2017). These populations also moved,
89 migrating from the countryside to the cities where they tended to concentrate (Cheng and
90 Urpelainen, 2015). Thus, between 1950 and 2019, the world population living in urban areas
91 increased from 30% (751 million inhabitants) to 55% (4.2 billion inhabitants) (United Nations,
92 2018). These populations have increasingly easy access to consumer society, implying an
93 increasing accessibility to consumer goods and services (Paek and Pan, 2004). These three
94 factors (i.e. replacement of traditional manufacturing materials by plastic, increase and
95 concentration of populations, and access to a consumer society) are widely responsible for the
96 increasing use of plastic materials in packaging.



97

98 Fig. 1. Time lines of packaging history (data from Berger, 2003; Risch, 2009). The first
 99 ceramics used to preserve food were dated to the Upper Palaeolithic Period and were widely
 100 used for this purpose until the 19th century, after which their use gradually declined. The use of
 101 glass is also ancient since the first traces of its industrialisation can be found as early as the
 102 Bronze Age in Egypt. From this period, manufacturing techniques were constantly improving,
 103 but it was not until the 19th century that the reduction in the cost of manufacturing glass
 104 containers made glass containers accessible to a larger part of the population. It was also in the
 105 19th century that cardboard packaging and paper bags were invented. Finally, the first metal
 106 cans were developed at the beginning of the 19th century. These new kinds of packaging, which
 107 made it possible to preserve food efficiently and facilitate its transport, experienced a major
 108 increase in demand until the beginning of the second half of the 20th century. Plastic materials
 109 then began to be mass marketed, passing from 1.7 Mt in 1950 to 348 Mt in 2017
 110 (PlasticsEurope, 2018, 2013, 2012). Their physico-chemical properties made it possible, among

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

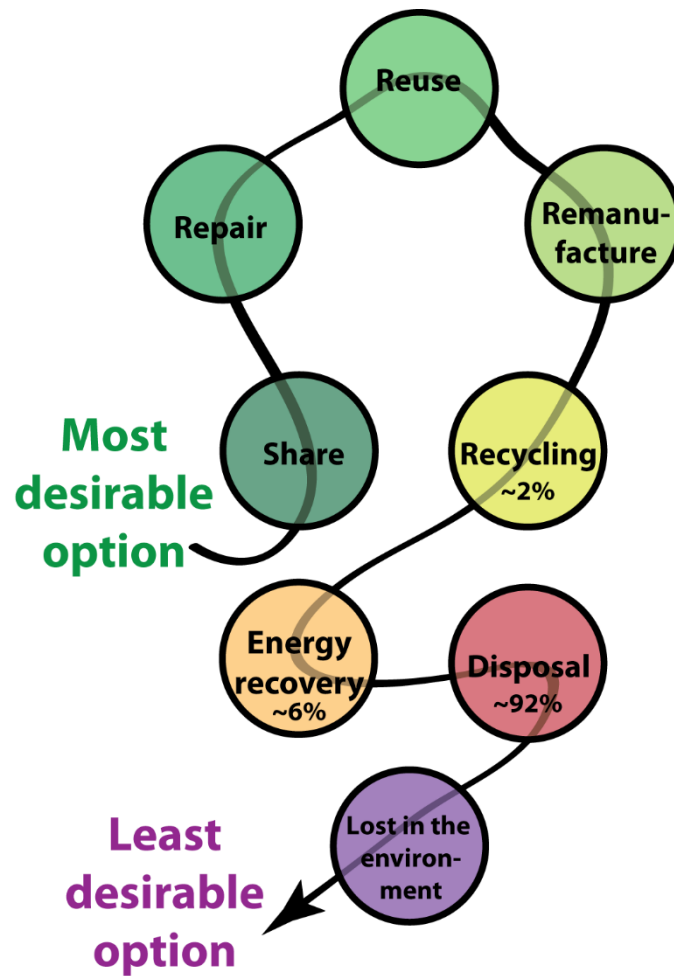
117 1.2. Voluntary abandonment of plastic waste: a source of plastics pollution

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

132 1.3. From plastic waste to pollution

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

135 has increased, the quantities of waste generated have also increased: of the 8,300 million tonnes
136 of plastic produced worldwide between 1950 and 2015, 4,900 million tonnes were discarded
137 (Geyer et al., 2017). Despite the potential for recovery, about 50% of the plastics produced are
138 of too little value for their recovery to be economically viable. Finally, less than 2% of the
139 plastic waste produced since the 1950s has been recycled, less than 6% incinerated and the vast
140 majority (about 92%) has been landfilled or disposed of in the natural environment (Fig. 2)
141 (Geyer et al., 2017). However, plastic waste is not limited to continents since approximately
142 4.8 to 12.7 million tonnes of plastic ends up in the oceans each year (Agamuthu et al., 2019).
143 However, unlike natural organic material such as wood, plastic materials degrade very slowly
144 in the environment. Thus, it is likely that a few decades to a few centuries will be necessary for
145 plastics to degrade if the environment is favourable in terms of physical, chemical and
146 biological conditions. As a result, plastics tend to accumulate in the environment and are not
147 harmless to it (Ballerini et al., 2018; Brandon et al., 2019). This implies implementing the
148 necessary means to reduce their impact, but also to be able to understand the reasons why human
149 beings do not manage their plastic waste properly.



150

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

152 1.4. Objectives

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

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

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

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

167 2.1. Risk avoidance mechanisms: general cases

168 The risk of infection by parasites is a significant threat to many living organisms and behaviours
169 allowing to avoid this risk is often a first line of defence (Buck et al., 2018; Hart, 1990). Humans
170 generally avoid objects that they believe to be contaminated by potential parasites, and tend to
171 eliminate waste that can harbour or feed parasitic organisms (Curtis, 2014). Disgust is an
172 emotion that is considered as one of these strategies for avoiding pathogens (Buck et al., 2018).
173 It can be induced by different stimuli from senses such as sight, taste and smell (Buck et al.,
174 2018; Hart, 1990). This emotion is a powerful way for the body to avoid a situation presenting
175 a risk of contamination by parasites (Buck et al., 2018; Hart, 1990; Weinstein et al., 2018). This
176 can be illustrated by shell middens (i.e. large accumulations of shellfish observed on the coasts
177 around the entire world), which is interpreted by archaeologists as a desire to remove the
178 organic remains whose decomposition can be a source of bad smells from living areas (Barton,
179 2002). Avoidance strategies originate both from innate reflexes, and also in learning from
180 cultural origins or through the experience acquired by the organism (Curtis, 2007). The
181 development of avoidance strategies acquired at a personal or societal level can be illustrated
182 by the example of the major epidemics of the Middle Ages. Thus, waste, particularly organic
183 waste, had a negative impact on the quality of life of people living in the Middle Ages. It is for
184 example the case of organic residues that infiltrated the soil and contaminated drinking water

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

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

197 2.2. Out of sight, out of mind?

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

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

213 However, while the direct consequences of plastics waste mismanagement for the individual
214 are modest, the consequences for the environment and ecosystems are greater. For example, the
215 ingestion of nano- and microplastics by planktonic organisms affects a wide range of functions
216 such as reproduction, growth or feeding behaviour (Besseling et al., 2014; Cole et al., 2015).
217 The ingestion of plastics has an energy cost for organisms that can result in reduced growth,
218 reproduction and health of the organism (Sussarellu et al., 2016; Watts et al., 2015). However,
219 while the ingestion of plastic can be observed by an informed fisherman, when cleaning his
220 catch for example, these kinds of impacts can only be highlighted by scientific means. In
221 addition to direct impacts during ingestion, it should also be noted that plastics interact with
222 additives and micropollutants in the natural environment. Some additives pose significant risks
223 to the environment and health such as DEHP, an endocrine disruptor commonly used as
224 plasticisers in PVC, and which desorbs during the plastic ageing process (Doyle et al., 2013;
225 Jeddi et al., 2015; Kedzierski et al., 2018; Manikkam et al., 2013). Plastics also adsorb
226 micropollutants in water such as metals (Boucher et al., 2016; Brennecke et al., 2016; Holmes
227 et al., 2014, 2012), endocrine disruptors (Fossi et al., 2014, 2012) or persistent organic
228 pollutants (Bakir et al., 2012; Lee et al., 2013; Rios et al., 2007). The ingestion by living
229 organisms of contaminated plastics could therefore constitute an additional pathway for these
230 pollutants, although this type of transfer is probably very secondary to micropollutant transfers
231 occurring between an ingested prey and its predator (Galafassi et al., 2019; Rist et al., 2018).
232 Most of these risks associated with plastic waste are unknown to the general public. Thus, while
233 plastic waste has a clear impact on the marine environment and ecosystems (Wright et al.,
234 2013). These impacts are not very sensitive from a human point of view and, even if they can

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

241 2.3. Two particular cases?

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

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

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

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

274 3. Uncontrolled landfilling

275 3.1. A behaviour deeply rooted in time

276 In the epidemic context of the end of the 15th century in Europe, hygienic trends appear and
277 lead to waste management measures being taken (Leguay, 1999). Thus, in the cities of 12th,
278 13th and 14th century England, household or commercial waste piles were not allowed for more
279 than a few days in the city (Schofield, 2002). In France, a city like Amiens had a waste disposal
280 service and the regulations required that this waste must be disposed of outside the city before
281 sunrise (Leguay, 1999). Waste is often exported out of the city, and is either dumped into rivers
282 or transported to areas of natural or artificial depressions (e.g. wells) (Bertolini, 2002).

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

294 3.2. Resistance of populations to good waste management practices

295 3.2.1. Incivility

296 Incivility is the main reason evoked by local actors to explain uncontrolled landfilling (ADEME
297 & ECOGEOS, 2019). Public archives of the Middle Ages testify to complaints against
298 individual selfishness and denounce the laxity of law enforcement officials (Leguay, 1999).
299 These complaints were particularly numerous during the 15th century, when the sharp increase
300 in urban populations, as well as epidemics, probably contributed to an awareness of the risks
301 associated with dumping waste on the streets (Leguay, 1999). The lack of awareness among
302 populations of the impact that waste disposal has on the environment and ecosystems is known
303 to be a source of reluctance to change practices. Thus, in Ethiopia, environmental security is a
304 secondary concern for its population (Tadesse et al., 2008). Furthermore, in the particular case
305 of packaging waste, it is often even less of a concern to local authorities than other wastes. In
306 France, the involvement of the police and the judiciary is therefore often less than for other
307 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

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

342 3.2.3. Impacts of collection facilities on uncontrolled landfills

343 The possibilities for collecting plastic waste have an influence on the discharge of waste into
344 the natural environment or the creation of uncontrolled landfills (ADEME and ECOGEOS,
345 2019). These include the cost of proper waste management, the distance to waste management
346 centres and public opposition to the establishment of waste management infrastructure.

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

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

363 The extensive use of pottery such as amphoras has sometimes led to significant accumulations
364 of waste. For example, Monte Testaccio in Rome is entirely made of 30 and 50 million amphora
365 broken between the first century BC and the third century AD and forming an artificial hill of
366 600,000 m³ (Havlíček and Morcinek, 2016). Modern landfilling is a continuous practice of
367 collective waste disposal practises in specific areas and currently the most common and
368 economical solution of waste management (Geyer et al., 2017). In modern times, and more
369 particularly between 1960 and 2002, the mass of household waste collected increased threefold
370 in line with the gradual increase in the population, but also because of the increase in plastic
371 consumption, as well as the best waste collection methods (Miller, 2009). At the same time,
372 waste regulations were becoming increasingly stringent, leading to a gradual decrease in the
373 number of landfills from about 8,000 in 1988 to 1,654 in 2005 (Miller, 2009). A similar
374 observation can be made in some European countries such as France, where between 1990 and
375 2013, the amount of household waste storage centres decreased from 500 to around 220
376 (Haeusler et al., 2017). This reduction in the number of sites may in some cases have led to the
377 exclusion of part of the population, particularly rural populations, from landfilling sites, which
378 are not very efficient from the point of view of good waste management, but have very low
379 management costs. In some cases, this may have encouraged the return of uncontrolled landfills.
380 In general, the reluctance to pay for efficient waste management is also one of the major points
381 to explain the existence of some uncontrolled landfills (ADEME and ECOGEOS, 2019).

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

391 4. Reuse: a (lost) cultural legacy

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

394 4.1. Management of ceramic packaging waste in the past

395 If ceramic techniques appeared as early as the Palaeolithic period, it was not until the diffusion
396 of Neolithic pottery that ceramic-based waste appeared in archaeological records (Fig. 2) (Rice,
397 1999; Vandiver et al., 1989; Wu et al., 2012). With them, the first non-degradable packaging
398 waste appears. As early as the 19th century, the Italian geologist Antonio Stoppani proposed
399 considering ceramic fragments as one of the possible markers of the ‘Anthropozoic’ era due to
400 the high amount of ceramic he found in soils (Stoppani, 1873; Turpin and Federighi, 2012).
401 However, despite their durability, the length of time of their use is sometimes relatively similar
402 to that of a comparable modern packaging. Thus, the duration of the use of an amphora during
403 the Roman Empire is in the order of a few months to a year, comparable to that of modern
404 plastic bottles (Geyer et al., 2017; Peña, 2007). Their relative fragility exposes them to the risk
405 of breakage and since the generated debris were generally quickly disposed of (Bertolini, 2002).

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

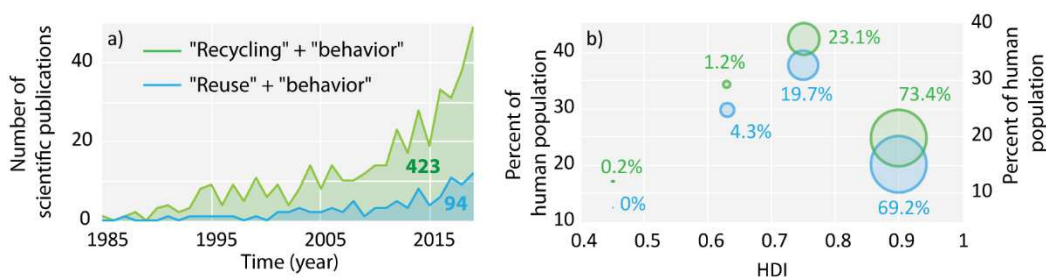
408 4.2. The transition to the consumer society

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

424 4.3. Reuse behaviour: an under-exploited source of innovation to improve plastic waste 425 management?

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

430 However, despite the predominance of this type of behaviour, scientific knowledge about it is
 431 comparatively lower than that of recycling (Barr et al., 2005; Corral-Verdugo, 2003; Kaplan et
 432 al., 2018). For example, whether it is for articles on recycling or reuse, in both cases, about 70%
 433 of these publications were made by countries with a very high Human Development Index
 434 (HDI) [0.8-1.0], but which account for about 20% of the world's population (UNDP, 2019;
 435 United Nations, 2019) (Fig. 3). Countries with a high HDI ([0.7-0.8]) account for about 20% of
 436 the publications. Nevertheless, this result is skewed by the fact that China published between
 437 65 and 70% of these publications. The share of scientific publications from countries with HDI
 438 below 0.7 is less than 5% for a population of about 3 billion people (about 42% of the world's
 439 population). Thus, global scientific research on these behaviours is therefore mainly carried out
 440 by the richest countries and probably reflects their needs (recycling rather than reuse). This
 441 imbalance leads to a profound lack of knowledge about one of the most important practices
 442 involved in the reduction of plastic pollution. Thus, one of the main modes of waste
 443 management is poorly documented from the scientific point of view, whilst this type of
 444 information could contribute to the development of relevant solutions contributing to the fight
 445 against plastic pollution.



446
 447 Fig. 3. Although reuse behaviours are very common in many countries (Innocent Sinthumule
 448 and Helen Mkumbuzi, 2019; United Nations Development Programme, 2018), scientific
 449 publications including the terms 'recycling' and 'behaviour' in their titles are 4 to 5 times more

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

452 5. Synthesis and conclusions

453 5.1. The weight of the consequences

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

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

479 5.2. Behavioural issues

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

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

498 5.3. Ways to reduce waste abandonment

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

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

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

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

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

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