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Plastics Recycling

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Summary

- *Only a small proportion of plastic waste is recycled because the recycling process comes up against technical, health and structural limits, regardless of the technology used. The plastics economy therefore remains very linear, contrary to the prevailing discourse which would lead the public to believe in a circular economy due to recycling.*
- *In the face of the multiplication of chemical recycling projects and in view of the uncertainties regarding their environmental impact and their ability to provide a response to the multiplication of single-use plastics, the public authorities must ensure that the conditions of use of this technology do not entail more drawbacks than benefits.*
- *The extended producer responsibility schemes have become unavoidable players in the management of plastic waste and plastics recycling. Nevertheless, the monitoring and control of these eco-organisations need to be strengthened to ensure that they act effectively in favour of a more circular economy and that recycling becomes a genuine part of an overall plastics reduction strategy instead of a substitute for it.*

Philippe Bolo, Member of the National Assembly
Angèle Préville, Senator

The characteristics of plastics recycling

The term is only loosely defined in the legislation, and would gain from being clarified

Article L. 541-1-1 of the Environment Code[1] defines recycling as "*any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and reprocessing into materials that are to be used as fuels or for backfilling operations.*" This generic definition, which is valid for all waste, refers to two types of recycling[2] without distinguishing between them:

- closed-loop recycling: recycled waste can be used to produce a new product with the same use, with no major functional degradation of the material's properties (such as the recycling of a PET bottle[3] into a new PET bottle);
- open-loop recycling: the properties of the waste material are degraded during the recycling process. The recycled material is used for a different application, one which requires a lower quality of plastic (such as the recycling of a PET bottle for textile applications).

Two main recycling techniques

✓ Mechanical recycling

Currently 99% of recycled plastics undergo what is known as "mechanical" recycling: after being collected and sorted to produce feedstocks of "homogeneous" polymers, the latter are ground,[4] washed,[5] resorted,[6] extruded[7] then turned into pellets to be used as recycled raw material, all without altering the structure of the polymer.[8] Mechanical recycling is called primary recycling when it processes post-industrial waste[9] and secondary recycling when it processes post-consumer waste.

✓ Chemical recycling

Chemical recycling encompasses any reprocessing technology using chemical agents or processes that directly affect either the formulation of the plastic or the polymer itself.[10] The chemical structure of the plastics is altered. Basically there are[11] three main categories of technologies:

- purification with solvents:[12] this is to selectively separate the polymer matrices from the other materials (especially in the case of polymer blends or formulations) and chemical substances (additives, pigments, substances added unintentionally, etc.). The plastic waste is immersed in a solvent bath which dissolves the target polymer, separating it from the other components. Once the purification process is complete, the polymer is exposed to a non-solvent solution (precipitation process) to be re-solidified;[13]
- depolymerisation: this consists of breaking down the polymer chain to return it to the state of monomer. Once depolymerisation has occurred, the monomers are recovered to be purified by distillation, precipitation or crystallisation;[14]
- conversion (or thermal depolymerisation): pyrolysis[15] and gasification[16] transform plastics and most of their additives and contaminants into basic chemicals.[17] These technologies rely on the heating of the plastics in the total

or partial absence of oxygen. In both cases, the molecules produced by these processes cannot be converted directly into polymers, but must be used as raw materials in a refining-conversion-polymerisation process.[18]

At the present time, industrial chemical recycling is still in the test phase, even if the potential for investment is high, especially in Europe.[19]

The expected benefits of plastics recycling

Recycling is supposed to limit CO_2 emissions and save energy. Currently, 98.5% of plastic is made from chemicals sourced from fossil fuels[20] and the industry accounts for 10.7% of oil consumption.[21] In 2018, total greenhouse gas emissions caused by plastics in the European Union were estimated at 208 million tonnes of CO_2 equivalent, of which 63% were caused by its production, 22% during the conversion of polymers into products and 15% during plastic waste treatment at end-of-life.[22] Globally, the carbon footprint of plastic amounted to 1.8 Gt of CO_2 in 2019.[23]

A study carried out in 2017[24] on CO_2 emissions and the energy saving linked to recycling showed that one tonne of recycled PET generates 70% less greenhouse gas and uses 83% less energy than the production of one tonne of virgin resin. The greenhouse gas and energy saving reaches 89% for the recycling of one tonne of HDPE.[25]

Recycling would also allow us to reduce our dependency on imports of fossil fuels and raw materials (such as polyester for textiles[26] or natural rubber for tyres).

On the other hand, the contribution of recycling to the fight against plastic waste is more mixed: concerning the production of waste, the proportion of open-loop recycling and the physical limits on the number of recycling cycles make it a temporal buffer that merely slows, but does not enable us to avoid the production of waste.[27] As for plastic pollution, it is not limited to plastics' end of life, but concerns all the stages in their life cycle (production, use, end of life).[28]

■ The reality of plastics recycling is very far removed from the circular economy

Only small quantities of the flows of plastic waste are recycled

The figures on plastics recycling vary by industry,[29] country[30] and the methods used.[31]

In addition, it is not because a plastic product is theoretically recyclable that it is necessarily recycled, and the real recycling rate depends on many different parameters: characteristics of the plastic product itself (size, shape, composition), ability to be collected and oriented to a sorting centre, ability of that sorting centre to sort said product correctly, existence of a recycling channel.[32]

According to the OECD, in 2019, globally only 15% of plastic waste was collected for recycling and only 9% was actually recycled.[33] In France, out of the 6.45 million tonnes of plastics consumed in 2020, 3.76 million tonnes are thought to have become waste. 929,000 tonnes were prepared for recycling (or 24.7% of waste), 690,000 tonnes were recycled at national level[34] (or 18.3% of waste) to obtain 440,000 tonnes of recycled raw materials (11.7% of waste).[35] The recycling process therefore involves losses of over 36%.

Furthermore, most recycling is open-loop, especially in the packaging sector (which accounts for 39.1% of the plastic consumed in Europe).[36] Even for PET the figures are low, only 17% (mass) are recycled into new bottles in Europe, the rest being recycled into textiles and food trays.[37]

A very low inclusion rate of post-consumer recycled plastics

In 2021, out of the 390.7 million tonnes of plastics produced[38] in the world, only 8.3% came from recycled plastics.[39] Furthermore, although packaging accounts for 39.1% of the plastics consumed in Europe, it only contains 8.5% recycled plastics.[40]

Persistent obstacles to effective plastics recycling in spite of the efforts made

✓ Technical, health, economic and structural obstacles

The technical obstacles are of several orders.[41] Firstly, not all plastics can be recycled.[42] In addition, most thermoplastics are not miscible[43] (whereas plastics are made of a wide variety of polymers and there are numerous formulations for the same polymer).[44] [and] [45] More generally, the properties of plastics degrade with use, ageing and end-of-life storage.[46] Moreover, the thermo-mechanical conditions of the recycling process will further accentuate that degradation.

The obstacles to mechanical recycling are also regulatory. Chemicals added to polymers include hazardous chemical substances (such as endocrine disruptors or brominated flame retardants)[47] and "legacy chemicals"[48] (such as lead stabilisers).[49] In addition, food contact plastics need to meet regulatory requirements guaranteeing that there is no risk of toxicity induced by contact with food or beverages. Currently, only r-PET is recognised as food grade[50] in the European Union.[51] The recycling of the other resins used for plastic packaging is therefore open-loop.

Recycling also faces economic obstacles.[52] The price of virgin plastics is not high enough to be an incentive to use recycled material, while certain manufacturers continue to harbour doubts about the latter.[53]

At the same time, the availability[54] and quality[55] of supplies of recyclable plastic and the existence of enough recycling plants remain major structural issues impacting the development of recycling.

✓ Efforts made to ensure the recyclability of plastics

Legislation has set targets for recycling and the inclusion of recycled material (RM) at both European and national level with a view to encouraging the plastics economy to become more circular.[56] At the same time, measures have been taken to boost collection, sorting[57] and recycling, by extending sorting instructions,[58] the introduction of incentive-based pricing[59] and the obligation to sort biowaste at source.[60] These measures involve significant financial efforts for local authorities,[61] which, in some cases with help from the State[62] and the eco-organisations,[63] have invested massively[64] in collection infrastructure (bins, lorries) and sorting facilities (sorting and recycling centres).[65] The number of extended producer responsibility (ERP) schemes has increased considerably to prevent and manage waste.[66] The recyclability of plastic waste

is the subject of numerous research projects at both national level[67] (in particular through a priority research programme (PEPR) on Recyclability, Recycling and Reincorporation of Recycled Materials) and European level,[68] and the progress made on encouraging high quality and even closed-loop mechanical recycling should be stressed. On the other hand, eco-design remains underdeveloped in spite of different incentive and prescriptive schemes set up by the eco-organisations and the public authorities.[69]

A recycling trajectory unable to cope with the strong growth in plastics production

According to the OECD, the amount of plastic waste produced globally is on track to triple between 2019 and 2060, from 353 million tonnes to 1,041 million tonnes.[70] Although the share of plastic waste that is recycled is increasing (17%),[71] it is still expected to account for a lower share than incineration (18%)[72] and especially landfilling (50%),[73] while 15% of plastic waste will still evade waste management systems altogether (some 153 million tonnes). As a result, plastic waste leaking into the environment is projected to double by 2060 (44 million tonnes compared to 22 million tonnes in 2019) and the stocks of plastic accumulating in aquatic environments are expected to triple to reach 493 million tonnes in 2060 (from 140 million tonnes in 2019). The environmental and health impacts of plastic pollution[74] are therefore likely to worsen considerably.

■ Encouraging effective recycling with a view to reducing overall plastics consumption

The pitfalls to be avoided

✓ Inversion of the waste management hierarchy

Saving resources means respecting a certain hierarchy in waste processing modes: prioritising prevention and the reduction of waste, developing reuse (for the same or a different purpose) and repair and then encouraging recycling.**[75]** And yet, in actual fact, circular concepts involving recycling give the impression that recycling alone could guarantee the circularity of the plastics economy.[76] Such a vision leads to a double risk: that of participating in normalising waste,[77] but also that of masking the alternatives to plastics consumption, by leading the public to believe that it is possible to control waste.[78] Very bold statements about chemical recycling, which is supposed to be able to recycle contaminated and heterogeneous plastic waste that mechanical recycling cannot process, give the impression that this is the solution that will wrap everything up, whereas these technologies are far from having proven that they are capable of recycling all types of plastics at an acceptable cost, whether financial or in terms of energy consumption and environmental impact.[79]

✓ Staking everything on technological solutions

To cope with very heterogeneous plastics, sorting[80] and recycling[81] have become considerably more sophisticated, leading to growing costs for local authorities.[82] There are currently 44 chemical recycling projects in 13 countries in Europe, including 13 projects for France alone. Nevertheless, the effectiveness of this technological race will remain limited without strong action on the two other levers that can improve the recycling rate, namely recyclability[83] and waste sorting.[84] Finally, the issues involved in recycling must be addressed holistically, taking in every stage from collection to the final valorisation of the waste product.

✓ Inadequate oversight of the eco-organisations

The eco-organisations have become an unavoidable part of the system of the extended producer responsibility schemes given the financial part they play in the collection and sorting of waste.[85] Nonetheless, whereas their mission is reduce the environmental impact of the products in the channel they manage, their shareholders are the manufacturers that place said products on the market, which can make the eco-organisations less effective,[86] and even lead to suboptimal decision-making,[87] in spite of the new measures taken recently in the AGEC law (anti-waste law for a circular economy) to get eco-organisations more involved in the reuse of products and waste reduction.[88] In addition, the introduction of monopsonies[89] in favour of the eco-organisations[90] gives them a decisive influence over the strategic orientations on recycling[91] which would gain from being overseen in close consultation with the other stakeholders,[92] including local authorities and Parliament.

✓ The development of chemical recycling to the detriment of mechanical recycling

Chemical recycling covers a variety of techniques which are still relatively little used on an industrial scale and which raise many questions,[93] concerning issues such as their environmental impact,[94] the elimination of toxic chemicals,[95] their contribution to the circular economy[96] and the traceability of the outputs from these technologies.[97] Chemical recycling is also subject to the same constraints as mechanical recycling in terms of sorting[98] and access to supplies of feedstock,[99] and its efficacy is also dependent on eco-design.[100] Chemical recycling is considered as complementary to mechanical recycling for waste that cannot be treated mechanically or reach the level of quality demanded by the market or required by the regulations.[101] However, certain recent decisions have cast some doubt on how this complementarity could work in practice.[102] It will therefore be necessary to ensure that for the same quality of recycled material, mechanical recycling takes precedence. Indeed, even though several studies have concluded that developing chemical recycling will be indispensable to improve recycling rates and meet growing needs in terms of obligations on the inclusion of recycled material,[103] the "lock-in effect" and "rebound effect" that chemical recycling will likely induce should not be underestimated.[104] Furthermore, the methods used to calculate life cycle assessments must be improved, while LCAs must systematically be done to ensure that the recycling solution envisaged is not worse than the waste.[105]

✓ Introduction of a recycling deposit on PET bottles

France's performance in the collection of plastic drink bottles and the recycling of household waste is not sufficient to meet the targets set by the European Union,[106] Inspired by examples abroad,[107] Article 66 of the AGEC provides for a debate on the introduction of deposit return schemes to increase recycling and reuse in 2023. The introduction of a recycling deposit return scheme on PET bottles has a number of drawbacks, however, on top of the confusion that it could cause among the population.[108] From the economic point of view, it would jeopardise the financial equilibrium of local authorities, in

particular that of the most virtuous[109] and would lead to the private sector capturing the most valuable waste whilst the local authorities would be left to deal with the most difficult waste.[110] On the environmental front, a deposit return scheme would tend to normalise the use of plastic bottles for drinks whereas France has set a target of reducing the number of these bottles placed on the market by 50% by 2030 compared to 2018.[111]

Levers to improve recycling rates and encourage high quality recycling

- **Make recycling part of an overall strategy to reduce plastics production**: recycling cannot, on its own, guarantee the establishment of a circular plastics economy nor will it enable the industry to achieve net zero by 2050. It must be integrated as part of a wider strategy aimed at reducing our consumption of plastics.[112]
- **Improve the recyclability of plastics by building in recycling from the design stage**: many tools have been developed to evaluate the recyclability of packaging at both national and European level.[113] It is now necessary to make sure they are applied by taking truly dissuasive measures to prevent non-recyclable products being placed on the market.[114] The goal is to limit the number of resins and colours, to standardise packaging and eliminate disruptors to make mechanical recycling more effective[115] whilst also reducing the costs.
- **Increase collection performance**: before embarking on a national recycling deposit return scheme,[116] there are many other things that can be done both upstream (through effective implementation of the 3Rs strategy)[117] and downstream (by improving selective collection performance, accelerating the implementation of incentive-based pricing[118] and better harnessing of non-domestic waste sources).[119] Beyond the waste sector, other sectors must also improve their performance in terms of collection.[120]
- **Prioritise mechanical recycling over chemical recycling in calls for tender, whilst encouraging high quality recycling**: in spite of reassuring talk of complementarity between the two recycling techniques, there is a real risk of seeing chemical recycling develop at the expense of mechanical on the pretext that the latter produces material of inferior quality. In actual fact, quality sorting and preparation of the material to be recycled very often allow for closed-loop mechanical recycling at lower costs and with better environmental outcomes than chemical recycling. In addition, the indispensable tightening of the rules on recyclability should facilitate mechanical recycling by developing more homogeneous waste streams and thanks to the simplification of plastics. Only then will chemical recycling be truly complementary to rather than in competition with mechanical recycling.[121]
- **Clarify the conversion[122] and allocation[123] rules for recycling by thermal depolymerisation**: depending on the output base taken into account, the conversion factor will vary. For reasons of transparency, the conversion factor must take account of the different elements likely to reduce the quantity of materials that credits can be allocated to (losses in the waste, conversion of inputs into energy form), and only outputs intended for materials applications must be taken into account. In addition, the calculation of the mass balance by the credit method, largely favoured by the industry, can lead to a significant decoupling between the physical reality of the recycled material content and the claim of a certain rate of recycled material. This method therefore cannot be used to quantify the recycled content.
- **Extend the obligations on incorporating recycled plastics to all industries**: recycling will only be able to develop if there is strong demand for recycled materials. Regulation can play a decisive role, as the strong growth in demand for recycled PET following the incorporation obligations imposed by the EU has shown. At the same time, penalties must be introduced for non-compliance with the recycled content obligations.[124]
- **Introduce the notion of "real" recycling with minimum collection thresholds and recycling rates[125]** in order to accelerate the setting up of effective recycling channels.
- **Continue and consolidate the research work being done on the environmental and health impacts of mechanical and chemical recycling.[126]**

OPECST websites:
http://www.assemblee-nationale.fr/commissions/opecst-index.asp
http://www.senat.fr/opecst

Références

[1] This article results from the transposition of Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.

[2] See Green Chemistry. Cutting-edge research for a greener sustainable future. Volume 24. Number 23. 7 December 2022.

[3] Polyethylene terephthalate.

[4] The plastics are cut up to be transformed into flakes.

[5] This process is intended to remove the contaminants (glue, labels, etc.) and odours from the flakes.

[6] Using technologies based on differences in density.

[7] The material is passed through filters to remove the last impurities. It then goes into an extruder (a heated tube equipped with an endless screw) to plasticise the material in a molten state. The melted material is recovered in the form of plastic rods, which are water or air-cooled and then cut into pellets. The material is stored in big bags.

[8] See Ifpen https://www.ifpenergiesnouvelles.fr/enjeux-et-prospective/decryptages/climat-environnement-et-economie-circulaire/tout-savoir-recyclage-du-plastique

[9] Waste generated in factories by production processes (defective products, production offcuts, etc.).

[10] See Crippa et al (2019). A circular economy for plastics – Insight from research and innovation to inform policy and funding decisions (M. De Smet & M. Linder, Eds). European Commission, Brussels, Belgium.

[11] See Mapping of advanced recycling technologies for plastic waste – providers, technologies, and partnership. Nova-Institute. 2022. This report details 103 advanced recycling technologies in development or already on the market.

[12] See Polyvia. Recyclage chimique : où en sommes-nous ? Edition 2022. https://www.polyvia.fr/fr/recyclage-chimique-ou-en-sommes-nous-definition-tendance

[13] The polymer obtained is of a quality close to that of virgin polymers and can be used for high-performance applications. The target materials are polyolefins (polyethylene and polypropylene), polyvinyl chloride and styrenes. Purification with solvents has certain limits. The purity of the final polymer can be compromised by residual contaminants not eliminated by the solvent. Furthermore, insofar as this process does not modify the chemical structure of the polymer, any differences in quality due to the blending of polymers of different grades in the material entering the process are maintained. In addition, as any mechanical transformation of a resin to form a plastic object (by extrusion or blow moulding) leads to physical and thermal constraints that reduce the length of the polymer chains, dissolving with a solvent is not a perpetual recycling method for plastics.

[14] See Sophie Duquesne. Le recyclage des matériaux plastiques. L'actualité chimique. No. 456-457-458. November–December-January 2020-2021. There are several kinds of depolymerisation. Chemical depolymerisation (or solvolysis) is based on the use of a solvent, which also acts as a reagent. Depending on the solvent used, there are different classes of solvolysis reactions: hydrolysis (reaction with water), methanolysis (reaction with methanol), glycolysis (reaction with glycol), etc. Enzymatic depolymerisation (or biological depolymerisation) aims to break polymer chains with enzymes. The Carbios company, in cooperation with the Toulouse Biotechnology Institute, has demonstrated that closed-loop recycling of PET waste using this process is feasible. Depolymerisation is mainly applied to polymers obtained by polycondensation, in particular polyethylene terephthalate (PET).

[15] See ADEME. https://expertises.ademe.fr/economie-circulaire/dechets/passer-a-laction/valorisation-energetique/dossier/ pyrolyse-gazeification/principes-pyrolyse-gazeification. Pyrolysis consists of heating plastic waste to temperatures generally between 350 and 650°C in the total or partial absence of oxygen. This produces a combustible gas, a liquid (oil or mixtures of hydrocarbons) which contains chemical compounds of interest (benzene, toluene, xylenes) that can be used in fine chemicals and a by-product (char). The proportion of gas, liquid and solid depends on numerous parameters such as the initial composition of the waste, the temperature and pressure during the transformation process, the residence time, etc.

[16] See ADEME. Above-mentioned website. Waste gasification is process where waste is heated to temperatures generally between 900 and 1200°C in the presence of a small quality of oxygen. Apart from the mineral fraction of the waste and a small quantity of unconverted fixed carbon, which make up the solid residue, the waste is entirely transformed into a synthesis gas. When the gasification reaction takes place at atmospheric pressure, this syngas generally mainly consists of carbon monoxide (CO) and hydrogen (H_2) as well as a few per cent of methane (CH_4). Depending on the process, it will also contain a varying proportion of carbon dioxide (CO_2) and nitrogen (N_2). It also contains a small quantity of long hydrocarbon chains called tars.

[17] See Crippa et al (2019). Above-mentioned article.

[18] https://expertises.ademe.fr/economie-circulaire/dechets/passer-a-laction/valorisation-energetique/dossier/pyrolyse-gazeification/principes-pyrolyse-gazeification

[19] See Polyvia (May 2022). Le plastic, l'atout bas carbone. At least €2.6 billion are due to be invested in chemical plastics recycling in Europe by 2025 and at least €7.2 billion by 2030. France has 13 chemical recycling projects, of which 4 were announced in 2022.

[20] Figures of Plastics Europe.

[21] Oil production in 2021 stood at 4,221 million tonnes according to Statista 2023. According to Plastics Europe, 390 Mt of plastics were produced in 2021, excluding textiles. Insofar as that sector represents about 60 Mt of plastics, global plastics production reached 450 Mt in 2021, namely 10.7% of oil production.

[22] See European Topic Center on Waste and Material in a Green Economy. Greenhouse gas emissions and natural capital implications of plastics (including biobased plastics), May 2021. European Environment Agency.

[23] This corresponds to 4.7% of greenhouse gas emissions. In comparison, digital technology (big data) accounts for 3.5% of greenhouse gases and air transport 3.8%.

[24] See Federec and ADEME. Evaluation environnementale du recyclage en France selon la méthodologie de l'analyse de cycle de vie, April 2017. The methodology rests on the defining of a functional unit (FU) which describes the function fulfilled by the system studied whose environmental impacts are going to be quantified. This FU is set based on the objective of the study. In this project, the FU corresponds to the collection, sorting and transformation of one tonne of waste to produce intermediate materials from RRMs (recycled raw materials) instead of intermediate materials made from virgin resources. The reference streams concerned are waste collected and sorted in France. The geographic scope of the production steps to arrive at the intermediate materials made from RRMs depends on annual exports. The assessment scope for the channel measures the impacts throughout the recycling chain as well as the impacts arising from this recycling channel (collection avoided, end of life avoided and production of virgin raw materials avoided). The method of calculation applies is based on the end-of-life formula recommended by the ADEME in its methodological guidelines on environmental information in France. The recycling method used is mechanical.

[25] High-density polyethylene.

[26] In 2020, 70% of polyester fibre was made in China.

[27] Mechanical recycling yields vary between 70 and 80% according to the inputs. When they appeared before the rapporteurs, the managers of Carbios reported yields of up to 90% for enzymatic recycling of PET.

[28] See Gontard et al (2022). Recognizing the long-term impacts of plastic particles for preventing distortion in decision-making. Nature substainability, 5.

[29] According to the statistics of Plastics Europe, in 2020, which cover the countries of the European Union plus the United Kingdom, Norway and Switzerland, the plastics recycling rate was 46% on average in the packaging sector compared to 25% in the construction sector and 7% in the leisure and sports sector. These figures were obtained at using the old method of calculating the recycling rate used in the European Union, which measures the quantities recycled as they leave the sorting centre and not when they are actually recycled (see *Note 31*). This method led to an over-estimation of the recycling rate.

[30] See Eurostat. In 2020, the plastic waste recycling rate was 23% in Malta, 25% in France, 34% in Italy, 39% in Belgium and 45% in the Netherlands.

[31] In Article 6a of Directive (UE) 2018/852 of the European Parliament and of the Council of 30 May 2018 amending Directive 94/62/EC on packaging and packaging waste, the weight of packaging waste recycled shall be calculated as the weight of packaging that has become waste which, having undergone all necessary checking, sorting and other preliminary operations to remove waste materials that are not targeted by the subsequent reprocessing and to ensure high-quality recycling, enters the recycling operation whereby waste materials are actually reprocessed into products, materials or substances. Previously, the quantities recycled were measured as they left the sorting centres. Now, the recycling rate is calculated when recycling actually takes place. Some scientists and the non-governmental organisations calculate the recycling rate by dividing the mass of plastic waste by the mass of recycled raw materials produced by the recycling process. This technique allows the actual quantities of plastics produced by recycling liable to replace virgin plastic materials to be taken into account. Depending on the methodology used, the recycling rates differ. Thus, in the EU countries, in 2020, 53.6 Mt of plastic were consumed, of which 29.5 Mt are thought to have become waste. 9.1 Mt were estimated to have been sent for recycling in European plants, i.e. 30.8%. However, after the recycling process, only 5.5 Mt of recycled outputs were recovered, i.e. 18.6% (which corresponds to a difference of almost 40%). In addition, there is no consensus on the calculation of the mass of waste. This is obtained by adding together all the tonnes of waste declared in each European country. But, the tonnes of plastic waste in household waste are difficult to quantify. Thus the "Reshaping Plastics. Pathway to a circular, climate neutral plastics system in Europe" report of April 2022, states that an estimated 43% of the plastic put on the market in Europe is unaccounted for in waste statistics, namely approximately 22 Mt per year. If this is the case, the rate of plastics recycled in the European Union amounts to 21.1% on entering the recycling process and 10.7% on coming out of the recycling process.

[32] Citeo has developed a packaging recyclability test (TREE) in five stages: to what family of material does the packaging belong? Is there a recycling channel for this packaging? Can the packaging be directed to and integrated into it? Calculation of recyclability, defining of the level of recyclability. In 2022, the plastic packaging recognised as recyclable by Citeo is bottles made of PET (polyethylene terephthalate), PE (polyethylene) and PP (polypropylene); pots, trays, tubes and other rigid packaging made of PE and PP; pots, trays and other rigid packaging made of PET without film lids and PE flexible packaging.

[33] See OECD. Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options. 2022.

[34] The exporting of plastic waste remains a complex issue given the difficulties tracing flows of waste, in particular those exported within the European Union to be recycled, those that are the subject of a simple transit within certain EU countries to then be exported to third countries and those that are exported directly to third countries. According to Plastics Europe, in 2019, the balance between French imports and exports of plastic waste probably resulted in net exports of 240,000 tonnes. Within the European Union, net exports for 2019 are thought to amount to 1 million tonnes. Given the uncertainties around what happens to exported plastics, especially in third countries, your rapporteurs prefer to base their statistics on recycling rates in France, even if this practice tends to under-evaluate the real recycling rate.

[35] The data on the quantity of plastics produced as well as on waste flows (and in particular on exports and imports) are imprecise, partial and scattered. There is a need for a better framework for overseeing these data and entrusting their management to a public entity that could guarantee their transparency and their truthfulness.

[36] According to Citeo, dark and opaque PET bottles are recycled in textiles and insulation membranes for buildings; HDPE and PP plastic bottles, tubes and boxes are recycled in car seats, garden hoses, flower pots and urban furniture; PE plastic films and flexible packaging are recycled in bin bags, irrigation pipes, bowls and buckets.

[37] See Systemiq. Circularité des emballages et textiles en PET/polyester en Europe. Synthèse des recherches publiées. February 2023.

[38] Plastics Europe figures excluding the production of plastics for the textile sector, namely some 60 tonnes.

[39] The share of recycled post-consumer plastics incorporated in new products is also low in Europe (9.9% in 2021) and in France (7.8% in 2020) in spite of the incentive and prescriptive mechanisms put in place by the public authorities and eco-organisations.

[40] In the other industrial sectors, automotive vehicles and electrical and electronic equipment include only 2.9% and 3.2% recycled plastics respectively whereas they represent 8.6% and 6.5% of the demand. Conversely, the recycled plastics incorporation rate reaches 25.4% in the agriculture field and 18.1% in construction whereas these sectors account for 3.1% and 21.3% of the demand for plastics respectively.

[41] The obstacles mentioned concern mechanical recycling insofar as that technology absorbs virtually all recycled plastics. Chemical recycling will be discussed further on.

[42] Thermosetting plastics have the particularity of being insoluble and not being able to be remelted because of their specific chemical structure (cross-linked). They therefore cannot be recycled by mechanical methods, and the same applies to vulcanised elastomers and composites.

[43] See Hannah Mangold, Bernhard von Vacano (2022). The frontier of Plastics Recycling: Rethinking Waste as a Resource for High-Value Applications. Macromolecar Chemistry and Physics, 223. The mixed recycling of thermoplastics with different characteristics can create uncontrolled heterogeneities in the material produced by recycling, weaken the mechanical performance, and can make processes like film blowing impossible, or deteriorate optical appearance.

[44] In the plastic manufacturing process, a polymer is mixed with additives to obtain specific properties in use. There are therefore several formulations for the same polymer.

[45] For example, the PET used in food trays does not have the same viscosity properties as the PET used in bottles (differences in shape, functionality, thickness, etc.). This can have consequences on recycling (a PET tray is more fragile than a PET bottle), in particular on its behaviour at raised temperatures, on the viscosity index of the recycled material, on the colour of the recycled material, etc. In this example, PET bottles can be recycled into trays, but not the other way round. The incorporation of 20% mono-PET unlidded trays does not disrupt the current stream of PET bottles, but it does substantially reduce yields.

[46] Under the effect of heat, water, oxygen and ultraviolet radiation.

[47] Plastics containing a brominated flame retardant represent 8% of the waste from electrical and electronic equipment. They constitute hazardous waste that is separated during sorting to be directed to special waste channels. Source: Ecosystem presentation to the committee.

[48] Legacy substances are additives added to polymers to make plastic products which have been banned between when they were incorporated in the product when the product comes to the end of its life.

[49] On 3 May 2023 the European Commission adopted a proposal for a regulation to restrict the presence of lead and its compounds in PVC (polyvinyl chloride) on the EU market. The lead content in PVC products (window profiles, pipes, cables, etc.) must be less than 0.1% of the weight of the recycled PVC. This ban will come into effect 18 months after the Regulation comes into force. However, it allows a 10-year derogation for the use of recycled rigid PVC which may contain up to 1.5% legacy lead in profiles and pipes for construction as long as the recycled PVC is covered by a layer of PVC (by lamination or coextrusion) or by another material containing less than 0.1% lead and provided that the recycling is done in a closed loop within 36 months of the entry into force of this decision. Finally, it allows a period of two years for articles containing flexible PVC to adapt to the new regulations.

[50] Currently not only is rPET recognised as food grade, but closed-loop recycling is strongly encouraged by the obligations on the incorporation of PET in plastic drink bottles. Thus Directive (EU) 2019/904 of 5 June 2019 on the reduction of the impact of certain plastic products on the environment requires that PET bottles contain at least 25% recycled plastic from 2025 and that all beverage bottles contain at least 30% recycled plastic from 2030. Nevertheless, certain scientific studies have revealed higher migration into food of toxic substances such as the antimony or bisphenol A in recycled PET compared to virgin PET (see Gerassimidou et al (2022). Unpacking the complexity of the PET drink bottles value chain: a chemical perspective, Journal of Hazardous Material, Volume 430). More in-depth assessment of the risks of migration of unintentionally added substances would therefore be pertinent to set a maximum level for the recycled content of PET drink bottles. One recent study has shown that the chemical contamination of recycled plastics mainly comes from compounds such as adhesives and inks (see Brouwer et al (December 2019). The impact of collection portfolio expansion on key performance indicators of the Dutch recycling system for Post-Consumer Plastic. Packaging Waste, a comparison between 2014 and 2017. Waste Management, Volume 100). In order to assess the newly emerging risks linked to the development of recycling the national metrology laboratory national has proposed to set up a national observatory on recycled materials and the separation of the streams of food containers from other waste streams in order to avoid contamination.

[51] However, other plastics are destined to be recognised as food grade after mechanical recycling. Concerning HDPE, Veolia is recycling milk bottles in a closed loop in the United Kingdom. As far as PS is concerned, Trinseo announced at its hearing that the closed-loop mechanical recycling of PS yoghurt pots should be authorised by the European Food Safety Authority in October 2023.

[52] The price of recycled plastics is determined by the price of virgin materials even though their production cost is governed by the cost of the raw material plus the structural costs of recycling (collection, sorting, etc.). It is generally lower than that of the virgin resins (this lower rate is supposed to translate the lower quality of the recycled material compared to virgin material and compensate for plastic manufacturers' and their clients' reluctance to use recycled material) with the exception of rPET for which there are re-incorporation obligations for plastic bottles and whose price is higher than that of virgin PET.

[53] The development of recycled material incorporation requires greater traceability of both the recycled materials (in particular to avoid fraud on the incorporation obligations or claims on the incorporation rate) and the composition of the materials being recycled.

[54] The following examples illustrate the difficulties of accessing supplies. According to Plastics Europe, in 2020, out of the 2.35 Mt of plastic packaging waste produced in France, only 0.78 tonnes were collected and sorted (i.e. 33.2%). In the waste electrical and electronic equipment field, according to the eco-organisation Ecosystem, out of the 1.8 million tonnes of products that ended up as waste in 2019, 450,000 tonnes illegally evaded the approved scheme, 144,000 tonnes were difficult to collect and 108,000 tonnes formed an undocumented pool of waste. As a result, the real supply represents only

850,000 tonnes, or 68.4% of the potential source. In the automotive sector, the plastic from end-of-life vehicles, which is currently handled by approved facilities, has very low levels of recovery, with only 9% being recycled or reused. The plastic used in vehicles is very dispersed, integrated in complex composites, and over 39 different types of polymers are used. These design choices lead to considerable end-of-life difficulties, in particular limited dismantling of plastic components (4% of the total plastic on average). See Systemic. ReShaping Plastics (April 2022). Pathways to a circular, climate neutral plastics system in Europe.

55 Thus, plastic packaging waste is soiled and contains commingled food and non-food packaging, which can lead to contamination. Certain agricultural plastic waste such as plastic mulches is also very soiled. The fact is, however, that the quality of the plastics collected has a decisive impact on the quality of the recycling. This is the reason why post-industrial plastic waste recycling, which treats homogeneous waste streams, lends itself better to closed-loop recycling than that of post-consumer plastic waste.

56 At European level, the recycling targets are as follows: by 2035, 65% of municipal waste must be recycled and only 10% of municipal waste by weight will be able to be sent to landfill; by 2030, 55% of plastics and 70% of plastic packaging must be recycled; by 2025, 70% of single-use bottles must be collected, and 90% by 2030, with the target of achieving a 100% recycling rate for all packaging by 2030. As far as the recycled plastics incorporation obligations are concerned, by 2025, PET drink bottles must contain 25% recycled material and by 2030, all plastic drink bottles must contain 30% recycled material. In addition, voluntary undertakings have been made in different branches of industry (automotive, electrical and electronic, etc.) to achieve 10 Mt of recycled plastics reused per year by 2025. France has adopted these regulations, setting itself even more ambitious targets such as the aiming for 100% of plastics recycled by 2025 (Article 5 of Law no. 2020-105 of 10 February 2020 on the Fight against Waste and the Circular Economy, referred to as the AGEC law in the rest of the Note).

57 Collection and sorting are decisive factors in the rate and quality of recycling.

58 The setting up of the extension of sorting instructions has been particularly slow. Following a series of trials conducted between 2011 and 2013 with a population of 3.7 million inhabitants, Law no. 2015-992 of 17 August 2015 on the Energy Transition for Green Growth provided for the extension of household packaging sorting instructions to all plastic packaging by 2022. The extension of sorting instructions facilitates collection, thereby improving the quality of the supplies, and helps to increase recycling rates. It has involved modernising waste sorting facilities to cope with the increase in the diversity of plastics to be sorted and the accelerated pace of processing (see *Note 65*). At the beginning of 2023, the extension of sorting instructions concerned 98% of the population in metropolitan districts. The above-mentioned law also provided for the comprehensive implementation of biowaste sorting at source and the roll-out of incentive-based pricing for the collection of household and similar waste, with a target of 25 million inhabitants covered by 2025 compared to 5 million in 2015. Transposing Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste, the AGEC law has set the date for mandatory the sorting of biowaste at source at 31 December 2023.

59 The 2015 Energy Transition for Green Growth law imposed the roll-out of incentive-based funding for public waste services. It set a target of 15 million inhabitants in 2020, then 25 million inhabitants in 2025. Its implementation remains very slow, as currently only 7 million inhabitants are concerned by incentive-based pricing. According to the ADEME, recent experience has shown that the introduction of incentive-based pricing allows a 31% reduction in the quantity of residual household waste, a 17% increase in packaging and paper collection and a 5% reduction in the quantity of household and similar waste.

60 See Article L 541-21-1 of the Environment Code. Biowaste accounts for one third of the contents of French people's residual waste bin.

61 Through inter-municipal public cooperation bodies (EPCIs), which are responsible for public waste management services, and the entities in charge of waste treatment.

62 The recovery plan topped up the ADEME's "Circular economy" fund for example, contributing an extra €84 million in 2021 and 2022 to support the roll-out of selective sorting in public spaces and the modernisation of public and private waste sorting facilities.

63 Citeo invested €119 million in the modernisation of waste sorting facilities between 2018 and 2022, under the territorial performance plan.

64 At their hearing, the Citeo managers explained that the modernisation of the waste sorting facilities and the reduction of the number of facilities from 270 to 150 cost a billion euros.

65 Waste sorting facilities centres have had to be adapted to the extension of sorting instructions. Whereas previously the yellow bin was only for bottles, it now contains pots, trays, tubes, films and other flexible plastic packaging. The sorting centres have had to reorganise the streams of sorted plastic waste. Nevertheless, the recyclers have encountered difficulties recycling material from bales that come from the sorting facilities applying these new stream: incompatibility between light-coloured PET trays and bottles, disruption of PP and PP recycling if PS is present, disruption of coloured PET recycling by opaque PET. In this context, a new stream has been created for plastics. This is the "development" stream, which includes the following categories of packaging: coloured PET, consisting mainly of bottles, opaque PET, consisting mainly of milk bottles, PET trays and multilayer trays, PS pots and trays. Out of 117 waste sorting facilities capable of sorting packaging from areas applying the extension of sorting instructions, 44 are able to separate the development stream from the other streams. Finally, 8 waste sorting facilities can separate plastics according to the different recoverable resins: PS packaging, coloured PET bottles, white opaque PET trays and bottles. Source: response to the questionnaire sent to Citeo.

[66] The EPR schemes are based on the 'polluter pays' principle: those responsible for placing certain products on the market are responsible for funding pollution prevention and management of the waste from their products at end of life. The EPR obligation involves joining an eco-organisation, paying a financial contribution to it and having a minimum of information on the products sold declared to the eco-organisation. The modulation of the contributions by the eco-organisation according to environmental criteria and a bonus-malus system are supposed to encourage them to adopt an eco-design approach to their products, in particular to facilitate their recycling. Before the AGEC law was passed, there were already 14 EPR schemes (concerning household packaging, electrical and electronic equipment, textiles, end-of-life vehicles, etc.). This law created 11 new ones, including a scheme for building industry products or materials, one for toys, one for sport and leisure goods, etc. The EPR schemes enable the organisation and funding of waste collection and recycling. Your rapporteurs are astonished, however, to see that Article L. 541-10-18-1 of the Environment Code provides for the eco-organisations to cover the costs incurred by the household waste and paper management service limited to a maximum of 80% for household packaging waste and 50% for paper and printed material waste.

[67] In France, as part of the France 2030 investment programme, the government has launched a national strategy to speed up recycling and the re-incorporation of recycled materials which is backed by priority research programme (PEPR) with €40 million of funding. For plastics, three areas of research have been defined: contaminants in plastics, the disassembly and dismantling of complex structures, chemical recycling. Finally, and again under the France 2030 programme, €300 million are due to be invested to develop new plastic recycling technologies.

[68] Research on improving recycling abounds, as the examples below illustrate. There is a consensus within the scientific community on the need to anticipate the recycling of plastics as of their design. There are therefore several research projects working on the eco-design of plastic raw materials from the synthesis stage and the design of macromolecular architectures. To overcome the dilemma of choosing between non-recyclable thermosetting plastics with good mechanical properties and recyclable thermoplastics with less good mechanical properties, researchers are developing reversible covalent bonds. The material becomes recyclable with a behaviour and properties equivalent to those of a conventional thermosetting plastic. See Lucherelli M. A, Duval A, Avérous L. (2022). Biobased vitrimers: towards sustainable and adaptable performing polymer materials, Progress in Polymer Science, Vol. 127: chemical groups are "added" to the polymer chain, which will react to a stimulus such as heat and form or undo reversible covalent bonds. Likewise, depolymerisation techniques using (infrared) light are being developed, in particular at the Institut des Sciences des Matériaux in Mulhouse. The development of mechano-chemical recycling is also a fast-growing research field. The aim is to achieve one or more chemical reactions in a blend of polymers in a molten state. The advantage of this process is that it avoids the stages to separate the different polymers that make up the plastic object (stages that are slow, difficult and energy-intensive). This process has been validated on multilayer flexible food packaging. However, it is not yet in industrial use. Biological (or enzymatic) recycling is supported at European level by several projects, including one that is looking at the recycling of commingled raw materials (EU project H2020 2019-2023 Mix-up) and another (EU project H2020 P4SB - from Plastic Waste to Plastic value using Pseudomonias putida Synthetic Biology) concerning the enzymatic recycling of polyurethanes (see Magnin A. et al (2019). Enzymatic recycling of thermoplastic polyurethanes: synergistic effect of an esterase and an amidase and recovery of building blocks, Waste Management, Vol. 85). In the chemical recycling field, a great deal of work is being done on the use of catalysts to reduce the temperatures needed for chemical reactions (and therefore the reduction of the energy used) and improve the purity of products (see Jia et al (2016). Efficient and selective degradation of polyethylenes into liquid fuels and waxes under mild conditions, Science Advances, Vol. 2, Issue 6).

[69] The management of end-of-life plastic products must be integrated into their design to ensure they are recyclable at a reasonable price. Article 61 of the AGEC law provides "*at the latest by 31 January 2030, producers, marketers or importers responsible for placing on the market at least 10,000 units of products per year and declaring a turnover of more than 10 million euros must prove that the waste generated by the products they manufacture, place on the market or import can be recycled in one of the waste recycling streams. This obligation does not apply to products that cannot be recycled in one of the recycling streams for technical reasons, including by modifying their design. The producers, marketers or importers of these products must then prove that this is impossible and will be obliged to reassess every five years whether it is possible to revise the design of the products concerned so that they can be recycled in one of the waste recycling streams. A Council of State decree lays down the conditions of implementation of the first paragraph of this section IV and the sanctions that apply to producers, marketers or importers whose products cannot be recycled in any of the recycling streams and who are unable to prove the impossibility of recycling them in such a recycling steam.*" The purpose of this provision is to constitute a strong constraint for those placing products on the market regarding the choice of the materials and formulations they use in their products in favour of greater recyclability. In addition, the eco-organisations provide producers with support on eco-design. Citeo, for example, has developed a packaging recyclability test (TREE) for the packaging sector. The amount of the eco-contributions paid by producers varies according to the recyclability of the product. Citeo has created a penalty-based system with three rates: 10% (for PET bottles with a non-perforated PETg, PLA (polylactic acid) or PS sleeve for example), 50% (for rigid dark plastic bottles and other packaging non-detectable by optical sorting, for example) and 100% (for opaque PET bottles and other packaging with a mineral filler content of more than 4% or non-recyclable, non-valorisable PVC bottles). Citeo has also introduced a bonus system, in particular to encourage the incorporation of recycled material in packaging.

[70] See OCDE (2022). Global Plastics Outlook. Policy scenario to 2060, OCDE Publishing, Paris. Short-lived applications such as packaging, consumer foods and textiles are expected to dominate plastic waste streams, accounting for around two-thirds of plastic waste in 2060. In addition, although plastics consumption is projected to double in the United States, the European Union countries and China, it will be multiplied by 5.5 in India and by 6.5 in Sub-Saharan Africa.

[71] The recycling rate should increase from 9% in 2019 to 17% in 2060. See OCDE (2022). Above-mentioned report.

[72] The incineration rate will go from 19% in 2019 to 18% in 2060. See OCDE (2022). Above-mentioned report.

[73] The landfilling rate will go from 49% to 50%. In addition 15% will escape proper waste management in 2060 (i.e. 153 Mt), compared to 22% in 2019 (79 Mt). See OCDE (2022). Above-mentioned report.

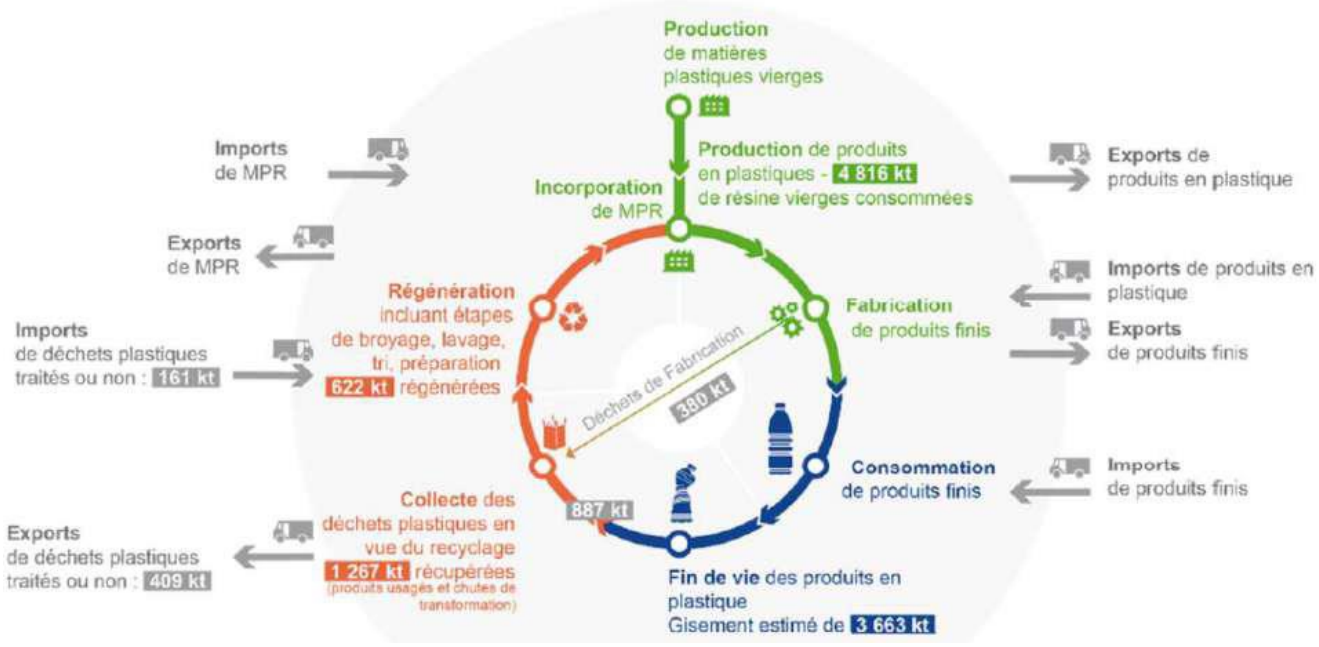
[74] See Philippe Bolo, Member of the National Assembly and Angèle Préville, Senator. Pollution plastique, une bombe à retardement. Parliamentary Office for Scientific and Technological Assessment (OPESCT). No. 3654 National Assembly, No. 217 Senate. 10 December 2020.

[75] The European Union has thus defined a strategy on plastics compatible with the setting up of a circular economy focused on three areas:

- curbing plastic waste by banning it for certain uses (cotton buds, single-use cutlery, plates, straws, stirrers and balloon sticks, food and beverage containers made of expanded polystyrene) and by imposing reductions (lightweight plastic bags, throwaway cups and food containers);
- improving collection, sorting and recycling by means of the following targets (already mentioned above): 65% of municipal waste must be recycled and only 10% of municipal waste by weight will be able to be sent to landfill. By 2030, 55% of plastics and 70% of plastic packaging must be recycled. By 2025, 77% of single-use bottles must be collected (90% by 2030).
- supporting the incorporation of recycled plastics.

The French legislation has borrowed this strategy and strengthened it. It therefore puts an end to the placing on the market of single-use plastic packaging by 2040 (with a goal of reducing the use of unnecessary single-use plastic packaging by 100% by the end of 2025). Several measures have been adopted to promote the sale of loose products and impose reuse (placing on the market of 5% reused packaging by 2023 and 10% by 2027) whilst quantified targets have been set for the reduction in plastics consumption (target of reducing the number of single-use plastic drink bottles placed on by the market by 50% by 2030; 20% reduction in single-use packaging by the end of 2025, including half to be obtained by reuse for the same or different purposes).

[76] The two diagrams that follow illustrate the circular presentation of recycling, which is in stark contrast to the reality. Source ADEME, Cycle de vie des plastiques en France, BNR, 2020 and Re-Fashion activity report.



[77] See Anette Svingstedt, Hervé Corvellec and Emma Samsioe (2020). The normality of industrial and commercial waste: economic, technical and organizational barriers to waste prevention, Detritus , Volume 13.

[78] See Eurostat and Commission staff working document. Executive summary of the impact assessment report. Proposal for a Regulation of the European Parliament and the Council on packaging and packaging waste, amending Regulation (EU) 2019/1020, and repealing Directive 94/62/EC, Brussels, 30.11.2022, SWD (2022) 385 final: in spite of the progress made on recycling plastic packaging waste, it increased by 26.7% between 2009 and 2020 in the countries of the European Union. In 2020, each inhabitant of the European Union generated 178 kg of packaging waste, 19.4% of which was plastic packaging (i.e. 34.5 kg per person). Without radical measures to reduce the production of packaging waste, it is expected to rise from 78 Mt in 2018 to 92 Mt in 2030 and 107 Mt in 2040.

[79] During the preparation of the new Basel Convention technical guidelines on the environmentally sound management of plastic wastes of 12 May 2023, the parties adopted, by consensus, the following resolution: *"Chemical recycling is an emerging technology, whereby plastic polymer molecules are broken down into smaller component parts (monomers or oligomers), subjected to further processing and used as base chemicals, including feedstock for plastic manufacture (feedstock recycling). Chemical Recycling, an evolving field, may be a complementary technology to mechanical recycling for certain plastic waste types. More evidence is needed on the applicability of the Environmentally Sound Management concept to chemical recycling."* UNEP/CHW.16/6/Add.3/Rev.1 http://www.basel.int/Portals/4/Basel%20Convention/docs/plastic%20waste/UNEP-CHW.16-6-Add.3-Rev.1.English.pdf

[80] Sorting technologies are more and more effective in identifying ever more complex plastics formulations, but also more costly. Currently, there are three main techniques:

- density separation which uses the difference in density between two materials to separate them. It should be noted that mineral or chemical fillers incorporated in plastics modify the density of the products and can, in some cases, lead to overlapping between the density ranges of two different polymers;
- spectroscopic methods: near-infrared spectroscopy uses the particular spectral signatures in this range of wavelengths (each wavelength range is associated with a specific material discrimination). However, this technique cannot be used to sort black products containing carbon black, which absorbs a wide range of the near-infrared signal. Technologies in the mid-infrared spectral region appeared in 2020 after 5 years of research and development, which can overcome the non-detection of plastics containing carbon black. Other techniques focused on the X-ray range are used to identify polymers, metals and fillers and additives such as brominated flame retardants still present in electrical and electronic equipment;
- triboelectric separation is used to separate different types of plastics based on their ability to become positively or negatively charged, according to their nature.

New methods are in development, such as separation by dielectric measurement (dielectric properties characterise a material's ability to be polarised under the influence of an electromagnetic field); digital watermarks, which are invisible markers printed on the surface label or moulded in relief in the plastic which can encode a great deal of information and allow very good traceability; artificial intelligence based on the processing of colour images, which works very well for common consumer products. Artificial Intelligence is applied to the spectroscopy data to reinforce selectivity. It could play an

important role in secondary sorting to separate PET bottles and trays, but also in distinguishing food packaging from other packaging.

81 Improving recycling will require the use of compatibilisers which can improve the physico-mechanical properties of the recycled materials from polymer blends. The use of anti-oxidants and stabilisers prevents recycled materials from losing properties such as impact resistance. The difficulties encountered with recycled blends from commingled plastics are often due to molar mass distributions in the polymer chains that are unsuited to the re-transformation processes for the applications sought. Solutions to homogenise the materials and restore the molar masses have been developed, based on the use of peroxides (compounds that can be used to cause polymer chain scission and recombination) and chain extenders. The costs of all of these treatment processes vary according to the degrees of purity and functionality required of the recycled plastics. See scientific note written by José-Marie Lopez-Cuesta and Didier Perrin (June 2023), Centre des Matériaux (C2MA), IMT Mines Alès, for this scientific note. During their hearings, your rapporteurs also met an entrepreneur who is using industrial waste (powder paints, toner, bank notes) to make additives that allow the recycling of plastic products that have not been recycled until now (paint cans, soiled plastic waste, multilayer films). Polymer decontamination techniques are also being constantly improved, in particular through the use of supercritical CO_2.

82 The Court of Auditors, in its September 2022 report entitled "Prévention, collecte et traitement des déchets ménagers : une ambition à concrétiser" (Prevention, collection and treatment of household waste: an ambition to be put into practice) stated that the specific cost of collecting and treating household and similar waste had risen in absolute terms by almost 50% between 2006 and 2016, to reach €10.9 billion in 2016. In addition, local authorities estimate the cost of managing the end of life of packaging (all materials included) at €1.6 billion.

83 In the packaging sector, 35% of packaging is not recyclable and the placing on the market of problematic new forms of packaging represents a massive brake on the improvement of the recycling rate. Some of this packaging has been developed with the aim of reducing the weight of plastics. Thus, a growing amount of dairy product packaging consists of a thin layer of plastic covered by a layer or paper/cardboard giving the packaging stability. The cardboard is often pre-cut so that the consumer can easily separate it from the plastic after consuming the contents. However, if this is not done, the sorting machines consider it to be paper packaging and the plastic disrupts the recycling of the paper. Similarly, a producer of ready meals has replaced its plastic trays with wooden tray. However, this material is not recognised by the optical sorting machine and will be rejected, and so go for incineration or landfill.

84 A 2019 IPSOS study on the quality of French people's sorting practices concerning lightweight packaging revealed that 89% of French people sort these items. However, only 51% do so systematically. Furthermore, only 28% do so correctly.

85 In its 2020 annual public report, the Court of Auditors included a reminder of the role of the eco-organisations: "*The main role of the eco-organisations is to optimise the management of the waste for which they are responsible, but also to prevent the production of waste. Within this framework, they support, organise and fund the prevention, collection, removal and treatment of waste as well as information and communication initiatives and research and development. Waste treatment falls within a European legal framework which is based on a five-level waste hierarchy, ranging from the most desirable, prevention (i.e. non-waste), to reuse, recycling (consisting of reusing waste in place of other materials), energy recovery (aimed at recovering the calorific value of waste by its combustion) and finally, landfill.*" In 2020, the income of the 14 eco-organisations amounted to €1.8 billion (€1.7 billion in eco-contributions and €100 million in proceeds from materials). On the expenditure side, €811 million were spent on supporting local authorities and €386 million paid to actors other than local authorities to support collection. With a turnover of €831.8 million in 2021, Citeo was the largest eco-organisation in financial terms. However, with 46 million tonnes of waste, the building products and materials EPR scheme that started up in 2023, is almost 9 times bigger than the household waste scheme (5.34 Mt) in terms of weight and handles 17 times more funds. The AGEC law created 11 new EPR schemes (professional packaging, toys, sports and leisure goods, DIY and gardening items, mineral and synthetic oils, tobacco products, chewing gum single-use hygiene textiles, fishing gear containing plastic, technical medical aids).

86 Certain contributors expressed regret, for example, that the application of the eco-modulation principle by the Re-Fashion eco-organisation only takes the form of bonuses (bonuses for durability, for obtaining certain environmental certifications, for incorporating recycled materials). In addition, many contributors observed that in spite of the modulation of the eco-contributions and the TREE and LESS decision support tools introduced by Citeo for packaging, the recyclability and usefulness of certain packaging placed on the market leave a lot to be desired.

87 For example, packaging is placed on the market without any prior consultation with the waste sorting facilities and recyclers, which leads to disruption of sorting and recycling processes. For example, a coloured PET tray containing carbon black is not recognised by sorting machines. Similarly, after they came onto the market, it was found that opaque PET bottles disrupt the recycling of other PET bottles. It took three years of R&D after the event to reduce the opacifier content in opaque PET bottles and enable them to be recycled. Since it is impossible to impose a limited number of resins and formulations that can be placed on the market, considerable investments are being made to develop recycling channels for resins that should not have been put on the market.

88 The AGEC law involves more EPR channels in the development of reuse for the same or a different purpose. Thus, the electrical and electronic equipment (3 E), home furnishings (EA), clothing textiles, household linen and shoes (TLC), sport and leisure goods (ASL), DIY and gardening items (ABJ) and toys EPR schemes have to pay into a reuse fund and a repair fund. In addition, the eco-organisations responsible for the household packaging channels have to contribute to achieving the national target of 5% of reused packaging in the packaging placed on the market in France in 2023 and 10% in 2027. The AGEC law also provides for 20% reduction in single-use plastic packaging by the end of 2025, at least half of which is to come from reuse (for the same or a different purpose) and a 100% reduction in the "unnecessary" single-use plastic packaging. Furthermore, the AGEC law sets a target of 100% of single-use plastic packaging by 1 January 2025. In concrete terms, it

must be recyclable, not disrupt the sorting and recycling processes and not include any substances or elements liable to limit the use of the recycled material.

[89] A monopsomy is a type of market where there are many sellers and a single buyer.

[90] See Denis Voinot (2021). La passation des marchés de prévention et de traitement des déchets par les éco-organismes. Revue juridique de l'économie circulaire. No. 1. The creation of the eco-organisations has revolutionised the waste treatment market. Whereas waste management providers would traditionally had contracts with thousands of clients, these economic operators now have only a few clients, or even just one, as their interlocutors. The waste management providers are therefore highly dependent on the eco-organisations, which can dictate their conditions, particularly on prices and length of contracts, at the risk of jeopardising the financial equilibrium of the waste management providers and hindering the investments needed to ensure quality recycling.

[91] The eco-organisations tend to control the entire value chain for a given stream, thereby creating a de facto monopoly on the collection, treatment and use of recycled material. This is the case for the development stream set up by Citeo.

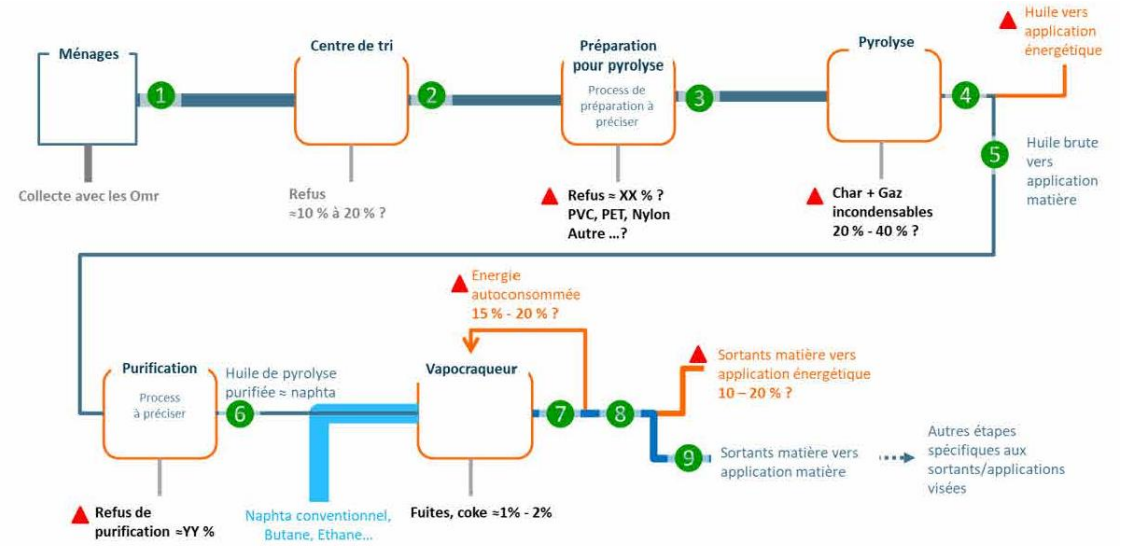
[92] The eco-organisations have certain statutory obligations with regard to waste treatment. Nevertheless, their financial aims (to limit the cost of treating waste for their shareholders) and strategy (their actions are mainly focused on the management of the end of life of waste) can be at odds with other objectives in terms of the circular economy (to prevent the production of waste, ensure quality recycling), industrial policy (to encourage the development of a national waste treatment industry) or environmental performance (to prioritise mechanical recycling over chemical recycling due to its lower environmental impact). In fact, the current governance of the eco-organisations does not allow these concerns to be taken into account in spite of the creation of a committee of stakeholders.

[93] See Simon Hann, Toby Connock. Chemical Recycling: State of Play. Report for CHEM Trust, 8th December 2020. "*Throughout this report the overriding finding is that there is a general lack of transparency or robust evidence base that can be used to verify claims or generate firm conclusions around the viability of many technologies. This is due, in part, to the sheer number of smaller, lab scale examples that demonstrate possibility rather than viability. At the commercial scale (or close to it), the competition to be first to market is strong and this appears to limit publicly available evidence. This also means that caution must be exercised as a lack of evidence can mean either a knowledge gap or that the answer is less favourable. In the interests of confirming the role, scale and scope of these technologies, there is an urgent need for more transparency within the chemical recycling industry. There is evidence to indicate that at least some technologies have promise, but important details around mass flows, chemical use and the viability of the processes in real-life waste management circumstances are largely incomplete. Investment should be reserved for those organisations that freely engage to improve the understanding around these missing elements.*"

[94] Little information is available and it mostly comes from the companies developing the recycling process, with no possibility of verifying the figures provided. In addition, depending on the technology involved, the energy and water consumptions and carbon footprints vary considerably. There is, however, a consensus on the fact that mechanical recycling remains the technology that emits the least CO_2, regardless of the chemical recycling method considered, even if the comparison of the performances of chemical recycling and mechanical recycling is only really relevant if the quality of the product obtained by the different technologies is similar. The thermal recycling technique (pyrolysis and gasification) would be the most impactful in terms of CO_2 emissions and could even have a worse environmental performance than the production of virgin plastic depending on the methodologies used to make the comparisons.

[95] See Chemical Recycling of Polymeric Materials from Waste in the Circular Economy. Final Report prepared for The European Chemicals Agency. August 2021: "*Analysis of research literature has shown fragmented knowledge about the fate of substances of concern in various chemical recycling processes. Available studies mainly focused on various types of pyrolysis of e-waste and the fate of brominated flame retardants; however, no studies were identified for other established chemical recycling technologies. It is important to note that various pyrolysis technologies demonstrated different abilities to cope with substances of concern. Furthermore, it is not clear if the technologies analysed in the scholarly literature have been applied in industrial settings.*"

[96] One of the arguments put forward in favour chemical recycling is that it is enables infinite recycling, with the exception of dissolution recycling (see above). However, the Chemical Recycling: State of Play report already mentioned points out the following: "*The 'infinite loop' is technically possible as the material itself isn't degraded during each recycling 'loop', but in practice this is not without - often significant - losses for each lifecycle and therefore a significant amount of virgin polymer would still need to be produced to meet any shortfall*." The quantity of virgin material needed depends on the yields expected. According to the information obtained by your rapporteurs during their hearings, the PET chemical and biological depolymerisation methods could achieve yields of 90%, as long as the feedstock is homogeneous (which implies prior sorting) and has been prepared (elimination of disruptors, especially for textiles - and contraindicated contaminants, shredding and washing). See Chemical and physico-chemical recycling of plastic waste (June 2022), RECORD no. 21-0919/1A Deloitte. On the other hand, yields with pyrolysis techniques are much more modest given the large number of steps involved which cause material to be lost during the sorting phase, during pyrolysis, when the pyrolysis oil is purified and during steam cracking.



Source: ADEME - Plastic recycling process by pyrolysis/steam cracking – illustration of the successive steps to be taken into account for household packaging waste

The ADEME therefore considers that pyrolysis and steam cracking yields are both only 70%. Consequently, and assuming that all of the pyrolysis oil is sent to the steam cracker, the maximum recycling rate is 0.70 x 0.70 = 49%. Other studies based on a yield from sorting of 90%, a pyrolysis yield of 70% and a yield in the steam cracking phase of 50% arrive at a recycling rate for plastic waste recycled by the thermal depolymerisation method of 0.9 x 0.7 x 0.5 = 31.5 %, which largely contradicts the idea of infinite recycling.

97 The question of the traceability of the material arises essentially for the thermal depolymerisation method. The pyrolysis oil can be used to produce motor fuel or heating fuel (plastics-to-fuel channel) or as a substitute for conventional base oils such as naphtha, as feedstock for steam crackers. However, given the huge capacity of steam crackers (several hundred thousand tonnes per year, and even several million in some cases), pyrolysis oils are mixed with conventional naphtha to serve as inputs, and it is not possible to physically measure the recycled content of the different steam cracker outputs. The proportion of recycled raw materials used in the production and the quantity of recycled products generated are then calculated by the mass balance approach.

98 Contrary to popular belief, chemical recycling is not currently destined to be used for the recovery of contaminated and heterogeneous waste for which separation and sorting are not economically and technically viable. Indeed, to be economically viable, chemical recycling needs to reach high yields, which means having access to inputs of sufficient quality in large quantities (homogeneity of streams). Furthermore, like what happens for mechanical recycling, the plastics are pre-treated to eliminate contaminants (glue, labels) and then shredded. See Chemical and physico-chemical recycling of plastic waste (June 2022), RECORD no. 21-0919/1A Deloitte. Even in the case of pyrolysis, which is intended to treat blended resins (polyolefins in particular), upstream sorting is done to avoid the presence of PVC and other waste containing halogens (chlorine, bromine), as their decomposition leads to the production of halogen acid gases such as hydrogen chloride. Not only are these gases toxic, but they cause thermal decomposition of the depolymerisation equipment. See Chemical Recycling: State of Play. Above-mentioned report.

99 Access to feedstock sources is an even more strategic issue for chemical recycling than it is for mechanical recycling. Indeed, given its high cost, chemical recycling can only be profitable if it handles large volumes of waste (several tens of thousands of tonnes).

100 See Sophie Duquesne (November-December-January 2020-2021), above-mentioned article. "*Like a battery that can theoretically be charged and discharged an infinite number of times, polymer chemists are expected to design plastics in the future that could be polymerised, depolymerised and then repolymerised with minimal changes in their final quantity or properties. For example, an original approach to the eco-design of carbon-fibre reinforced composites has recently been proposed by Yu et al* [(2016). Carbon fiber reinforced thermoset composite with near 100 % recyclability, Advanced Functional Materials, 26, https://doi.org/10.1002/adfm.201602056.] *The method involves the dissolution and repolymerisation of an epoxy matrix in ethylene glycol (EG) by a transesterification reaction at high temperature*".

101 In the packaging sector for example, PET is the only mechanically recycled resin recognised as food grade. However, chemical recycling (chemical, biological and thermal depolymerisation) can produce materials with the same quality as virgin material.

102 The development stream includes a secondary sorting stage to separate plastics according to the different recoverable resins: PS packaging, coloured PET bottles, PET trays and white opaque PET bottles. This extra sorting allows the closed-loop mechanical recycling of the materials. Thus, 70% of the pots and trays market has been captured by Paprec, which will

initially mechanically recycle single-layer trays with return to food grade. However, when the Eastman chemical depolymerisation facility goes into service 2025, the treatment of all PET pots and trays will be transferred to Eastman for a period of 9 years, and this will include both multilayer trays (mechanically non-recyclable) and single-layer trays (mechanically recyclable).

[103] See Lase et al (May 2023). How much can chemical recycling contribute to plastic waste recycling in Europe ? An assessment using material flow analysis modeling. Resources, Conservation and Recycling, Volume 192 or Systemic (March 2022). Above-mentioned report.

[104] Many environmental organisations are concerned about the lock-in effect of chemical recycling. Indeed, it requires substantial investments, which can only pay off if supplies of plastic of sufficient quality and quantity can be guaranteed over a long period. Consequently, chemical recycling can lock in public waste management policies for the long term and thwart initiatives aimed at reducing the volume of plastic waste. The rebound effect consists of encouraging the use of plastic by giving consumers the impression that the end of life of plastics is under control. Furthermore, chemical recycling allows the large petrochemical conglomerates to "green" their image by incorporating a portion of recycled plastics in their steam cracking facilities. The promise of chemical recycling has also stymied the government and parliament's attempts to eliminate PS from the food packaging market, as Nestlé and Danone agreed to do when they signed the National Plastic Packaging Pact in 2019. Thus, a consortium was set up in autumn 2020 at the instigation of Citeo, Valorplast and Syndifrais bringing together companies from the dairy, meat and poultry sectors to promote a polystyrene recycling channel by 2025. The aim was to achieve a recycling rate of 100% of recyclable PS in France in 2025. To this effect, the companies have undertaken to incorporate recycled polystyrene in their packaging. Following a call for tenders put out by Citeo, two contractors were selected. 80% of the market has gone to Belgian company Indaver, which is in the process of building a pyrolysis recycling plant in Antwerp, which should be operational in 2024. 20% of the market has gone to Spanish mechanical PS recycling company Eslava. It should be noted that Citeo has committed to a stream of 10,000 tonnes, whereas 100,000 tonnes of polystyrene packaging is placed on the French market every year. In spite of this low recycling rate, the government considers that there is a recycling channel for polystyrene. Consequently, the ban on polystyrene packaging in the bill against plastic packaging harmful to the environment and to health was removed when it passed its first reading in the National Assembly on 6 October 2022 and the bill now only bans the use of certain extruded PS packaging by fast food outlets.

[105] See Les synthèses de l'Office. Les enjeux scientifiques du traité international visant à mettre un terme à la pollution plastique. May 2023.

[106] While the targets for the collection for recycling of plastic drink bottles were set at 77% for 2025 and 90% for 2029, the rate in France was 60% in 2022. Likewise, the recycling rate for household plastic packaging in France stood at 23% in 2021 (European average 37.6%), while the target is 50% in 2025 and 55% in 2030 at European level. France is therefore second to bottom in the European ranking. France's poor performance on recycling has considerable financial repercussions due to the non-recycled plastic tax introduced in 2021 to cover the cost of the European recovery plan. Under this system, the ten richest Member States pay 80 cents to the Community budget per kilogramme of unrecycled plastic waste. In 2021, France thus paid €1.247 billions to the European Union. It should be noted that some countries (such as Spain and Italy) have decided to pass on this tax on non-recyclable single-use plastic packaging. France has opted to cover the cost of this tax out of its national budget.

[107] All the countries that have introduced a deposit return system have seen a steep rise in their collection and recycling rates. For example, collection rate for PET bottles has reached 90% in Germany and Finland and 85.5% in Estonia.

[108] Many local authority leaders pointed out that the introduction of a recycling deposit return scheme muddies the waters and detracts from the message on the extension of sorting instructions, which emphasises the simplicity of waste sorting practices: all plastic packaging is to thrown in the yellow bin.

[109] The PET bottle collection rate varies widely from one region to another. It reaches 82% in Bourgogne-Franche-Comté, 80% in Pays de la Loire, 49% in the Paris region (Ile-de-France) and 44% in Provence-Alpes-Côte d'Azur. Generally speaking, the outcomes are less good in group housing, tourist areas and when on-the-go-consumption is involved. Consequently, large conurbations perform considerably less well.

[110] PET bottles are the waste with the highest resale price. Thus for local authority Angers Loire Métropole, plastics account for 15% of waste, but 50% of income. In addition, 75% of the operating costs of the waste sorting facility are overheads, with no direct link to the volumes collected.

[111] According to the information provided by the ADEME, whereas the number of plastic drink bottles placed on the market had been falling since 2018, it started to rise again in 2022.

[112] Long defended exclusively by the public authorities and environmental organisations, this idea is now shared by marketers and trade associations such as Plastics Europe, the pan-European association of plastics manufacturers. Beyond the recognition of the need to reduce plastics consumption, the question nevertheless arises as to what measures to prioritise to achieve that objective and how to implement them effectively. The above-mentioned April 2022 Systemiq report estimates that by 2050, the plastics system could achieve 78% circularity by 2050 by 30% of waste avoided through reduced consumption and substitution with other materials and 48% being recycled, (including 27% by mechanical recycling and 21% by chemical recycling). This would leave only 9% going to landfill and incinerators. This study therefore backs up the 3Rs strategy that France and the EU have been trying to impose for several years: "Reduce, reuse, recycle". In this respect, the proposal for a Regulation of the European Parliament and of the Council on packaging and packaging waste, amending Regulation (EU) 2019/1020 and repealing Directive 94/62/EC aims to rebalance the efforts to be made, which until now were very focused on recycling, to arrive at a true circular economy of packaging. This proposal insists on the need to limit

the production of waste and puts forward several measures to prevent waste, to encourage packaging reuse and combat unnecessary packaging. At national level, the AGEC law and the Climate and Resilience law (Law no. 2021-1104 of 22 August 2021 on Combating Climate Change and Strengthening Resilience to its Effects) contain ambitious objectives on reducing plastic packaging and packaging reuse that the government must take into account in its strategic decisions on recycling in order to pursue a consistent policy in favour of a circular plastics economy.

[113] Such as TREE developed by Citeo, Circpack by Veolia or RecyClass by Plastics Recyclers Europe. It would be preferable to decide on a European standard which would establish design criteria for recycling, along with a recyclability assessment procedure. This is part of the challenges of the above-mentioned proposal for a Regulation of the European Parliament and of the Council on packaging and packaging waste which the European Commission is currently preparing.

[114] Under Article 62 of the AGEC law, the contributions paid by the marketers of plastic packaging are modulated according to the recyclability of the packaging. The Citeo scale has three levels of penalty, ranging from 10% of the total contribution per Consumer Sales Unit (for PET bottles with a PETg, PLA or PS sleeve, for example) to 100% (for opaque PET bottles and other packaging with a mineral filler content of more than 4%, for example). However, these rates do not seem to be dissuasive when set against the marketing gains the producers can make thanks to certain types of non-recyclable packaging. It would therefore be necessary ether to ban them or apply a tax, like the €0.45 per kilo tax introduced by Spain and Italy on single-use plastic packaging.

[115] Simplification and homogenisation of formulations offers several advantages: it would overcome the technical limitations of mechanical recycling caused by the great heterogeneity of the inputs and facilitate high quality closed-loop recycling. Furthermore, the reduction of the number of streams should lead to greater consolidation of those streams, inducing economies of scale and in the end reducing the cost of recycling.

[116] It should be noted that if France does not manage to reach the collection rate targets required by the European Union, it will be forced by the new European regulations to introduce a recycling deposit return scheme.

[117] Improving collection rates will in fact also mean reducing the amount of waste to be collected (by eliminating unnecessary packaging, reducing the remaining packaging and developing reusable packaging) and improving the quality of the collection (through the recyclability of all packaging).

[118] Incentive-based pricing can nevertheless raise issues of acceptability with the population and lead to increased dumping and leakage into the environment.

[119] The extension of sorting instructions has only been operational everywhere in the country since the beginning of 2023. It is therefore necessary to get citizens on board to improve sorting practice. In their previous study of plastic pollution in 2019-2020, your rapporteurs observed that awareness-raising among citizens carried out directly by waste coordinators by means of personal interviews was more effective than general information campaigns, although they are more expensive to carry out. It would therefore be appropriate that Citeo covers a larger proportion of these communication costs. Generally, it is necessary to increase the density of facilities available to inhabitants, in particular in urbanised areas. Thus, in Paris, the quantity of plastics sent for incineration per inhabitant is 40% higher than in semi-urban areas. In addition, there is a great deal of room for progress in recovering the pool of waste generated by out-of the-home consumption (evaluated at 140,000 tonnes). The AGEC law provides for the costs relating to the comprehensive introduction by 1 January of separate collection for the recycling of packaging waste from products consumed out of the home to be covered by the eco-organisations responsible for the household packaging channel. Out-of the-home consumption also concerns public and private places that do not use the public waste management services (railway stations, airports, museums, theme parks, shopping centres, etc.). The new approval of the eco-organisations for the household packaging channel provides for technical and/or financial support from the eco-organisations for at least 60,000 tonnes per year (all materials included). Currently, only 20,000 tonnes of out-of-the-home waste are collected.

[120] Whether they be the construction, end-of-life vehicles or the electrical and electronic sectors.

[121] In light of these reflections, there is a need to amend section II of Article L. 541-1, which lays down the hierarchy of waste treatment modes, making a distinction between mechanical recycling and chemical recycling for waste that cannot be recycled mechanically. It could also be specified that chemical recycling should prioritise the technologies with the most favourable environmental impact (impact that could be established on the basis of transparent life cycle assessments, which are documented and subjected to a critical review process).

[122] See Hugrel Charlotte, Palluau Magali (Bleu Safran) (2021). Approche « Mass balance » et recyclage chimique des plastiques. Revue des enjeux méthodologiques pour la voie pyrolyse – vapocraquage. The conversion factor makes it possible, at steam cracker level, to quantify the volume of "circular" credits that can then be allocated to the outputs taking account of the quantity of oil produced by pyrolysis of the plastic waste that goes into the steam cracker. However, there are three ways of calculating the output base taken into account: (1) either by taking account of all the outputs except the losses in the strictest sense of the term (losses to fugitive emissions and coke): in this case the output base includes energy self-consumption, material destined for energy applications and material outputs destined for material outputs; (2) or by taking account of the outputs destined for energy applications and outputs destined for material outputs; (3) or by taking account of the outputs destined for material applications only.

[123] This is the rule for the allocation for the recycled content present in the materials going into the steam cracker to the products coming out of the process The pyrolysis oils constitute a secondary input compared to conventional naphtha. The steam crackers will manage the feedstock as a blend, and it is not possible to physically measure the recycled content of the outputs from a steam cracker. To be able to define the quantity of recycled material, the mass balance approach is used, which consists of quantifying the credits to which the characteristic "recycled" are attached and then assigning them to certain products obtained as outputs from the steam cracker. Two methods can be used: (1) the "rolling average" method in which

the proportion resulting from the end products is calculated on average for all the finished products; (2) the "credit method" in which the credits are allocated freely between the outputs, regardless of their actual recycled product content. This method, which is preferred by industry, allows them to freely choose the outputs (ethylene, propylene, butadiene, benzene, etc.) which benefit from the recycled credits depending on demand on the market. For the end customers, this allows them to procure supplies of monomer plastics certified "100% mass balance recycled" regardless of their actual recycled content, which is much more attractive than a claim consisting of a small percentage of recycled content.

124 At the present time, the incorporation of recycled materials constitutes a bonus on the eco-modulation scales of both Citeo and Re-Fashion. If incorporation of recycled materials becomes the rule, the failure to comply with this obligation must entail dissuasive penalties. The United Kingdom has introduced a tax on virgin plastics which obliges the companies that produce or import packaging containing less than 30% recycled plastic to pay a tax of £200 a tonne. The extension of the obligations on incorporating recycled materials must concern all producers to avoid undermining equality of treatment and allowing unfair competition. To avoid fraud, it will be necessary to develop reliable methods of traceability of recycled content. As it is currently worded, the French legislation *de facto* bans products made from plastics recycled by pyrolysis from claiming a percentage of recycled plastic. In fact, the law requires that the minimum guaranteed percentage of recycled material in the packaging be indicated when this type of claim is made. And it is impossible to define, for one item of packaging or product, the proportion of the material from the mass balance actually used to make it. On the other hand, chemical recycling by pyrolysis allows the nature of the polymer constituting the waste treated by pyrolysis waste to be decoupled from the nature of the recycled polymer produced. This means that it is possible to obtain recycled PS from polyolefin waste. The placing on the market of recycled resin can therefore have no connection with the actual conditions of the management of that resin at the end of its life. That risks cancelling out the knock-on effect expected between requirements on the recycled material content of a polymer and the improvement of its recycling rate. See Hugrel Charlotte, Palluau Magali (2021). Above-mentioned study.

125 Decree no. 2022-748 of 29 April 2022 on the informing of consumers on the qualities and environmental characteristics of waste-generating products defines recyclability as the ability to actually recycle waste from identical or similar products. Recyclability is characterised for this waste by:

- the ability to be efficiently collected within a given territory, by providing the population with local collection points;
- the ability to be sorted, that is to say oriented towards recycling channels to be recycled;
- the absence of elements or substances that disrupt sorting or recycling or that restrict the use of the recycled material;
- the fact that the recycled material produced by the recycling processes used represents more than 50% in mass terms of the waste collected;
- the ability to be recycled on an industrial scale and in practice, in particular via a guarantee that the quality of the recycled material obtained is sufficient to guarantee the long-term viability of the outlets, and that recycling channel can prove it has enough capacity to handle the products that can be included in that stream.

126 As regards mechanical recycling, it will be necessary to ensure that the recycling of plastics, and PET in particular, does not represent a risk to the consumer due to a concentration of contaminants and additives in recycled materials. As far as chemical recycling is concerned, its legitimacy will involve providing researchers with access to the data on its yields, the management of contaminants and the development of scientifically validated life cycle assessments.

Persons consulted in alphabetical order

Mr Luc Avérous, professor at the University of Strasbourg.

Mr David Azoulay, Director of the Environmental Health Program at the CIEL (Center for International Environmental Law).

Ms Cécile Barrere Tricca, Director of the Chemistry for Industry business unit and Mr Abdelhakim Koudil, Plastics Recycling program manager at IFP Énergies Nouvelles.

Mr Romain Bentz, Deputy Public Affairs Manager France, Mr Christophe Rahier, Director of Sustainable Materials and Circularity and Mr Christophe Durand, Director of Sustainable Material Solutions and Partnerships at Michelin.

Ms Délia Bergonzi, Deputy Director and Mr Olivier Vilcot, Director of the French national union of plastics recyclers (Syndicat national des régénérateurs de matières plastiques, SRP).

Ms Flore Berlingen, writer and independent expert, author of the book "Recyclage, le grand enfumage".

Ms Clara Bermann, Head of Public Affairs & Sustainable Development, Mr Vianney Burucoa, sport and leisure goods EPR project manager and Ms Stéphanie Bailly, textile EPR project manager at Decathlon.

Mr Eric Boël, chairman of the sustainable development committee of the Union des Industries du Textile and director of Les Tissages de Charlieu, Ms Maud Hardy, director of Re-fashion and Mr Pascal Denizart, director of the CETI (European Centre For Innovative Textiles)).

Mr Henri Bourgeois Costa, spokesman for the Tara Océan foundation.

Mr Olivier Brette, lecturer in economics, Ms Valérie Massardier, lecturer and research supervisor in chemistry and polymer engineering and Ms Nathalie Lazaric, research director at the CNRS.

Ms Chloé Brumel-Jouan, Director of Institutional Relations, Legal Affairs and Internal Control, Mr Xavier Lantoinette, Environmental Performance Director at Ecosystem.

Mr David Buhe, Policy Officer for Packaging Waste, Directorate-General for Environment, European Commission.

Mr Manuel Burnand, General Manager and Mr Christophe Viant, Chairman of the Plastics section of Federec.

Mr Mauricio Camargo, university professor, head of the Innovative Processes research team at the University of Lorraine.

Mr Thibault Cantat, research director, head of the Circular Carbon Economy at the CEA, Mr François Legalland, director of the Innovation Laboratory for New Energy Technologies and Nanomaterials (LITEN) and Mr Richard Laucournet, head of the New Materials Technologies department at ITEN.

Mr Bernard Chaize, director of Chaize Environnement.

Ms Stéphanie Coullon, engineer in the Environment department of the French Builders Federation (Fédération française du bâtiment).

Ms Hélène Courades, general manager of soft drinks industry federation Boissons Rafraîchissantes de France and Mr Olivier Larose, packaging manager at CCEP-Coca-Cola Europacific Partners.

Mr Hervé Corvellec, professor at Lund University (Sweden).

Mr Jean-Yves Daclin, General Manager and Ms Véronique Fraigneau, Public Affairs and Communication Manager at Plastics Europe France.

Mr Sylvain Dagand, chairman and managing director of Bioval and Mr Nicolas Bois, Revalgreen site manager.

Mr Olivier Dalle, chairman of Environnement Massif Central.

Mr Jean-Louis Demois, Vice-President of Angers Loire Métropole, Mr Jean-Luc Davy, President of SPL Anjou Tri Valor, Mr Damien Grasset, President of Trivalis and Mr Erwan Calonnec, General Manager of Services at Trivalis.

Ms Muriel Descamp, general manager of SYDED du Lot.

Mr Christophe Doukhi-de-Boissoudry, President of the French Association for Biobased Compostables (Association française des compostables biosourcés, AFCB) and Ms Chloé Jouglas, public affairs consultant.

Mr Mathieu Durand, lecturer at Le Mans University and Ms Jeanne Pérez, PhD student.

Ms Sophie Duquesne, Professor at Centrale Lille.

Mr Nicolas Garnier, managing director of Amorce.

Mr Jean-François Gerard, lecturer-researcher, assistant scientific director at the Institut de Chimie.

Ms Valérie Goff, Senior Vice-President Polymers and member of the Refining & Chemicals Management Committee and Mr Bernard Hoffait, Vice-President Institutional Relations at Total.

Ms Nathalie Gontard, research director at the National Research Institute for Agriculture, Food and Environment (INRAE).

Mr. Baptiste de la Gournerie, chairman and Mr Slimane Bendjilali, co-founder of the Utopia association.

Mr Hervé Guerry, chief executive of Créastuce, chairman of the Cycl-add startup.

Mr Sylvain Guinaudie, President of SMICVAL and Mr Yann Herber, chief of staff.

Mr Jean Hornain, CEO, Ms Sophie Génier, Head of Recycling Services and Mr Thibault Boucher, Public Affairs Officer at Citeo.

Mr Gilles Istin, Marketing and Innovation Director and Mr Philippe Chanu, Public and Institutional Relations Director at KNAUF Industries.

Mr Nicolas Joly, Vice-President Plastics and Mr Julien Renvoise, Sustainability Business Development Leader at Trinseo France.

Mr Samuel Just, head of the waste prevention department at the Ministry of Ecological and Solidarity Transition (MTES), General Directorate for Risk Prevention (DGPR).

Ms Catherine Klein, Managing Director and Mr Alban Cotard, R&D Manager at Valorplast.

Mr Emmanuel Ladent, CEO and Mr Alain Marty, Scientific Director at Carbios.

Mr Thomas Ladreyt, Deputy General Manager and Ms Louana Lamer, Head of EPR for Textiles at Emmaüs France.

Mr Khalid Lamnawar, professor at the University of Lyon.

Mr Bernard Le Moine, Director of the French Committee for Plastics in Agriculture (CPA) and Mr Ronan Vanot, Director of Adivalor.

Mr José-Marie Lopez-Cuesta, Director of the Materials Centre (C2MA) at IMT Mines d'Alès.

Ms Stéphanie Lumbers, Sustainable Development Director at the French cosmetics industry federation FEBEA

Mr Marc Madec, Sustainable Development Director at Polyvia and Mr Gilles Dennler, Research Director at the Industrial Technical Center for Plastics and Composites (IPC).

Mr Patrick Maestro, Scientific Director, Research and Innovation, Mr Guy-Noël Sauvion, Eco-efficiency Manager and Mr Sergio Mastroianni, Growth Initiative Leader at Solvay.

Mr Roland Marion, Circular Economy Director, Mr Raphaël Guastavi, assistant manager of the Products & Materials Efficiency department and Ms Alice Gueudet, plastics engineer at the ADEME.

Ms Muriel Mercier-Bonin, research director at the INRAE and Ms Véronique Gayrard, professor of physiology.

Mr Baptiste Monsaingeon, lecturer at the University of Reims.

Mr Vincent Monteil, research director at the CNRS.

Mr Patrick Morel, Research and Innovation Director at Kem One.

Ms Lise Nicolas and Mr Enzo Muttini, co-founders of Mr et Mme Recyclage.

Mr Renaud Nicolaÿ, professor at ESPCI Paris (Higher School of Industrial Physics and Chemistry).

Mr Jean-François Nogrette, CEO and Mr Benoît Perreau, Markets & Clients Director at Veolia.

Ms Magali Renaud-Simeon, professor at the University of Toulouse, Ms Isabelle André, research director at the CNRS.

Ms Marion Richard, Environment and Environmental Regulatory Watch Manager at the Legrand group.

Mr Nicolas Richard, manager of Global Recov.

Mr Vincent Roucoules, director of the Institut des Sciences des Matériaux in Mulhouse and Mr Arnaud Spangenberg, research fellow.

Ms Inari Seppa, Technology Innovation Director & Circular Economy Advocacy Leader and Ms Fatma Sahin, Government Affairs Director EMEA at Eastman.

Ms Sophie Sicard, Deputy Director for Sustainable Development and Institutional Affairs, France & Europe at Paprec.

Mr Jérémie Soulestin, professor at Institut Mines Telecom Lille-Douais.

Mr Olivier Teillac, Public Affairs and Sustainability Manager at BASF France.

Mr Mathieu Tuau, Corporate Packaging Director and Mr Fabio Brusa, Public Affairs Director at Nestlé.

Mr Thierry Vincelot, head of the Chemistry of Materials department and Mr Jean-Mario Julien, R&D engineer at the French (National Laboratory of Metrology and Testing (LNE).

Mr Denis Voinot, professor at the University of Lille.

Ms Anne-Charlotte Wedrychowska, Director of Circular Economy & CSR at the FIEEC (Federation of Electrical, Electronic and Communication Industries).

Ms Sabine Zariatti, Industrial Partnership Development Manager and Mr Arthur Huin, Director of Public Affairs, Waste Recycling and Recovery, France at Suez.

Visits on 19 April 2023

- ✓ *To EVERÉ*

Mr Roland Mouren, Vice-President with responsibility for waste at the Métropole Aix-Marseille-Provence.

Mr Béranger Saltel-Pongy, Environment, Methods & Communication Manager at Everé.

Ms Mélodie Turelier, head of the waste recycling and recovery department at the Métropole Aix-Marseille-Provence.

- ✓ *To Pellenc ST*

Mr Laurent Petit, Business Development Director at Pellenc ST.

Mr Raphael Josselin, ecodesign engineer at Pellenc ST.