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Pathways to sustainable plastics – A discussion brief

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STEPS

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Summary

The growing attention to the negative side-effects of our use of plastics has led to numerous calls for changing the current plastics system. However, there is lack of coherent and systematic assessments of how and in what direction the plastics system should change to become more sustainable. This discussion brief explores five potential pathways: *Bio-based, Biodegradable, Recycled, Fewer types* and *Reduced use*. Each pathway is assessed in terms of the promise it makes, what it entails and how it has been criticized. With a growing number of voices on the need for sustainable plastics, this discussion brief provides an overview of the opportunities and challenges of the pathways that can potentially take us there. The diversity and complexity of the system, as well as the lack of clear direction for what is a more sustainable plastics system, make it difficult to govern. Furthermore, there is no history of building an institutional capacity and expertise in, for example, government and research around policy and governance for plastics. Plastics is a critical material for sustainability in many areas (e.g. food, water and energy), but policies are needed to reduce the use of fossil feedstock, increase circularity and resource efficiency, and prevent leakage to the environment.

Acronyms

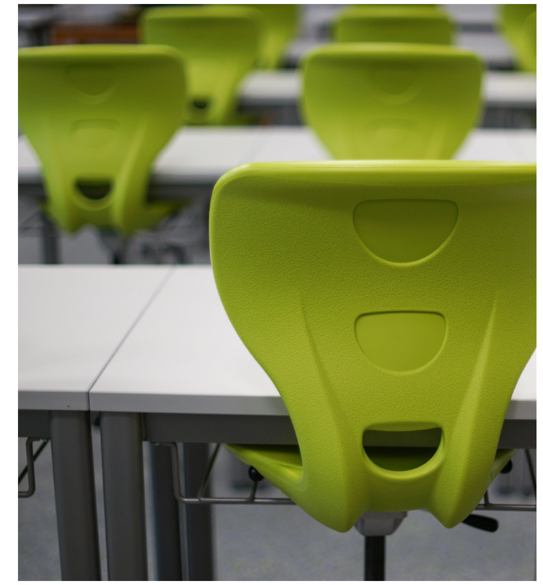
- bio-PE .... bio-based polyethylene
- bio-PET .... bio-based polyethylene terephthalate
- CCU .... carbon capture and use
- EPA .... Environmental Protection Agency
- PBS .... polybutylene succinate
- PEF .... polyethylene 2,5-furandicarboxylate
- PET .... polyethylene terephthalate
- PHA .... polyhydroxyalkanoates
- PLA .... polylactic acid
- REACH .... Registration, Evaluation, Authorisation and Restriction of Chemicals
- TPS .... thermoplastic starch

Introduction

Plastics are ubiquitous in society, and increasingly so in nature. Frequent reports highlight the problem of plastic pollution from remote beaches littered with plastics, to plastic gyras in the ocean and microplastic found in our drinking water. Meanwhile, plastics are an integral and important part of a modern and more sustainable society. They protect food and help reduce food waste, enable the design of lighter vehicles, and facilitate efficient transmission of electricity as an insulator in cables. Plastics offer many solutions, but also generate problems.

One challenge of the plastics system is the dependence on fossil feedstock, resulting in emissions of greenhouse gases which is not compatible with the Paris Agreement and the need to reach zero emissions. Other challenges are insufficient waste management and leakage into the environment, both of which have caused a concerning amount of plastics in nature with partially unknown effects. There is a range of private and public initiatives aimed at tackling the sustainability challenges of plastics, from beach clean-ups to bans on plastic carrier bags. However, different actors in industry, politics or civil society often promote specific solutions to particular problems, such as microplastics in wastewater (e.g. through bans on microbeads in cosmetics), littering in nature (e.g. through biodegradable plastics) or low recycling rates (e.g. through waste legislation). The solutions are sometimes conflicting, and there is no shared vision or clear direction for a sustainability transition of the plastics system as a whole.

A recent effort to develop such a shared vision, and a contribution to the debate, is the European Commission's work on a Strategy on Plastics in a Circular Economy. The starting point of this work, in analogue with many other initiatives, is that plastics is an important material for the EU economy, and that a strategy is needed to handle its sustainability challenges. The two primary priorities in the strategy are: (i) increasing recycling, and (ii) decreasing leakage into the environment (EU Commission, 2018). Following the EU Commission, the Swedish government has also initiated a government inquiry on sustainable plastics (Dir. 2017:60).



This discussion brief is motivated by the lack of coherent and systemic approaches to the plastics system and its sustainability challenges. It takes its starting point in the three main and generally acknowledged problems of fossil feedstock dependency, insufficient waste management and plastic leakage into the environment. It provides a critical assessment of five potential pathways toward more sustainable plastics commonly proposed and discussed. These are named after the main promise that they each make, i.e., *Bio-based, Biodegradable, Recycled, Fewer types* and *Reduced use*. Each pathway is assessed in terms of the promise it makes, what it entails and how it has been criticized.

Our objective is to present the main advantages, or promises made, and the challenges of these five potential pathways, and identify potential synergies as well as conflicts and issues concerning the governance of plastics. They are assessed separately, although all will be needed in a future more sustainable plastics system. This is probably a future in which plastics are more highly valued in monetary terms, but also for what they contribute to sustainability.

The bio-based plastics pathway

Bio-based plastics are mainly based on biological feedstock, typically oils, starches and sugars from agricultural crops. Feedstock can also be cellulose, bio-waste, and even carbon dioxide. Bio-based plastics include materials with different properties and applications. Some bio-based plastics are distinctly different from conventional plastics (e.g. PLA, PBS, TPS), whereas others are drop-in[1] plastics that are identical to conventional plastics (e.g. bio-PE, bio-PET). Some bio-based plastics are also biodegradable, e.g., PLA, PBS and PHA, yet bio-based and biodegradable plastics are not synonymous (see next section).

The current global production of bio-based plastics is approximately two million tons, which accounts for less than 1% of the total plastics production. Most bio-based plastics (almost 60%) are used in packaging (European Bioplastics, 2017). Packaging is an application that is close to consumers, and one in which bio-based adds value.

What does the pathway promise?

The main promise of this pathway is that using renewable biomass feedstock will: a) reduce dependence and import dependency on fossil resources, b) reduce greenhouse gas emissions, and c) if locally sourced would generate rural development. 'Plant-based', 'bioplastics' and 'green' are terms commonly used to signal the positive aspects of bio-based plastics.

Greenhouse gas emissions from a fossil plastics system will potentially account for a growing share of global emissions as the energy and transport sectors necessarily decarbonize to meet climate targets.[2] Biogenic carbon, whether from agricultural plants (including sugars and starch, as well as residues), wood, or captured as carbon dioxide from anaerobic digestion, combustion or gasification (or even direct air capture), will necessarily be the key building block for plastics in a fossil-free future (Palm et al., 2016). Biorefineries is a promising concept that is currently pursued through efforts in research, development and innovation. The concept is analogous to oil refineries, but uses multiple biomass conversion processes to produce various fuels and other products, including polymers.

Agro-based feedstocks, e.g., sugar cane and corn, make up the majority of feedstock for bio-plastics today. Thermal gasification of woody biomass and waste is a technology that could increase the diversification of feedstock for bio-based plastics. Using the thermal gasification route to produce syngas, and then simple hydrocarbons, is closer to existing petrochemical processes and would not rely on biotechnical conversion routes. This is an important option in the context of biofuels for transport, often called second-generation biofuels, though the option is hardly discussed in the context of bio-based plastics. Woody biomass and waste products, such as straw from agriculture, could considerably increase the resource base for feedstock sourcing.

How is the pathway challenged?

Bio-based plastics are mainly a solution to the dependence on fossil feedstock and associated greenhouse gas emissions. However, there are discussions over whether certain types of bio-based plastics complicate recycling. Drop-in bio-based plastics have exactly the same properties as their fossil-based counterparts, and thus do not add complexity. Biodegradable plastics are compostable (in an industrial setting), yet may end up in the 'wrong' stream since they are difficult to tell apart from non-biodegradable plastics. Moreover, without proper labelling and awareness, consumers may confuse bio-based plastics with biodegradable plastics.

Bio-based plastics are also challenged from the perspective of sustainability in terms of how much better they are from a life-cycle analysis perspective and their land-use implications. A recent environmental impact assessment shows a great variation in greenhouse gas reduction from starch-based plastics versus their conventional counterparts, from an 85% reduction to an 80% increase depending on the plastics composition (Broeren et al., 2017). The primary production of biomass feedstock typically accounts for a large share of the emissions (Tufvesson, 2010).

At the current production level of bio-based plastics, there is no urgent concern for feedstock scarcity or land-use competition. Nonetheless, it is difficult in the longer term to escape the biomass feedstock issue. The total global arable land is approximately 1,400 million hectares, which are primarily used for food and feed. Currently, the production of bio-based plastics accounts

for approximately one million hectares of arable land (European Bioplastics, 2017), but if a total conversion to bio-based plastics were to take place the arable land use for plastics would amount to approximately 150 to 300 million hectares.[3] This suggests the need to diversify the non-fossil resource base to include other biomass feedstock and the use of captured carbon dioxide as feedstock, in addition to pursuing increased recycling and reduced use. On the other hand, while several actors express concern for the sustainability of biomass feedstock for plastics, they often do not share this concern over the sustainability of fossil feedstocks.

[1] Drop-in plastics refer to bio-based plastics that are equivalent to conventional plastics in terms of chemical structure, application and recycling. These plastics are essentially 'dropped into' the pre-existing system.

[2] The Ellen MacArthur Foundation (2016) estimates that by 2050, 'plastics share of global oil consumption', to be 20%.

[3] This is based on the simple assumption that the current 1 Mha for producing 2 Mton of bio-based plastics is scaled up to 150-300 Mha to produce 300-600 Mton (present and future projected demand). Less land use and higher resource efficiency is possible through using cellulosic feedstock and various waste streams or by-products from agriculture and forestry.

The biodegradable plastics pathway

The biodegradable plastics pathway implies a system in which plastics are able to decompose into carbon dioxide (aerobic) or methane (anaerobic), water and compost or digestate when exposed to certain environmental conditions (e.g. temperature), and microorganisms such as fungi and bacteria. In most cases, this is achieved through industrial processes, such as industrial composting or anaerobic digestion, but not in 'natural' environments. These processes, in which biodegradable plastics are decomposed, are sometimes called organic recycling.

Biodegradable plastics can be fossil- or bio-based, but are most often bio-based, as it is the chemical structure and not the feedstock in itself that determines this. In 2017, the market share for biodegradable plastics amounted to less than half a percent of the plastics produced worldwide. The most common bio-based and biodegradable plastics are PLA and starch blends (European Bioplastics, 2017).

What does the pathway promise?

Different actors make varying promises with regard to the potential of the biodegradable plastics pathway. Some claim that the biodegradable pathway is a better way of disposing of plastics that are too complex to collect at end-of-life, such as mulch film and fish nets. From this perspective, the pathway promises to reduce the accumulation of plastic pollution on both land and sea.

Other actors claim that the biodegradable pathway is a better way of disposing of products that are collected but difficult to recycle, e.g. products with a high level of food contamination. From this perspective, the pathway promises that plastics not suitable for recycling could instead be treated biologically, and hence avoid incineration or landfill. Examples of the latter include bio-waste bags, plastic coating and or food packaging, in which biodegradability would enable plastic to become a natural part of the bio-waste and organic recycling streams.

The biodegradable pathway also enables the development of new types of plastics with distinct properties compared to conventional plastics. For example, the high water vapour barrier of PLA makes it particularly suitable for fruit packaging, as it prolongs shelf life (van den Oever et al., 2017).

How is the pathway challenged?

The pathway's promise to reduce the accumulation of plastic pollution (e.g. biodegradable in soil/aquatic environments) has been heavily disputed, and proponents of this promise argue for a very limited set of applications.

Another challenge is the risk of biodegradable plastics (for industrial composing) to end up in the wrong streams. The mixture of biodegradable and non-biodegradable plastics could cause quality issues on both parts. Therefore, biodegradable plastics often necessitate technical modifications in existing waste management systems. There are discussions over the compatibility and economic costs of biodegradable plastic facilities (Rujnić-Sokele and Pilipović, 2017). Even so, this has been disputed by proponents of biodegradable plastic pathways highlighting that low levels of, for example, PLA do not disrupt waste management streams (cf. BMEL, 2017).

Another challenge of the pathway is the confusion and misunderstanding that biodegradable plastics are subject to. Similar sounding concepts related to the degradation of plastic, including photodegradation and oxo-degradation, are at times mistakenly equated with biodegradation (EN13432).

The EU Plastics Strategy takes various steps toward improving this. First, the Commission intends to restrict the use of oxo-degradable plastics. Second, the Commission plans to develop a clear regulatory framework for plastics with biodegradable properties to avoid misconceptions. Third, through life-cycle assessment, the Commission will identify applications where biodegradability has clear environmental benefits, and will in these cases consider measures to stimulate innovation in the specific areas (European Commission, 2018a).

From a critical perspective, biodegradable plastics could be considered a wasteful use of resources. Instead, the reuse and recycling of plastics should be prioritized over biodegradation.

The recycling plastics pathway

The (material) recycling pathway is intimately linked to ideas of a more circular economy in which material loops are narrowed or closed through improved end-of-life processes and better product design. Currently, the recycling of plastics in the EU is lower than for other materials, as approximately 30% of plastic waste is collected for recycling (Plastics Europe, 2017). However, not all of the 30% was actually recycled; until 2018, much of this was sent to China for further processing.

Plastics waste is primarily divided in two different recycling streams. First, post-industrial plastics waste from manufacturing processes, which often consists of uncontaminated streams with a known polymer composition. Second, post-consumer plastics waste resulting at a product's end-of-life; this is typically a mixed waste stream in which plastic can be 'contaminated' with organic waste, or where the polymer composition, in some cases, can be unknown. In general, post-industrial plastic waste is recycled to much higher degree than post-consumer plastics.

What does the pathway promise?

The recycling pathway promises to unlock material and energy savings by enabling plastic waste to re-enter the system after use and replace virgin raw materials in new products. In the EU Plastics Strategy, recycling is highly prioritized as a mean to increase sustainability of the plastics system. Against the backdrop of China's current ban on certain plastic waste imports, European countries will need to direct even more attention towards the issue (European Commission, 2018).

Increasing the amount of recycled plastics can also reduce the dependence on fossil virgin feedstock, and thereby limit the global carbon dioxide emissions associated with plastics (estimated at approximately 400 million tons, see Ellen MacArthur Foundation, 2016).

The most common method for recycling plastics is mechanical recycling. This typically entails a sorting, shredding and washing process, where the clean plastic flakes are pelletized into granulates, which can (ideally) be converted into material for new products (Ragaert et al., 2017). One successful example of this is the deposit systems for PET bottles.

However, mechanical recycling has its limitations, for example when it comes to laminates or black-coloured plastics, so therefore new and innovative approaches to recycling are under development. A current example in the early stages of development is chemical recycling, in which plastics waste is broken down into monomers or other basic chemicals, and then reused for polymerization into new plastics.

Another approach is to improve the traceability of plastics, so that waste management systems can more easily identify the polymer composition in order to improve recycling efforts.

How is the pathway challenged?

A major challenge for the mechanical recycling of plastics is maintaining a high level of material quality. First, material quality is a result of degradation processes where, under certain conditions, polymers in plastics degrade (i.e. chain scission). Degradation takes place during production when the polymers are heated and exposed to shearing (thermal-mechanical degradation). Secondly, plastic products are exposed to environmental factors such as oxygen, heat or solar radiation (degradation during their lifetime). This is mostly significant for items used for longer time periods, and especially for outdoor applications.

Second, material quality can be compromised by unknown polymer compositions. This means that recycled plastics, in which different types of plastics are not correctly sorted or contain multi-layered laminates, will have a lower quality than virgin materials (Ragaert et al., 2017). The quality of the polymer and additives also affect the quality of recycled plastics. The difficulty of maintaining quality in recycled plastics is an important question since the quality ultimately decides, whether, and what applications the material can be reused for. In most cases, recycled plastics are 'downcycled' and used in lower value applications.

Third, there is a low demand for recycled plastics, in part due to the question of quality, low volumes and the low price of virgin material. The EU Plastics Strategy highlights that the demand for recycled plastics only accounts for roughly 6% of the plastics market in the EU (European Commission, 2018).

Fourth, the challenge with mechanical recycling is that it is not technically possible or economically viable to recycle all types of plastic products. Multi-layered, composite materials, and thermoset plastics are all difficult to recycle, but provide benefits such as enchanced food preserving qualities, lighter materials (used in cars), or in the case of thermosets, provide an essential material for the windmill industry.

Designing products suitable for recycling is a crucial part of this pathway, but in itself is not enough. Some of the above-mentioned challenges of mechanical recycling could potentially be overcome by chemical recycling and improved tracing and sorting technology. These technologies, however, are only in their early stages of development, and their potential yet unclear. One issue that is often highlighted is the need for better information exchange across value chains.

The fewer types of plastics pathway

This pathway proposes an extensive redesign of the plastics system. Plastic is a diverse material with multiple applications. Only seven groups of polymers make up the majority of plastics, yet they can be combined or modified (with the use of additives) to create thousands of different plastic applications, each with its own composition and characteristics. This has made plastic a very flexible material with many different properties.

Still, its diversity can add significant complexity when it comes to recycling and reusing plastics. For example, different types of plastics are often mixed when collected, as plastic laminates or composite products, differences in quality and recyclability all complicate the recycling processes. There are attempts to fix these with improved technical solutions for waste managers, although this pathway looks more towards controlling (simplifying and purifying) the waste streams that go into waste management systems.

What does the pathway promise?

This pathway promises to decrease the complexity of the plastics system, and enable cleaner flows and an improved recyclability and reuse of plastics. This could achieved by phasing out certain types of additives, which are difficult to recycle, by promoting more use of mono materials, by limiting the number of polymers used for certain applications such as packaging, and by steering future plastics innovations away from adding complexity to the plastics system.

Proponents argue that implementing a system with fewer types of plastics addresses the issue of the highly complex and costly plastics separation needed for recycling. Furthermore, it would improve the recycling rates, since the risk of plastics with a low recyclability to contaminate flows of recyclable plastics would decrease.

Fewer types also means reducing the use of certain additives, which are potentially hazardous or complicate waste management systems. This could include banning the use of, for example Bisphenol A, as well as certain flame retardants or plasticizers that could potentially be labelled as 'hazardous substances or endocrine disruptors' by regulators (cf. Galloway et al., 2018; Tukker, 2000; REACH). It also means reducing the use of 'low quality' plastics products or additives such as pigments, which reduces a product's recyclability.

Having only a few types of plastic for certain applications would also enable better alignment across value chains and better integration between national or regional plastics systems. It is argued that some low hanging fruits exists, such as an improved material choice or even a 'one polymer strategy'[4] for certain packaging with low materials demands. This is said to both increase recyclability, and the opportunity to use recycled material in the products.

In what way is the pathway challenged?

A major challenge for this pathway is the fear that regulating the plastics system in this manner will cause both a return to less advantageous types of plastic applications and hamper future innovation. Critics point out that reducing the amounts of, or choosing one, plastics is a naïve approach that will likely increase the overall use of resources.

Another key critique is unfavourable material substitution. In some case, the benefits of using plastic or plastic laminates may outweigh the costs. Take, for example, laminates used in plastic food packaging; although they are difficult to recycle, they offer advanced food protection, thereby reducing food waste, and they also lead to less plastic used, thereby increasing material and resource efficiency. The value of food protection is likely to outweigh the cost of poor mechanical recyclability in most cases, but such assessments may be difficult make.

By the same token, critics also point out the difficulties of deciding who gets to choose which types of plastic should be allowed, and on what premise? One could think of replicating the PET bottle deposit systems to other plastic applications or polymers, thus creating closed-loop systems with a single polymer, e.g., a cleaning product packaging made of only PP. Nonetheless, this is dependent on key actors agreeing on principles and priorities.

[4] cf. Marks and Spencer's Plan A 2025.

The reduced use of plastic pathway

Motivated by both environmental and health-related consequences of the current plastics system, this final pathway calls for a reduced use of plastics. Various ways of reducing the use of plastics are advocated, such as design options, material substitution, changing habits or outright refusal to use.

The pathway calls for both individual and political action. Individuals are encouraged to live a low plastics life or decrease their amount of waste by refusing plastics. Political action is called upon to tax or ban certain types of plastics applications (or additives and fillers), either through legislation or public procurement guidelines.

As such, this can be seen as both a radical pathway, in which consumers fundamentally question their use of plastics, but also as more of an incremental pathway, in which sustainable plastics entails reducing certain non-essential applications.

What does the pathway promise?

This pathway makes three promises. First, it promises to reduce the problem of plastic waste and leakage into natural systems by calling an end to the unnecessary use of certain plastics products. Single-use products such as plastic beads, straws or bags account for a large proportion of the eight million tons of plastics that leak into the ocean every year (Ellen MacArthur Foundation, 2016). In May 2018, the European Commission proposed a legal text to ban specific single-use plastic items at high risk of leaking into marine environments, including straws, dishware and balloon sticks (European Commission 2018b).

Second, in connection to this, the pathway questions our throw-away culture, and thereby decreases the overall resource use in a wider system. An estimated 79% of all the plastic that has been produced to date has ended up in landfills or the natural environment, and if production and waste management trends continue, roughly 12,000 Mt of plastic waste will end up there by 2050 (Geyer et al., 2017). Examples of this pathway include voluntary initiatives and civil society actions on changing consumer habits, such as reducing consumption of water bottles (One less, 2018), avoiding plastic straws (Strawless In Seattle, 2017), or reusing take-away coffee cups (Freiburg cup). It also includes a growing number of public policies on for example plastic carrier bags (cf. EU Commission, 2015), including strict bans (cf. Rwanda 2008 and Kenya 2017).

Third, proponents of reducing plastic use also criticize plastics for their potential hazards and risks; hence, the pathway also promises to decrease this risk by decreasing exposure, for example removing old plastic items in playgrounds (Naturskyddsföreningen, 2014).

How is the pathway challenged?

It can be complex to determine the negative impact of plastic products compared to alternative materials (Chaplin-Kramer et al., 2017), which in turn makes it difficult to choose which plastic applications to tax, refuse or redesign. Certain cases are highlighted as good examples (e.g. the banning of single-use plastics), but many applications are in the grey zone. Alternative materials can, on certain parameters, have larger environmental footprints, and studies have highlighted the risk of unfavourable material substitution (cf. Danish EPA, 2018; Trucost, 2016).

In connection to this, a key critique of this pathway is that it is the misuse of plastics that needs to be addressed, not the use.

The reduced pathway also risks diverting attention away from larger issues. For example, plastic microbeads in cosmetics have gained a substantial awareness, and have been banned in several countries. However, they only account for a relatively small part of the microplastic leakage into the oceans. In comparison, leakage from tire dust is a much larger contributor (cf. Naturskyddsföreningen, 2017), but has received relatively less attention.

Different directions

The plastics system is associated with three primary sustainability challenges. First, fossil feedstock dependency, second, improving resource efficiency and increasing the rates of recycling and reuse, and third, lowering leakage into the environment. Several plastic challenges are addressed by the five individual pathways, but no single pathway simultaneously addresses all three sustainability challenges.

The bio-based pathway promises an alternative to fossil feedstock, but does not directly solve recycling or leakage. The biodegradable plastics pathway promises an organic recycling solution for certain types of plastic applications, yet critics question its ability to deal with leakage, in addition to its compatibility with existing waste management systems.

The recycling pathway promises to improve the low levels of plastic recycling, and to reduce the use of virgin feedstocks. Yet, fossil dependency is not directly addressed by this pathway, and increased recycling rates do not equal lower levels of leakage. The fewer types of plastics pathway also promises to improve plastic recycling rates, but does not address the issues of fossil feedstock dependency. The reduced use of this plastics pathway promises to reduce leakage (cf. European Commission, 2018b), but does not directly address the fossil feedstock dependency or issues concerning plastic recycling. Thus, there is no single pathway that leads to a sustainable plastics system!

This is further complicated because the pathways do not always supplement each other unproblematically. When assessing the five pathways in relation to each other, both synergies and conflicts are revealed. The degree of conflict or synergy depends on assumptions concerning feedstock production, the sorting of waste, recycling and other factors, which makes it difficult to be conclusive in Table 1.

There is a potential synergy between the bio-based and biodegradable pathways. There is also a clear synergy between recycling and fewer types pathways since the promise of reducing complexity in the plastics system supports plastic recycling. The reduced use of plastics could co-exist with all the pathways; however, it could also be used to highlight the need to reduce the overconsumption of plastics and not rely, for example 'only' on increasing recycling rates while continuing current consumer habits.

Critics of the biodegradable pathway argue that it conflicts with the recycling pathway and fewer types by adding complexity to recycling streams. While proponents argue that this can be fixed with technical solutions, which are currently already in place or being developed (e.g. near infrared spectroscopy). Nevertheless, such conflicting viewpoints reflect the complexity of plastics and the interests involved, but also the need for further value chain integration.

Rather than putting too heavily an emphasis on one pathway, policymakers need to think of multiple routes and different ways to combine the pathways. A sustainable plastic transition necessitates the involvement of all pathways. Focusing too heavily on one neglects the opportunities and solutions that the others bring. Even so, the complexity of the system, as well as the ambiguity and uncertainty associated with different pathways, presents a real challenge to policymakers.

Table 1. Simplified overview of individual pathway promises and challenges, as well as indicative examples of potential conflicts and synergies with other pathways.

Pathway	Pathway promise	Pathway challenge	Potential synergy	Potential conflict
Bio-based	Alternative to fossil feedstock and reduces greenhouse gas emissions and dependence on fossil fuel imports. Promotes reual development.	May add complexity to recycling if not drop-in. Concern for future biomass scarcity and land-use competition. Scaling-up and fossil-fuel lock-in.	Biodegradable	Recycling (unless drop-in)
Biodegradable	Provides 'organic recycling' options for certain applications and mitigates some form of leakage issues. Novel plastic types with new distinct properties	Collection and industrial facilities still required. Potential consumer confusion about collection and recycling.	Bio-based	Recycling Fewer types
Recycling	Reduce use of virgin feedstock and thus emissions, and improved resource efficiency.	Maintaining high material quality. Low demand for recycled material and risk of down-cycling	Fewer types	Biodegradable
Fewer types	Decrease plastics system complexity and improve plastic recycling and reuse	Fear of hampering innovation and increasing the use of resources.	Recycling	Biodegradable
Less use	Reduced plastic littering, use of resources, and exposure to potentially harmful chemicals	Risk of unfavourable material substitution or other negative impacts of not using plastics	All pathways	-

Governing the plastics system

The plastics system is not governed as a sector in itself, but, much like its material characteristics, cuts across- and is influenced by a number of other political domains. On the EU level, the plastics system has been mainly governed through waste management and chemicals policies aimed at improving resource efficiency and avoiding hazardous substances. The EU Strategy on Plastics in a Circular Economy is a first attempt at developing a more comprehensive approach to the multiple aspects of the plastics system. Upcoming negotiations on ecodesign, the Marine and Water Framework, REACH (European Regulation on Registration, Evaluation, Authorization and Restriction of Chemicals), end-of-life vehicles, as well as the EU's other bio- and circular economy strategies, will likely expand the range of EU policies affecting plastics. On the national level, member states are dealing with plastics in various ways, from waste management strategies, to public-procurement and a host of policies targeting specific plastic applications, and from plastic microbeads in cosmetics and all-weather sports pitches to plastic bottles and bags, in many cases aimed at addressing the issue of plastic leakage. Beyond this, there are a broad range of non-state initiatives and actions aimed at raising awareness and changing consumer behaviour and/or policies on plastics.

A key challenge for the EU Plastics Strategy, and indeed for governing a sustainable transition of the plastics system more generally, lies is orchestrating the complexity of the plastics system and further integrating the various stages of the value chain. For example, policies on waste management need to be better integrated with production, consumption and design-related policies. This necessitates a holistic approach in which trade-offs and synergies of the multiple policy areas of plastics need to be considered. In contrast to plastics, other sectors, such as energy, waste and transport, have decades of institutional development, academic research and government agencies. To maintain a clear direction, there needs to be mechanisms for coordination between levels, sectors and different policy domains. We are not (necessarily) saying that an EU Plastics Agency is needed, though the cross-cutting nature of plastics and the complexity of the system require a high level of strategic coordination. To facilitate more coordination, future policy packages should include a broad spectrum of policies, including regulations (eco-design measures), market-based instruments (taxes on fossil feedstock), financing and investments (development of waste management infrastructure), flanking policies to avoid carbon leakage, as well as research and innovation.

The design of specific policy instruments is beyond the scope of this paper, but some general observations can be made. More efforts are needed develop a shared vision, for learning and strategizing about policy, in addition to policy integration. For this there needs to be a framework to facilitate inclusive deliberations among industry, public authorities and civil society in the policymaking process. Capacity building for governing bodies (and public awareness) is essential. There is currently a heavy reliance on industry for information compared with other sectors that have had decades of broader institutional capacity and knowledge building. There is also a need for mechanisms for greater transparency across the value chain and for the monitoring and evaluation of policy.

A future scenario

The assessment of five proposed pathways to more sustainable plastics shows that there are no straightforward solutions to the three overriding problems of plastics. The plastics system is characterized by a high diversity and complexity, with plastics being an essential or clearly superior material in many applications. The pathways can have synergies, or even be in conflict, but often the answer to questions about the pros and cons of the pathways is: 'it depends'.

In this discussion brief, we argue that all pathways are needed, and that we need to envision them all in a positive future scenario for sustainable plastics. Below, we briefly outline a future scenario, and explore the governance challenges of transitioning the plastics system.

Using less plastics, at least in certain applications, is perhaps the least controversial pathway, assuming that using less does not have adverse side-effects, e.g., increasing food waste. In our simple scenario, the use of plastics is reduced as a result of economic incentives, with at least a carbon price on fossil-based plastics, regulation such as the European Commission's proposal to ban certain plastic applications and changes in socio-cultural norms and everyday practices around plastic bags, single-use plastics, textiles, packaging, etc. Fewer types of plastics in selected applications is a pathway worth pursuing, as it would help simplify certain streams to improve the control and quality of recycled material, not least in packaging (e.g. using monomaterials such as PE, PP, PET/PEF), which is possibly supported by refund schemes. Increased recycling is obviously very important in a more sustainable scenario. It can be closed-loop recycling in which, when possible, a product is returned to the producer, but it ranges all the way to the chemical recycling of atoms, monomers and other molecules. Chemical recycling can be waste gasification to produce a syngas from which methanol is produced, followed by a methanol-to-olefin process to produce new plastics. A fossil-free scenario such as the recycling of carbon, also known as carbon capture and use (CCU), will complement the carbon loop for bio-based plastics, in which the carbon is absorbed through photosynthesis. Biodegradable plastics will be important in certain applications, for example where it is beneficiary to feed plastics into bio-waste streams, e.g., bio-waste bags or certain food packaging.

More widely shared visions for a sustainable plastics system have yet to be formed and take shape. In our simple scenario, the pathways are complementing rather than competing, although the balance between pathways in a transition cannot be detailed in advance. Technology development, institutional changes and human behaviour will create new opportunities and problems along the way. It is probably a future in which plastics are more highly valued in monetary terms, but also for what they contribute to sustainability. Along the way, policy and governance approaches have to be tried and adapted to different contexts to help facilitate experimentation and learning.

Conclusion

The plastics system is hugely diverse, and faces difficult sustainability challenges. The wide range of different plastic types with various properties and applications makes the system highly complex compared to other basic materials such as metals, paper or glass. Besides the guidance offered by the recent European Commission's Plastics Strategy, there is no clear common vision for what constitutes a more sustainable plastics system. Consequently, private, public and civil society actors have promoted various solutions, many of which address only one aspect of the sustainability challenges related to the plastics system. Motivated by this lack of a coherent direction, this discussion brief presents the main advantages and challenges of five potential pathways toward a more sustainable plastics system. We identify opportunities, gaps and governance implications that may follow from the pathways.

No single pathway by itself addresses all three primary sustainability challenges associated with the current plastics system. There are both synergies and conflicts between the different pathways. An EU-wide or national strategy on plastics needs to incorporate elements of all pathways to form a shared vision on sustainable plastics that can be used as guidance for learning and strategizing about policies on plastic.

The immediate need to improve low recycling rates of plastic necessitates a strong emphasis on the recycling pathway. However, this should not come at the expense of policies promoting non-fossil feedstock, including biomass and carbon dioxide, nor a discussion around whether, and if so how, we could consume less plastic. Moreover, there are several options that deserve more attention including chemical recycling and power-to-plastics, which links the renewable energy and plastic sectors.

Plastics lack the established institutions, academic research and government capacity that are there in other sectors such as energy and transport. Plastics have an important role in a more sustainable future through their material properties and their functionality in different applications but the problems of plastics must also be decisively addressed. This requires the development of institutions, more knowledge and stronger government capacity. It also requires clearer and more widely shared ideas about in which directions we should go and the role of different pathways.

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Short introduction to STEPS

This research program was initiated during autumn 2016 after being awarded the funding for Mistra´s call of proposals on "Plastics in a Sustainable Society".

The program, with a strong support from important stakeholders, has a vision of a future society in which plastics are sustainably developed, produced, used and recycled in a circular economy. STEPS is planned in close dialogue with industrial partners, and thus reflects the market needs for sustainable plastic systems both on a short-term and long-term basis.

It is based on the concept of designing eco-friendly plastics having desired material properties and -life cycle by matching appropriate carbon-neutral building blocks and their derivatives. Major focus in the programme is on polyesters, which represent a plastics group with varying properties for wide range of applications and a sizable global market.

STEPS aims to play a key role in instigating and accelerating this sustainability transition by strengthening the knowledge and research base for technology- and product development and innovation, developing and assessing key niche products with industrial partners, and analysing the sustainability, institutional and policy implications of potential transition pathways.

STEPS

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