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How Can Circular Economy Strengthen the Recycling of Plastic Packaging Wastes? Exploratory and Qualitative Case Study of the Danish Plastic Industry

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This paper investigates how companies in the plastic value chain can comply with the requirements put forward in the European Union's Extended Producer Responsibility (EPR) scheme for plastic packaging wastes, which must be fully adopted in a Danish context ultimo 2024. Plastic packaging waste for recycling is expected to increase when the EPR scheme enters into force, just as national regulation seeks to avoid the incineration of plastics. Multiple case studies, applying an exploratory and qualitative approach, were conducted with three best-case companies within the plastic value chain to illuminate technical capabilities in sorting and further processing of plastics, current recycles strategies and market positioning. To access the possibility to prevent, reuse, recycle, and recover plastic wastes we make use of the waste hierarchy in combination with a circular economy approach, where suggestions to activities along the cascading chain are proposed to qualify the analysis. This paper reveals that only few recycling plastic value chains have been established that originate from plastic packaging waste from household, and there are none for food packaging reusage; the current unfavorable management practices mostly lead to downcycling of the plastic value chain to recovery only. It is further concluded that strengthening the EPR scheme is important, by applying, for example, eco-design, hereunder to utilize mono plastics of polyethylene (PE), polypropylene (PP) and polyethylene terephthalate (PET), and by fee-modulation using taxes/penalties to spur on the plastic industry to produce environmentally friendly products. Finally, alternative sources of handling and producing plastics are outlined as watermark technology, bio-plastics and PtX-nafta.

Keywords: circular economy, extended producer responsibility, plastic packaging waste, sustainability.

Introduction

Plastic packaging waste is regarded as the main cause of coastal plastic pollution, and there are 10 product types with the highest leakages – and hence plastic pollution – that derive from plastic packaging applications, for example plastic bottles and food boxes (Gayer et al., 2017). This is also caused by the short lifetime of the applications, as plastic packaging materials leave the use phase within the first year – and for some types of plastic packaging only within days – of being manufactured, whereas, for example, plastic used for construction applications has a much longer use phase before being discharged (ibid.). In this sense, the EU Packaging and Packaging Waste Directive 2018/852 from 2018 (Eurolex, 2022) – including plastic packaging wastes – is targeting an obvious application (namely plastic packaging), and its disposal challenges our health and the natural environment. Around 26 million tons of plastic waste are generated within the EU on an annual basis, where 41% of all plastic packaging waste is being recycled, hence 37% of the total from European households. In Denmark, 38% of all plastic packaging waste is being recycled, where 17.2% of the total originate from households (Plastics Europe, 2019). This is only a small fraction of the 350 000 tons of plastic waste being generated on an annual basis, hereof 215 000 tons being plastic packaging waste specifically.

Besides Hungary and Croatia, Denmark is the only country within the EU which has not yet adopted the Extended Producer Responsibility scheme (EPR scheme) for plastic packaging waste, which must be effectuated ultimo 2024. The ERP scheme is a tool under the Polluter Pay Principles (PPP) re-introduced with the EU Waste Framework Directive (WFD) in 2018 (EC, 2022), which require that "in accordance with the PPP, the costs of waste management, including for the necessary infrastructure and its operation, shall be borne by the original waste producer or by the current or previous waste holders." Given the ERP scheme, the Danish plastic industry is hence obliged to develop systems and methods for the waste packaging products to be reused or recycled, which eventually will increase the flow of recyclable plastics within the value chain of the plastic industry and potentially lower the pressure on virgin resources.

In Denmark, no guidelines on how to implement the EPR scheme have been proposed until 30th August 2022, where a new EPR Deal (Danish Ministry of Environment, 2022) was agreed upon by Parties within the Danish Government. This EPR Deal merely provides some overall directions to the adaptation of the EPR scheme in a Danish context. Details are, according to the EPR Deal, to be negotiated by various stakeholders involved. In the EPR Deal, it is suggested that plastic packaging wastes are exempt from tax/fee, if they are in the circular system and hence being recycled, which is perceived to be favorable to spur the use of recycled plastics (ibid.). The EPR Deal is, however, not addressing any quantitative targets for reduction and recycling of plastic packaging wastes in Denmark, and do not suggest how to identify reuse and recycling opportunities within companies in the plastic value chain. Thus, we suggest adapting to more circular production systems in the manufacturing and utilization of plastic wastes in Denmark, by looking deeper into circular economy approaches for creating such future systems through cascading activities.

Circular economy is an approach in which materials and energy flow are designed and shaped with the purpose of facilitating re-use and recycling. Circular economy can be applied to re-think the existing production and consumption patterns. The purpose is to develop sustainable environmental and commercial circles and cascades within industrial and agricultural resource utilization. The inspiration derives mainly from the Industrial Ecology theory (Genovese et al., 2017), in which natural eco-systems are applied on industrial activities. In these natural systems, nothing is wasted, and resources go through eco-systems from plants to animals and eventually predators, who then die and decompose in which nutrients, for example, are provided to plants, animals, and micro-organisms (Jelenski et al., 1992; Lowe et al., 1997; Erkman, 1997; Ayres and Ayres, 2002).

The circular economy thinking is thus a termination with the concept of linear-economic thinking, where goods are utilized in a classical use-dispose matter. The linear economy puts pressure on natural ecosystems through an overconsumption of non-renewable resources and creates large quantities of waste, which should be avoided (McArthur Foundation, 2013). Ellen MacArthur Foundation provides the following definition of Circular Economy (ibid.): "A Circular Economy is an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models."

Numerous research studies of how to apply more circular economy approaches in, for example, waste and energy utilization have been applied through different research studies. Li and Ma (2015) have, for example, analyzed how to obtain a more sustainable and less energy consuming and waste generating paper industry in China, whereas Zabaniotou et al. (2015) investigate how small-scale bio-char technology can provide environmental, economic, and societal benefits for South European farmers. Genovese et al. (2017) have researched how a more sustainable supply chain management system can be developed by adapting to the circular economic approach. Bucknall (2022), on the other hand, investigates how to achieve and operate a circular plastics economy, by looking at the need for societal and behavioral changes, new business practices and technology innovations. In this paper, we explore the circular economy potentials of plastic packaging waste being re-ycled within companies in different parts of the plastic value chain to facilitate the adaptation of the EPR scheme for plastic packaging waste in a Danish context.

Thus, in the first part of the paper, we conduct exploratory case studies investigating how to increase the volume of recycled plastic appropriate for recycling, and how plastic can be integrated into manufacturing processes of companies within the plastic value chain. Emphasis is on the following issues: What are the current limitations of the Danish waste sorting plants, and are recycling facilities established producing easy recyclable plastics manufacturing companies? Which strategies do plastic packaging companies already apply, and plan to apply, to adapt to future recycling requirements? And how can companies manufacturing plastic products integrate recycled plastics in their product portfolio, and do customers require recycled plastic in their products? In the second part of the paper, we discuss and elaborate on future perspectives for producing, sorting, and managing plastics to expand the outreach activities proposed by the EPR scheme. We investigate how the reuse of plastics can be introduced for plastic packaging as opposed to recycling and look at the potential for producing plastics from new materials, like the watermark technology, bio-plastics and PtX-nafta.

Methods

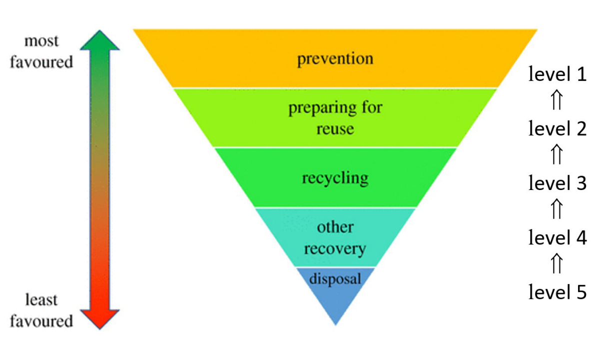
In this section, we outline the overall methodology adopted in this paper. Initially, we present our theoretical approach and then continue elaborating on our collection of empirical data.

Circular economy through cascading activities

Cascading of resources is a central method for optimizing the use of resources in the circular economy. Cascading is the use of outputs from one process (level) to be used as an input in another process (level) in a cascade chain. The aim is here to extend the overall utilization time and maintain the resource quality as long as possible (Sirkin, 1990). At every level in the cascading chain, three options need to be addressed: i) upcycle the resource to a higher level in the same cascading chain or in a new cycle; ii) maintain the resource quality at the same utility level; or iii) cascade the resource to a next (lower) level in the cascading chain (Sirkin and ten Houten, 1994). This paper will provide suggestions on how to enhance the utilization of plastics within level 1–3, depicted in *Fig. 1*, based on empirical data from case companies' capabilities and future visions. Hence, we will only superficially address aspects of disposal and other types of recovery (level 4 and 5). In the following, we emphasize the five levels of waste hierarchy (*Fig.1*) in relation to plastic wastes/resources, assessed up against the flow of plastic wastes from Danish households *(Fig. 2*) to indicate in which part of the flow cascading potentials are likely to be deployed.

Plastic waste *disposal* (level 5) through landfill or controlled/uncontrolled dumping wastes is no longer applied in a Danish context, but a measure for *recovery* (level 4) by means of energy production from wastes has been applied since the 1960s when the first waste incineration plants were implemented in larger cities (Kleis and Dalager, 2007; Johansen and Verner, 2022), thus, moving from level 5 to level 4 in the waste hierarchy. The use of plastic waste for energy production is hence an obvious up-cycling of the resource utilization, compared to any type of disposals, but should be avoided or minimized to keep the plastics in a circular

Fig. 1. *Generic waste hierarchy with indications of favored level 1–5 (source: authors; modified from DEFRA (2011) and Bucknall (2020))*

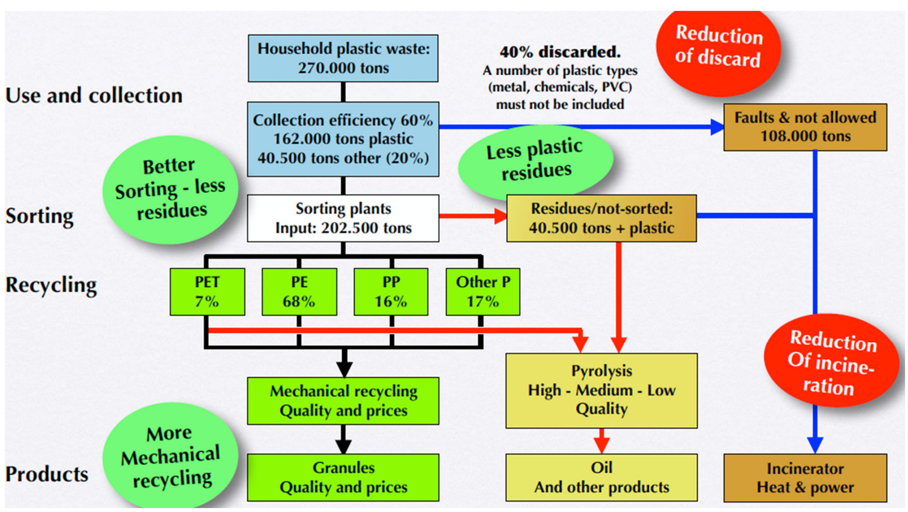


system (level 3) and not to be wasted in the cascading chain when simply being incinerated ('reduction of incineration' red circle in *Fig. 2*). The EPR scheme is expected to reduce the quantity of plastics being incinerated in Denmark, as more emphasis will be on recycling (within level 3) to keep the resources in the cascading chain as long as possible, and hence to reduce the drawing on new virgin resources.

To enhance *recycling* (level 3) of plastics, it is important to ensure that plastic packaging waste at the household level is recyclable and that the sorting quality is high and uniform to avoid unwanted fractions as metals, PVC, and chemicals, which lead to immediate downcycling of the plastic resources by means of incineration ('reduction of discard' red circle in *Fig. 2*). Hence, to facilitate higher recyclability of plastics, waste sorting plants must be equipped to handle the sorting tasks efficiently, resulting in a reduction of plastic resources being wasted ('better sorting – less residues' green circle in *Fig. 2*). This will minimize downcycling where plastic leaves the cascading chain being improperly sorted and ends up being incinerated ('less plastic residues' green circle in *Fig. 2*). Besides this, recycling facilities producing, for example, granules from sorted plastics must be deployed to ensure the further recyclability of plastics in the cascading chain ('more mechanical recycling' green circle in *Fig. 2*), preferably to maintain the resource quality at the same utility level (level 3).

To enhance the recycling of plastics and sustain the quality as long as possible in the cascading chain, certain types of single polymer plastics are preferred over others, such as polyethylene terephthalate (PET), polyethylene (PE) and polypropylene (PP) being high quality plastic materials. PET, recycled as food packaging material, for example, is favorable because the quality of this plastic is reversible, as opposed to PE and PP. The natural degradation of PET polymers when utilized can be rebuilt (but not infinitely) to the same high quality during the chemical decontamination process, removing heavy metals and pathogen organisms that might hamper recycling. PP is also utilized for food packaging

Fig. 2. *Flows of household plastic waste in Denmark where 215 000 tons are plastic packaging waste specifically, with circles indicating activities and reduction impacts by adapting to the EPR scheme (source: authors)*



purposes, but can, as opposed to PET, not be recycled again for food packaging purposes. Using PP for food packaging will eventually lead to downcycling of the resources for energy recovery purposes (level 4) or will be recycled for lower quality nonfood purposes (level 3). Here, the PET material will potentially maintain its quality at the same utility level for several cycles, before eventually being downcycled to lower quality (level 3) or simply used for energy purposes in a recovery process (level 4).

The average sorting efficiency of sorting plants is, however, low, ranging between 40% and 58% on the most modern state-of-the-art plants (Eriksen and Astrup, 2019), leaving valuable resources to be downcycled for incineration purposes (level 4), or being transported to, for example, Germany more capable of recycling plastics, and thus maintaining the current value. Higher efficiency on sorting plants requires, among others, a standardization of packaging products' shape/size in the future to make them easily sortable at the sorting plants in combination with new technology. Recycling of PET bottles is, on the other hand, more efficient, and 660 million bottles were hence collected in Denmark in 2021 through the bottle deposit system (Danish Return System), whereof 84% were recycled for producing new bottles (Dansk Retursystem, 2022), thus maintaining the resource quality at level 3. The recyclability and sortability of plastics, addressed above, is very important, but there is also a need to support a domestic market from recycled plastics, and to investigate the opportunities for integrating recycled plastics in the manufacturing processes of plastic companies.

Another activity which can reduce the pressure on virgin plastic resources is to enhance the *re-use* (level 2) of plastics connected to household wastes and packaging materials. The high fee on, for example, plastic bags has resulted in a reduced demand in Denmark, and plastic bags are now being used several times before discarded, and thus downcycled. Re-used food packaging plastic is not widely disseminated, but could be a future solution adopting, for example, a deposit system to support it. Finally, *prevention* (level 1) in the use of plastic for packaging purposes is out most important and has been applied in various ways by, for example, substituting plastics with wood, cardboard materials, and paper in packaging designs. Some countries within the EU already adopting the EPR scheme have, for example, through fee-modulations and requirement of eco-design on packaging materials, sought to completely avoid or limit the use of plastics in packaging (OECD, 2014; IEEP, 2017; WWF and IEEP, 2020). Also, prevention of virgin plastics could potentially be achieved if other types of materials and processes in the future were used, such as bio-based plastics or PtX technology; e-nafta.

Empirical data collection

Below, we detail our methods related to collection of empirical data, our choice of case companies and how other types of information were approached.

Case study approach

We select an exploratory case study approach to the case studies conducted, as we did not expect pre-determined outcomes when entering the empirical research field. We thus approached the interview situation without exact knowledge of the stakeholder position to the EPR scheme, their technology level as far as recycling plastics, their reluctance/welcoming of more plastics to be recycled in the future, nor the companies' capabilities to address future requirements. According to Andersen (1990) and Yin (1994), exploratory case studies are also appropriate when you need to gain very detailed descriptions of a social phenomenon. The exploratory case study is used to explore presumed causal links that are too complex for a survey or experiment. According to Yin (2014), case studies are appropriate when asking "how," "why," "what," and "who" questions.

Multiple case study

We apply a *multiple case study* approach in the investigation of companies within the Danish plastic value chain to be able to grasp the context and situation of the companies involved. According to Yin (2017), "… a multiple-case study includes two or more cases or replications across the cases to investigate the same phenomena. The difference between the single- and multiple-case study is the research design; however, they are within the same methodological framework." A single case study approach would not have contributed to sufficient information about the performance of companies in the plastic value chain, as far as challenges with sorting efficiency, lack of recycle facilities, current and future recycle opportunities within different companies, and the impact of the EPR-scheme.

Choice of case companies

To assess the plastic industry's view on the possibilities imposed by the EPR scheme, as far as higher quantities of plastic to be recycled, we collected empirical data from three 'best-cases' companies (Ellet, 2007), each having their own position in the plastic value chain, with the aim to identify future circular economy potentials.

Three case studies were thus conducted with the company managers, the first from 'Damifo' in Vojens, which recently won a tender for sorting plastics from source separated household waste, previously transported to Krefeld in Germany to be sorted and processed further for recycling purposes. Hence, only the combustible plastics were returning to Denmark for incineration purposes. The company is interesting as being a frontrunner in applying new technology and sorting plastic for further recycling within Denmark hereby limiting transportation requirements and relying on more local recycling chains. Besides this, 'Damifo' is representative for the size of waste handling companies in Denmark as being small and medium size companies (SMEs) with less than 500 employees, and currently holds 30 people occupied.

The second company selected within the plastic value chain is 'Færch' in Holstebro, which produces plastic packaging products mainly for the food industry, and where a future ambition is to become a larger part of the entire value chain for food packaging plastic. Today, 'Færch' is one of the leading suppliers within the EU of thermoformed food packaging and has recently bought its German competitor 'Paccor' and now, internationally, they employe more than 6000 people. Within the Danish branch in Holstebro, the company holds approximately 400 people occupied and is categorized as an SME. 'Færch' is considered as a frontrunner in the recycling of plastics for the food industry and hence illustrates how the recycling movement can be adopted at the industry level.

Third, the company 'Gibo' in Skjern was selected as an example of a traditional Danish company within the plastic value chain, which welcomes future recycling of plastics, but where logistical, structural, and quality issues currently hamper this. The company produces technical plastic components by, for example, extrusion and rotational molding, where the processes require a certain quality and type of plastic. The company is, therefore, interesting as being representative for other companies in the plastic value chain, who look for opportunities to utilize recycled plastics in products. The company holds approximately 50 people occupied and is an SME.

Semi-structured qualitative interviews

The interview methods rely on the semi-structured interview approach in which only parts of the interview situation are controlled by predefined questions in the interview guide. This method gives the interviewee a possibility to elaborate on new or surprising phenomena, and hence reveals important information not included as questions to discuss in the interview guide (Kvale and Brinkman, 2015). Ten questions were initially formulated for the interviews with an expected duration of one hour. Due to the open structure of the interview, and the following tour of the company site, the visits lasted on average two hours each. Notes were taken during the interview and the company site tour, and a full resumé was then immediately executed.

Literature

Besides data from interviews and company visits, this paper relies on information from peer review journal papers, reports, surveys, and statistics addressing topics and issues related to plastics. Besides this, directives and regulation from the European Union were assessed to capture the current framework conditions for plastic packaging waste in a European context.

Results

In the following two sections, we proceed to i) elaborate on the findings from our empirical data collection within companies in the plastic value chain, followed by ii) findings from our discussion of a future outlook for producing, sorting, and managing plastics to expand the outreach activities proposed by the EPR scheme. We will elaborate on circular economy initiatives through cascading and waste hierarchy approaches, applying the theoretical framework described in the methodology section.

Sorting quality and recycle facilities

It is evident from the collection of empirical data that improving sorting plants and further recycling facilities to produce, for example, granulates are needed, as

'Damifo' (sorting plant) and 'Aage Vestergaard Larsen' (recycling facility) are examples of the few industries in Denmark in this part of the value chain. According to 'Damifo', it is, however, possible to expand the sorting and processing of plastic for recycling further, if the supply of clean source separated household plastics increases. New value chains for recycled PE plastics from household waste are slowly being applied but should be upscaled in quantity and include other types of plastic like PP and PET in the future (Heinzl, 2022).

As pointed out by the interviewee, source separation at the household level must be easy and the technology at sorting plants must be upgraded with new technology like watermarks that provide evidence of the type of plastics. The manager from 'Damifo' stresses that "... *we need to increase the quality of the sorted plastic, by for example leaving out PS and LDPE, and develop and apply better product design of PET, PE and PP...".* The interviewee confirms this by continuing "...*Only focusing on a few high quality types of plastic will make it easier for household and industry to recycle the plastic..."* (Heinzl, 2022).

From the interviews it is clear that the lack of harmonized rules within Danish municipalities how to source separate household waste is interpreted as one of the largest barriers for recycling plastic packaging in a Danish context. A consequence of this is downcycling, as seen at 'Gibo', where sorted household waste undertook recycling, but as the manager puts it "...*we did not know what it was, but it was not a clean material, so we could only produce fences, tables and chairs and floors..."* (Borg, 2022). This is confirmed further by the manager from 'Færch', who said *"... 1m3 waste contains up to 80% PET, but the sorted fractions are only around 40%. The goal is quality in and quality out..."* (Thellesen, 2022). Higher quality and more uniform collection and sorting systems are hence requested by the company managers, and the rules and regulations must be harmonized to secure quality and quantity. A large barrier is thus the municipalities in Denmark who have failed to deliver efficient systems to customers (Thellesen, 2022; Borg, 2022; Heinzl, 2022).

More advanced sorting plants and recycle facilities are thus needed in Denmark, including those for recycling plastics for food packaging usage, which currently are supplied by companies outside Denmark. A few recycling value chains have, however, been established for plastic waste from households, but not to be utilized for food packaging. These actors can, however, increase the recycling quantities depending on the available plastic for recycling (Heinzl, 2022). The informants agree that it is outmost important that better source separation systems are deployed within Danish municipalities, which is substantiated by the EPA Deal (Danish Ministry of Environment, 2022). This should make sorting easier for citizens and prevent contamination of plastic and secure high plastic quality with emphasis on PE, PP, and primarily PET.

Recycle opportunities and barriers

In the case of 'Gibo', we identified that logistical barriers, size structures of the market, and the technology applied, however, hamper recycling of their own plastic products. Currently, the company re-use regenerates from their own production of plastic components mainly to the industry. But, if clean PE from source separated household waste can be supplied to 'Gibo', they would, however, welcome the use of this material in their extrusion processes based on granulates. Hence, a part of the production relies on high quality PE granulates used in extrusion processes, but all raw materials are in general supplied from outside Denmark due to the size of the plastic plates needed. As the manager mentions "... *no Danish suppliers have the size of machinery needed for this and the market is too small in Denmark. Therefore, we have to get in transported over long distances from very large industries with many costumers..."* (Borg, 2022). For 'Gibo', long distances make recycling unsustainable, just as the lack of Danish recycling facilities providing quality products ready to be recycled. As the manager states: "...*we need to recycle more locally or regionally; otherwise, it does not make sense, and for us, it is plastic for extrusion processes where we can recycle..."* (Borg, 2022).

'Færch' already utilizes 70% recycled plastic in their PET products and have adopted and plan for further recycling activities, outside the EPR scheme, to assure the quality of the returned plastics. A buyback program has, for example, made it possible for 'Færch' to get their own plastic trays back, and hence to recycle a material that they already know the quality of, and such programs could very likely expand in Denmark (Thellesen, 2022). In the new EPA Deal (Miljøministeriet, 2022), mentioned earlier, industries are encouraged to do so, but the empirical data show that companies have already applied such programs for some time now to secure the return of plastics. The watermark system is welcomed by the companies, to identify both the type of plastic to facilitate recycling and the original producer and is referred to as the Holy Grail (research project) (Thellesen, 2022; Heinzl, 2022).

The issue of contamination is very important for producers of food packaging, and today a coating with virgin plastics is applied on some food packaging products. Due to this coating, it is challenging to obtain 100% recycling, which means that downcycling is evident and the drawing on new resources is unavoidable. But, as the manager from 'Færch' states *"… In the future, if we are limited in the amount of virgin plastic that we can utilize, new resources can be acquired from PtX technology, which is capable of producing plastics…"* (Thellesen, 2022). Currently, there are no recycling facilities in Denmark that process plastic used for food packaging to granulates, which can be recycled within the food industry again without coating, thus, maintaining it at the same quality level in the cascading chain. At 'Færch', plastic for recycling is delivered to their company 'Cirrec' in Holland that has a capacity to clean and upgrade the plastics to be recycled for food packaging again (Thellesen, 2022). If plastic packaging from households is sorted appropriately, being high quality, this waste can, according to the company, also be processed in Holland and used for food packaging (Thellesen, 2022). Thus, it is clear, that improving the Danish sorting and processing industry would be beneficial, and 'Færch' is currently investigating options for deploying a 'Færch'-owned recycling facility in Denmark, or within Scandinavia, to tap into this unsaturated market for recycling plastic, (Thellesen, 2022), as emphasized below.

Market for recycled plastics

From the case companies investigated, it is evident that a Danish market for recycled plastic is already established and growing. Industrial customers like windmill manufactures and supermarket chains are requiring recycled plastics. The production of recycled plastic in Denmark is, however, too small to saturate the Danish market, where the Danish Return System, for example, only can deliver 20–25% of the recycled plastic that 'Færch' utilizes, and the remaining is hence supplied from outside Denmark (Thellesen, 2022). From the empirical data we also saw that Danish companies within the plastic value chain are keen on utilizing recycled plastic in their products due to environmental considerations, but also because of requirements from their customers (Thellesen, 2022; Borg, 2022; Heinzl, 2022). There is hence a need to systematically map where recycled plastic can be utilized within the plastic industry to substitute virgin resources. The empirical data show a tendency towards companies consolidating themselves, by becoming a part of a larger value chain for plastics; hence possessing both sorting plants and recycle facilities, as well as being plastic product manufacturers, like in the case of 'Færch'.

The EPR scheme

The empirical data show that case companies are not concerned about any future influenced by the EPR scheme, and will collaborate and establish partnerships, despite any EPR scheme applied. If a business case looks favorable, because of increased quantities of sorted plastic waste, the industry will hence act by themselves. We identified that the EPR scheme is not a major issue for the companies, who, however, welcome more plastic packaging wastes to be recycled (Thellesen, 2022; Borg, 2022; Heinzl, 2022). But until the quality is assured, companies within the plastic value chain focus on other issues like buyback programs and cooperation with actors in the value chain to valorize the current flows of plastics. Within our case study industries, the recycling of plastic was welcomed. But to make sure that all industries in the plastic value chain commit themselves to recycle plastic, it is suggested by the case companies to require a certain mix or percentage to be utilized, proposed at a Danish or even EU level (Thellesen, 2022; Borg, 2022; Heinzl, 2022). By this, the plastic industry's customers are forced to include other types of plastics in their portfolio of products due to a regulation imposed on their suppliers. This will assist in increasing the market for recycled plastic further. Also, economical penalties for companies not recycling waste are suggested being applied, just as a gate fee ensuring the quality of sorted plastics could be deployed (Thellesen, 2022; Borg, 2022; Heinzl, 2022).

Discussion – Outlook

In the following, we elaborate and discuss a future outlook for producing, sorting, and managing plastics to expand the outreach activities proposed by the EPR scheme. The EPR scheme solely targets plastic packaging waste, which accounts for 40% of our waste disposals. But our remaining plastic disposals (60%) also need to be addressed more thoroughly and systematically.

Bacterial enzymes and larva recycling plastic

Experiments and research are conducted within this field to harvest microbes' enzymes – proteins that speed up chemical reactions – and use them in recycling certain types of plastics, as for example plastic made from carbon atoms joined by an oxygen atom as opposed to plastic made by bonds linking atoms directly together. Utilizing enzymes to breakdown PET could potentially save energy and virgin resources; they could become a supplement to the current chemical industrial recycling processes. Enzymes are seen as a greener approach to the one applied currently; they will also be able to target specific types of plastics in the waste mix. The breakdown process happens as the organisms, by low temperature requirements, feed on the PET plastic, and produce two building blocks: ethylene glycol and terephthalic (Cornwall, 2021). Research conducted by Tournier et al. (2020) demonstrates that biological recycled plastics using enzymes can obtain the same properties as petrochemical PET, hence virgin materials.

The French company 'Corbios' has built a demonstration plant, intended to be upscaled for commercial purposes, and they plan to market recycled plastic by means of such enzymatic and bacterial treatment (Cornwall, 2021). A partnership with the Danish company Novozymes has been agreed upon for developing enzymes for PET degradation contained in various plastics and textiles. Depolymerization of PET is conducted in the process where the monomers are purified to be able to repolymerize the plastic, equivalent in quality to virgin materials. The PET can hereafter be utilized for manufacturing new plastic products (Carbios, 2022). With the increasing demand for recycled waste such solutions might be viable in the near future.

A final method, which we mention here, is the use of larvae (worm) for biological treatment of plastic, which is in its very infancy of research. The wax worms are the caterpillar larvae of wax moths, which belong to the family *pyralidae* and are a specimen. The enzymes which the caterpillar produces have proven to be able to dissolve plastic as they are reared in a controlled environment, or alternatively, the enzymes are extracted as a sort of concentrated gastric juice to be utilized separately (Ball, 2017). Both methods described above, if fully adoptable, will maintain the plastic quality at a high utility level and even purify the monomers to be able to re-polymerize the plastic, equivalent in quality to virgin materials. Downcycling and hence contamination of PET, which occur in the existing recycling system, can thus be avoided providing promising perspectives for infinite recycling (level 3) in the future.

Watermarks to trace plastic type and origin

As seen from the case studies, companies within the plastic value chain hope for plastic sorting and producer identification systems, like the one investigated in the Holy Grail project, and, for example, commercially available from the Dutch company 'FiliGrade' with their 'CurvCode' watermark reading system applied on plastic packaging products (FiliGrade, 2022). The watermarks are printed or embossed on the plastic products when being produced, and hence both the origin of the plastic and the specific type of plastic can be identified by sorting machinery using light and cameras. The color of the plastic is not important, and in this way plastic producers are not restricted to avoiding black, which many customers prefer for food packaging (Thellesen, 2022).

The Holy Grail 2.0 project also investigates and tests the usability of watermarks on plastic waste, initiated by the Alliance to End Plastic Waste and the AIM European Brand Association, and includes more than 160 companies who participate in the initiative, for example, 'COOP', 'Danish Crown', and 'Arla'. Watermark technologies, implementation barriers and investigation of cost improvements are among others assessed in the Holy Grail 2.0 project (AIM European Brand Association, 2022). The watermark technology can provide valuable data about industries within the plastic value chain; for example, which companies do, or do not, utilize recycled plastic in their products and to what extent. In this way consumers can require changes and impact the manufacturing of future plastic products, while regulatory tools are easier to target relevant stakeholders (Møhl, 2022). Thus, this is a promising technology that could imply that the EPR scheme will be supported by relevant technology and innovation to facilitate its further deployability. Adaptation of such technology on a larger scale will increase the efficiency of sorting plants and hence the quantities of plastics to be recycled (level 3), thus minimizing downcycling by incineration (level 4). Besides this, companies are more easily regulated when the origin of plastics is clear, and the companies – on the other hand – will be able to get back their own plastic waste for recycling purposes more easily.

Bio-plastic

Bio-plastic is often regarded as a future pathway in our use of plastics, and there are overall two types of categories – bio-degradable plastic and bio-based plastic. *Bio-degradable plastic* is interpreted as a solution to the plastic pollution in our natural environment, but the decomposition of the plastic requires temperatures that are not found in the natural environment. Some of the bio-degradable plastics are, for example, mainly based on fossil fuels like oil or natural gas, like in the case of green food-waste bags within Copenhagen municipality. If the bio-degradable plastic is mixed with other sorts of plastic without the same configuration, it will hamper the recycling option. *Bio-based plastics* are manufactured from biological materials as, for example, corn (maize) and sugarcane. Unless the biological feedstock is based on agricultural residues, and not only harvested with the purpose of making plastics, it will also increase the pressure on agricultural land to feed the growing global population (Bigum, 2018). The plastic industry seems to be in favor of the bio-based plastic, as it can be included and recycled together with the existing fossil plastic materials composed of PET, PE, and PP.

Bio-based plastic is regarded as a favorable product as being carbon neutral, by only releasing the amount of carbon when wasted, as it takes up when growing. The bio-based plastic could hence act as a carbon sink, taking up CO_2 and hence storing it in the plastic product. As presented at the beginning of this paper, plastic packaging materials, however, have a very short lifetime, possibly only days or weeks before they end up as waste. Thus, their function as a carbon sink in this sense is only possible if the plastic packaging waste is recycled, besides of course being used in products with a much longer lifespan as, for example, in construction materials, as mentioned in the introduction. Bio-based plastics can hence prevent (level 1) the use of traditional virgin plastic resources, potentially store carbon when recycled and should ideally be produced from agricultural residues only.

Expanding the Danish Return System to include plastic packaging waste

As of now, the EPR scheme adopted within the EU has not led to reduction in the amount of plastic packaging waste (WWF and IEEP, 2020), as emphasis mainly has been on handling plastic wastes, as, for example, recycling, rather than on deploying solutions that reduce the use of plastic packaging. In this paper, we mainly address the recycling of plastic waste, but *reuse* strategies are also important and, thus, rank higher in the resource pyramid (level 2). Plastic packaging is rarely reused, especially not within the food sector, except from, for example, beer and milk crates. We suggest applying a pilot project in which more rigid and durable food trays are produced, which are to be collected by, for example, Danish Return System, rinsed and cleaned to be utilized again for food packaging. The material should be able to withstand several cycles of reuse and be reusable without risks for the consumer. The tray could be delivered to the return machines within supermarkets, like in the case of cans and bottles, and the tax on the product returned. This provides an upcycling in the cascading chain from level 3 to 2, before the quality decay hampers further reuse, and the plastic can hence undertake recycling for other purposes.

Besides this, knowledge from our neighboring countries can also be valuable, as, for example, from Sweden, Germany, as well as France. Here, the ambitions for plastic packaging reuse are supported by quantitative political targets for reuse (refill). In Sweden, the share of reusable packaging must increase to 20% from 2022 to 2026, and to 30% by 2030 (Grøn Omstilling, 2022). In Germany, at least 70% of drinking bottles must be reusable by 2022, and a reusable packaging choice at take-away restaurants must be given to customers not adding to expenses. In France, 5% of all packaging materials must be reusable by 2023 increasing to 10% by 2027 (Grøn Omstilling, 2022). Another option could be to make it mandatory for supermarkets to have a flea market section in which grocery and food products are sold without packaging, which in turn are brought as reusable containers by customers themselves. This is already seen in some small shops, but not widely disseminated. Besides leading to reuse of packaging – and not necessarily plastics – instead of recycling, it could spare food wastes as customers are expected only to bring back home what they need.

PtX plastic

Plastics made from the PtX technology (power-to-x, x being variables) rely on electricity from renewable energy technologies, often windmill electricity, which split water (H_2O) by electrolysis into oxygen (O) and hydrogen (H_2), where the latter can be utilized for various purposes. PtX can also be used to produce many things that currently require fossil fuels such as medicine, plastics, and paints (Kibsgård, 2022). Plastic can be made from PtX where synthetic raw oil is produced, and further refined to a product ‘nafta’, which can be used for various plastic products. Thus, the plastic industry will not necessarily be dependent on traditional virgin resources in the future, if the PtX technologies can be implemented efficiently. In the Danish city Vordingborg, for example, the scheduled PtX facility is expected to produce 25 000 tons of synthetic nafta to be utilized within the Danish plastic industry, when being ready to operate (Olsen, 2022). PtX can potentially prevent (level 1) the use of traditional virgin resources in the production of plastics, but when first entering the cascading chain of plastics – no matter which origin – it must undertake the same recycling and reuse activities as already highlighted. Even though plastics can be made by other resources than fossil fuels (e.g., bio-based and PtX addressed here), the ambitions are the same: to keep the resource at the highest quality level as long as possible.

Conclusions

The exploratory case study analysis within companies in the Danish plastic value chain revealed a need for Danish municipalities to improve their plastic waste management. Collection systems must be harmonized and streamlined to increase the quantity and quality of source separated plastic packaging waste from households (purity of and recyclable plastic). Different types of waste collection systems are currently adopted despite harmonized rules, and companies within the plastic value chain request more clear framework conditions and uniform rules related to waste collection, which could increase the amount, type and, hence, quality of plastics to be recycled. The empirical data further revealed a need for deploying more modern and state-of-the-art sorting plants and introduce recycling facilities in a Danish context, the latter mainly provided by recycle facilities located within other EU countries. This is also the case for recycling of plastics for food packaging usage, which solely is provided by companies outside Denmark. A few PE recycling value chains have been established from plastics that originate from household wastes, however, not for food packaging usage, although our data suggest that it is possible to increase the production quantity depending on the availability of plastic packaging waste for recycling. Thus, in the current management of plastics, downcycling mostly happens (from level 3 to 4), and high quality plastic wastes are exported for external recycling and returning plastics for incineration.

Companies in the plastic value chain show interest in utilizing recycled plastic in their manufacturing processes, which their customers increasingly request. A systematic mapping of where recycled plastic can be utilized within the plastic industry, to substitute virgin resources, would be beneficial just as quantitative targets for plastics to be recycled are needed. The empirical data further show that the EPR scheme is not a major issue for companies, as they welcome more plastic packaging to be recycled, but until the quality is assured, companies focus on other strategies, for example, buyback programs and cooperation with actors in the value chain to valorize the current flows of plastics. Some of the plastic companies consolidate themselves, by becoming a part of a larger value chain for plastics; hence possessing both sorting plants and recycling facilities. To make sure that all industries are committed to recycling plastic, we propose that a certain mix percentage can be required in Denmark and preferably also within the EU. Besides this, economic penalties for not utilizing recycled plastic and gate fees addressing the quality of sorted plastics before entering recycling facilities are hence suggested by companies to increase the quality of recycled plastics. Such an initiative will potentially maintain the plastic quality at the same utility level (level 3) for a longer time and, hence, help avoid immediate downcycling in the cascading chain (level 4).

In connection to the EPR scheme, we suggest applying eco-design – hereunder to utilize mono plastics of PE, PP and PET – and fee-modulation to spur on the plastic industry to produce more environmentally friendly products. Future fee-modulation requirements must include eco-design, and not only increase the sortability and recyclability of plastic packaging waste by lowering the fee on, for example, PET plastic, but also request materials substitution and reduction of use. The EPR scheme adopted within EU countries – and soon also in Denmark – must emphasize more on reduction and reuse of plastic packaging in the future, besides the current focus on plastics being recycled. Hence, both reuse (level 2) and prevention (level 1) must be emphasized more strongly in the future. Thus, an expansion of the Danish Return System to include plastic packaging waste could, however, quite easily be applied for reuse of rigid plastic packaging and become a part of the existing system for cans and bottles. Plastic packaging reuse (refill) strategies have already been adopted by some of our neighboring countries. Besides this, it could be mandatory for supermarkets to have a flea market section in which grocery and food products are sold without plastic packaging but brought as reusable containers by customers.

The future perspectives of the watermark technology, especially in the light of the EPR scheme, could be extensive, and the knowledge obtained about the flows of plastic is an important tool to achieve higher recycling rates of higher quality plastics (level 3). Biological methods, such as bacteria and enzymes treatment are also interesting, but so far not adopted on a larger scale albeit some promising results are identified, as far as the quality of recycled PET is completely restored. Biobased plastics are made from biomass, which increasingly is becoming a scarce resource unless based on agricultural residues. The PtX technology can provide many benefits as far as a fossil free society, and hence also produce non-fossil plastic, and is scheduled to be implemented in Denmark on a large scale. Both biobased plastics and PtX nafta are systems that prevent (level 1) the use of traditional fossil fuel-based plastics but should – adapted on a larger scale – undergo the same recycling ambitions to maintain their high quality in the cascading chain as long as possible (level 3).

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