Prospects for standardisation of industrial PET plastics to support the transition towards a circular economy

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Abstract

The consumption of plastic has significantly increased, emerging as a vital material in contemporary society, primarily derived from fossil fuels. Plastic usage aligns with the linear economy of "take, make, dispose", i.e. including mishandling of plastic waste and an ineffective use of resources, prompting the need for a shift towards a circular economy, advocating for the principles of reduce, reuse, and recycle. The objective is to enhance the value of the material, fostering more sustainable utilisation. Polyethylene terephthalate (PET), a prevalent polymer in the plastics industry, finds applications in both industrial and consumer contexts, including foamed PET used in windmill blade composites. The industrial PET sector faces challenges in achieving circularity, emphasising the necessity for comprehensive measures, with standardisation being a prominent tool. The thesis aims to explore the potential benefits and challenges associated with implementing standards for industrial PET to overcome existing linear industry practices. A literature review is complemented by a semi-structured interview study involving twelve industry experts, resulting in twelve themes: Barriers to standard implementation, Composition variations, Design for recycling, Engagement, Infrastructure and waste management system, Chemical recycling, Understanding and dissemination of knowledge, Material and recyclate quality, Price/cost, Rules and legislation, Time, and Volumes. The findings indicate a consensus among interviewees and in the literature that standards can enhance circularity for industrial PET, although uncertainties persist regarding their implementation specifics. Standards are acknowledged as a complex system requiring greater understanding and dissemination of knowledge to demystify the intricacies of standardisation across diverse industry sectors.

Keywords: Standard, standardisation, industrial PET, polyethylene terephthalate, circular economy, plastic.

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First and foremost, I extend my gratitude to my supervisors, Per Hökfelt at DIAB, and Malin Planander at Sustainalink. They have consistently believed in me throughout the project, providing positive and encouraging energy when everything seemed overwhelming. Per's visionary approach and Malin's realistic perspective were invaluable. I would also like to express my sincere thanks to Fredric Bauer, my supervisor from LTH, for keeping me on track with his valuable support and advice throughout the project. Additionally, a warm thank you to all the interviewees whose participation made this thesis possible.

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Agnes Ström
2024

Contents

Nomenclature

Circular economy	The opposite idea of a linear economy, ultimately utilising materials put on the market for as long as possible by reusing and recycling
Downcycling	Process in which material or products are recycled but the resulting recycled material is of lower quality or value compared to the original material. It often involves that material or products transform into products of lower quality. Therefore, the material may not be suitable for the same applications or industries
Harmonised standard	A European standard that is referred to within a directive
Incineration	Energy recycling as a waste management treatment
Industrial PET	The usage of the polymer PET on the industrial side of the industry
Intrinsic Viscosity	The IV value reflects the material's melting point, tensile strength and crystallinity related to the polymer's molar mass.
Post-consumer	Stage of life cycle after consumer usage when discarded or recycled.
Post-industrial	Separation of material during manufacturing separated from the waste stream before the consumer stage.
Recycling	Used material or waste are transformed into new products or material.
Spiral economy	Circulation of material accepting downcycling of the material
Standard	(*European Standards*, n.d.) a standard is defined as: "*...a technical document designed to be used as a rule, guideline or definition. It is a consensus-built, repeatable way of doing something. Standards are created by bringing together all interested parties such as manufacturers, consumers and regulators of a particular material, product, process or service. All parties benefit from standardization through increased product safety and quality as well as lower transaction costs and prices*."

List of Acronyms/Abbreviations

CEAP	Circular Economy Action Plan
CENELEC	European Committee for Electrotechnical Standardization
CEN	European Committee for Standardization
GHG	Greenhouse Gas
EPR	Extended Producer Responsibility
ETSI	European Telecommunications Standards Institute
EU	European Union
IEC	International Electrotechnical Commission
ITU	International Telecommunications Union
ISO	International Committee for Standardization
IV	Intrinsic viscosity
PC	Polycarbonate
PE	Polyethylene
PET	Polyethylene Terephthalate
PP	Polypropylene
PS	Polystyrene
rPET	Recycled PET
SIS	Swedish Standards Institute
vPET	Virgin PET

1. Introduction

The consumption of the Earth's resources has increased tremendously over the past decades, fossil fuels in the form of plastic is one of them. Plastic has become essential within the industry as it is durable, functional, and lightweight. The production of plastic waste in the world has doubled within two decades, where 50 percent of the plastic waste is landfilled, 20 percent incinerated, and 22 percent leaked out into the environment (OECD, 2022). In 2019 the global plastic production reached 460 million tonnes, where only 9 percent was recycled successfully. Globally the lifecycle of plastics accounts for 3.4 percent of the global greenhouse gas (GHG) emissions. Moreover, in Europe around 114 kg of plastic waste per person is generated annually (OECD, 2022). This entails the strong representation of a so-called "Linear Economy Model" based on the principle "take-make-dispose" (Shamsuyeva & Endres, 2021). With the increasing awareness of the problem of the mishandled waste management of plastic as well as the increased use of fossil fuels in the plastic industry, the promotion for a change from the linear model to the circular is clear.

Circular economy promotes reuse as well as effective and efficient recycling, minimising the amount of waste by reintroducing the material into the loop, ultimately eliminating the usage of virgin material. This is accordingly with the European waste hierarchy; prevention, reduce and reuse, recycling, incineration, and disposal, where disposal is the least acquired (Directive 2008/98). By increasing the value and usage of the resources it increases the retention time of the material in the system. Furthermore, it would promote reducing waste by increasing the recycling yields and collection rates, improvement of current recycling technologies or new development regarding both upcycling and downcycling (Gracida-Alvarez et al., 2023). However, the introduction of a circular economy for plastic faces numerous challenges. Barriers and hindrances that are associated with prevention of the implementation of circular economy can be design, market, cultural, technical and regulatory barriers (Mangers et al., 2023). The problem has grown during the past years due to increased consumption of plastics and the dynamic development of plastic products. There is today an increased variety of polymers, material properties, chemical formulas, and contaminants. Consequently, the possibilities to reuse or recycle the plastic into new applications and products gets intricate. It also depends on the type of polymer of plastics to what extent it can be recycled or even at all. One common polymer of plastic is polyethylene terephthalate (PET), a thermoplastic that has the chemical properties enabling recycling (Eriksen et al., 2020).

Introducing a standard is one tool that can be used for promoting a circular economy. Standardisation is a cooperative solution to recurrent problems, reached through deliberation and voluntary consensus among all stakeholders (Jakobs, 2016; SIS, n.d.). These standards encompass diverse domains from the design of everyday objects like nails to vital sectors such as healthcare, communications, and environmental preservation, reflecting the market's collective interest (SIS, n.d.). They serve as specifications that not only create constraints but also stimulate trade and innovation within the system. Standards extend beyond merely limiting variety; they provide norms for markets and technologies, fostering focus, credibility, and critical mass within emerging technology markets. Moreover, standards have the potential to expand existing markets or even initiate new ones (Jakobs, 2016).

PET has a wide range of areas of use, from textiles, packaging, and electronics to thermoplastic resins. There is a need to distinguish the products within the consumer side, such as PET in packaging, from the industrial side where for example PET is used in the foamed core material for wind turbine blades (Lassesson et al., 2021). During 2023 it was acknowledged by the Swedish municipality of parliamentary control, called National Audit Office (Swedish NAO), that the State had not ensured effective management of end-of-life wind turbine blades (Riksrevisionen, 2023). It was stated that there is a lack of encouragement of reuse and recycling in line with the circular economy and the priorities of the waste hierarchy. Today's policy instruments for plastic are insufficient or non-existing regarding the support of management for the long-lived products, (*Plastics Strategy*, n.d.) ensuring and promoting effective handling at the blades end-of-life state, (Riksrevisionen, 2023) and the industry is also aware of the problem. PET on the industrial side (industrial PET) is therefore an area where it is interesting to study the possibilities of how standardisation can be of help within the transition to a circular plastic economy.

1.1. Aim

The aim of this thesis is to investigate the advantages and challenges of the introduction of a standardisation within the field of industrial PET and if it would help get past the hindrances that now cause the industry to be linear. Furthermore, the questions that the report will answer are the following.

1. What is the current status of standards, guidelines, or laws affecting industrial PET?
2. What are the advantages and challenges associated with recycling of industrial PET plastic?
3. What are the benefits and challenges of implementing standardisation for industrial PET?

1.2. Scope

This study delves into the realm of the circular economy and plastic recycling, with a specific focus on industrial PET, within the framework of the European Union (EU) and more specifically, Sweden as the study's implementation location. By confining the scope to the EU and Sweden, the study facilitates a more detailed and localised analysis of the specific challenges and opportunities unique to the region. This approach provides insights that may be directly applicable to the Swedish context, offering a clearer picture of the evolving regulations and practices surrounding circular economy and industrial PET in this geographic area.

Standards, in contrast, are not only bound by the same geographical constraints since they are also often formulated within a broader landscape, impacting not only specific industries or sectors but also contributing to global practices. Hence there are both global, European, national and sector standards that could potentially have an impact. In the context of industrial PET, standardisation transcends geographical boundaries, providing a common framework that extends beyond national borders. As industries become increasingly interconnected, the influence of standardisation reverberates globally, shaping the production, utilisation, and recycling of materials like industrial PET across various regions and markets. However, there is a specific focus on standards related to PET as a product or material to narrow the thesis's scope.

Moreover, this thesis only focuses on industrial PET as far as the literature provides knowledge in the field, excluding specific details related to the consumer side of the polymer PET and related systems. However, if the distinction cannot be drawn between the consumer and industrial sector a general overview has been stated to elaborate the current image of today's system from the perspective of plastic and PET.

1.3. Report outline

The structure of the report is outlined as follows:

Approach, methods, and data collection: Chapter 2 details the methodologies employed for the thesis, including the co-creation of knowledge with DIAB.

Literature review: Chapter 3 delves into the aspects of plastic and industrial PET in the context of a circular economy, covering plastic streams, the market, and governance. It also includes the definition and features of standardisation concerning plastic and industrial PET.

Thematic analysis: Chapter 4 presents the results from the semi-structured interviews regarding the benefits and challenges of implementing standards for industrial PET. Additionally, it discusses aspects to enhance the circularity of the material via a standard or other measurements.

Conclusions: Chapter 5 provides answers to the posed questions and draws conclusions, reflecting and avenues for further research.

2. Approach, methods, and data collection

To answer the research questions, a combination of qualitative methods was used. Firstly, a structured literature review was conducted to understand the foundation of the topic conducting the base for the background. Secondly, a semi structured interview study was performed and analysed thematically, creating the foundation for the result of the thesis.

2.1. Co-creating knowledge with DIAB

This thesis project was initiated and planned in collaboration with the company DIAB AB. DIAB is a company that produces foam core materials that can compete with the mechanical properties of steel but to an extensively lower weight. They produce foamed PET that can be used as the core structure in sandwich composite applications, for example in windmill blades. The company sees a lack of value for the material at the end-of-life state, hindering them to attain a circular economy that they are aiming for.

Inspired by the circular flow of PET bottles, DIAB recognised the potential for a similar system in the application of industrial PET, particularly in the context of windmill production. This exploration aimed to position the company to meet future market demands within a more circular economy. Building on this foundation, specific research questions were formulated to obtain a comprehensive understanding of industrial PET as a material. DIAB's invaluable support and insights, including a study visit to their production facility in Laholm, facilitated interviews, and collaboration including feedback and discussion, enriched the thesis by providing diverse perspectives and ideas for improvement.

2.2. Structured literature review

This study employed a structured literature review combined with an iterative process with the primary objective of identifying pertinent articles and studies related to specific keywords and topics. Chosen keywords that formed the basis of the search strategy can be found in Appendix 1.

The literature for the review was conducted using the database LUBsearch to ensure comprehensive coverage. To refine results and uphold source quality, specific criteria and limitations were applied:

1. **Peer-Reviewed Sources:** Only peer-reviewed articles were considered to ensure the reliability and academic rigour of the selected literature.

2. **Time Frame:** The selection focused on articles published within a defined time span (2013-2023), determined during the search process.

Multiple search attempts were conducted, with the first attempt yielding 225 hits, prompting adjustments to narrow results down to a maximum of 50 hits. Further screening involved reading titles and abstracts to identify the most relevant articles for inclusion in the literature review.

Various combinations of keywords were tested in multiple search protocols [see Appendix 1], providing a comprehensive overview and enabling the refinement of the study's focus. The iterative nature of this process allowed for adjustments and improvements to narrow down the literature. In total, 14 sources were found, with one being a duplicate, resulting in a total of 13 articles used for the literature review. Additional articles and literature were iteratively included to ensure a holistic understanding of the research topic, utilising additional databases such as Web of Science and Google Scholar.

2.3. Semi structured interviews and thematic analysis

The interviews were conducted using a Semi-structured interview method. This is a qualitative research method that combines elements of both structured and unstructured interviews (Blomkvist & Hallin, 2014). The structured part of the method is the set with questions or topics that are predetermined whilst the unstructured part provides flexibility in the order and the wording of the questions during the interview, meaning that additional questions are asked for interest and clarification. Furthermore, the aim of the research using interviews was to gain new perspectives within the area of standardisation of plastics and industrial PET. This would help to nuance the picture of the current situation, concerning recycling and opinions on the topic, from different actors within the industry. The questionnaire was created based on the research questions broken down into approximately 10 to 15 questions [Appendix 2].

Selection of interviewees was made from seeking different perspectives on the potential implementation of a new standard for PET. Interviewees were found from diverse backgrounds, encompassing various businesses, governmental bodies, and other organisations. The intention was to engage with a spectrum of stakeholders, each holding a vested interest or potential impact in the advent of a new PET standard. This inclusive approach aimed to capture insights from different sectors, ensuring a comprehensive understanding of the varied implications and requirements associated with the proposed standard.

Multiple interviewees were contacted including municipalities, companies, recyclers, industry associations, and researchers. Respondent actors that participated are presented in Table 1 below. Each interviewee is represented by a number from 1-12 and is used throughout the report when referring to their answers. All except DIAB remain anonymous, as the collaboration has been conducted with the company.

Table 1: *Actors from different organisational levels that participated in the interview study.*

Interviewee	**Sector**	**Field of expertise**
1	Municipality	Waste management

2	Recycle industry	Recycling regarding post-industrial plastic
3	Research	Expert on circularity, plastic and standards
4	Recycler	Recycling regarding post-consumer plastic
5	Industry association	Expert on plastic
6	Research	Expert on plastic and chemical recycling
7	Recycler	Recycling regarding both post-consumer and post-industrial
8	Manufacturer/DIAB	Purchasing
9	Manufacturer/DIAB	Sustainability
10	Recycler	Recycling regarding post-industrial
11	Recycler	Sorting of post-consumer plastic
12	Municipality	General expert in plastic

Depending on the person interviewed, the order of posing the questions differed but with the overall aim to answer all the questions followed by complementary questions for clarification and interest. With the interviewees consent, the interviews were recorded and transcribed.

To analyse the interviews, an inductive thematic analysis was conducted. This is a qualitative research method exploring and understanding the participants' experiences, perceptions and opinions in this case regarding plastic, industrial PET and standardisation (Säfsten & Gustavsson, 2019). To analyse the transcribed material, the program NVivo was used to thematise the interviews inductively, qualifying the themes without strict frames and from my level of understanding as a researcher. Themes found were; Implementation of a standard, *Composition variations, Design for recycling, Engagement, How standards work, Infrastructure and waste management system, Chemical recycling, Understanding and dissemination of knowledge, Quality of the plastic material and recyclate, Aspects of PET or industrial PET, Price/Cost, Rules and legislation, Standards - opinions from interviewees, Time, What the customers want,* and *Volumes*. They were further analysed, refined, and compiled in Chapter 4 and later used to answer the questions posed in the thesis.

3. Literature review

This chapter presents the idea of circular economy, what polymers and additives are and industrial PET's place in the circulatory system, regarding current market and recycling methods. Positives and negatives with respective recycling methods are presented and plastics including industrial PET's current context regarding policies and means of control are explained. Lastly, the chapter includes a description of what a standard is and current existing standards affecting industrial PET.

3.1. Plastic and industrial PET in a circular economy

Plastic permeates every aspect of modern society, owing to its remarkable versatility, which allows it to assume a wide range of applications. Plastics offer the advantages of being lightweight, durable, and cost-effective when compared to alternative materials, coveted in specific applications such as windmill blades. The primary raw materials for plastic production are petroleum and the condensed form of natural gas, along with the utilisation of fossil energy resources through the value chain regarding production and transportation. Collectively, the production of plastic accounts for 6 percent of the total global fossil fuel consumption (Lindahl et al., 2022).

Within a circular economy, the value of materials, resources and products remain in the economy for as long as possible, extending their usage and minimising waste (European Commission, 2023; Naturvårdsverket, n.d.). This approach is argued to significantly reduce the negative environmental and biodiversity impacts of human activities. New products must be designed with longevity, repairability, and upgradability in mind to minimise overall waste generation. Additionally, they should be designed for efficient material recycling, facilitating effective recirculation at the end of their lifecycle. According to the European Parliament (2023) 9.1 percent of the GHG emissions within the EU originate from industrial processes and products, with the design phase accounting for more than 80 percent of a product's environmental impact. However, this varies depending on the country and its raw material prices (European Parliament, 2023).

To address the negative environmental effects and combat climate change while transitioning from a linear to a circular economy, there must be proactive actors who pave the way (Lindahl et al., 2022). Today there is a lack of incentives that promote a more sustainable approach to product design - one that prioritises durability, recyclability, and the use of resources with minimal environmental impact. Sustainable development is defined as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). The challenge lies in attaining profitability when opting for the extended outsourcing of recyclable materials. Moreover, the cost of import and export has increased over the last decades between the EU and the rest of the world. The adoption of a circular economy would reduce the reliance on virgin materials, thereby mitigating risks associated with supply, including price volatility, import dependence, and availability of plastics and other materials (European Parliament, 2023). Transitioning to a circular economy could also enhance competitiveness, fuel economic growth, foster innovation, and generate new employment opportunities. In the EU, it is estimated that by 2030 alone, it could create 700,000 jobs, according to the European Parliament (2023).

3.1.1. Polymers

Plastic is a general term for a big group of different polymers that creates synthetic or half synthetic materials. A polymer is a large molecule made up of many smaller molecules that have been tied together in a long chain. In the middle of the 20th century the endless possibilities of the materials' qualities cached the eyes of the market creating endless opportunities within the society. The simplified explanation of the composition of plastic is that it is made up of one to four polymers mixed with one or more additives. Furthermore, there exist two major categories of plastics: thermoplastics and thermosetting plastics. The former is the most extensively used, with some of the most prevalent examples including polycarbonate (PC), polyethylene (PE), polypropylene (PP), polystyrene (PS) and PET. Thermoplastics have intermolecular bonds making it possible to reshape the material at increased temperatures. Thermosets however have irreversible chemical bonds hindering reshaping of the construction as the chemical structure is destroyed. From a recycling point of view thermoplastics are therefore a more applicable material (Lindahl et al., 2022).

Additives

The characteristics of plastic can easily be changed by adding additives creating possibilities and applications within many different fields. This is one of the many factors making plastic such a versatile material. Additives like dyes, insulators, plasticizers, antioxidants, stabilisers are a common example of qualities that producers want for their product. The additives can also be added to change density or volume or to reinforcing materials or adding fire protection (Lindahl et al., 2022).

PET

One of the most used and well-known polymers of plastic is PET. It belongs to the polyester family and is also known to have excellent properties such as thermal, mechanical, and chemical resistance and dimension stability. In its natural state it is a highly flexible, colourless, and semi-crystalline resin. Some of the key features of the material is that it is very strong and lightweight, has electrical insulation properties, approved to use for foods and beverages, transparent and does not break or fracture (Sarda et al., 2022). Moreover, this makes PET suitable for many applications. The polymer is found in products spanning both the consumer side, including packaging and textiles, and the industrial side, encompassing applications such as films for automobile components, electronics, construction materials like windmills, and household items. The climate impact from the production of one kilo virgin PET (vPET), not covering the usage until the end-of-life of the product, is according to Ljungkvist Nordin et al. (2022) 2.8 kg CO_2 equivalents. On average 1.5 litre PET bottle weighs 35 grams, resulting in approximately 28 bottles per kilogram PET (*Waterschools - Environmental Impact of Bottled Water*, n.d.). A standard windmill blade is 65 metres long and consists of around 20 m^3 foamed industrial PET with an average density of 100 kg/m^3 resulting in a total weight of 2 tonnes (P. Hökfelt, personal communication, January 2, 2024). The total emissions from the core of foamed PET in a windmill blade is therefore 5600 kg CO_2 equivalents. To put this into further perspective, by 2021 an average private car in Europe emits 0.1163 kg CO_2 equivalents/km (Lindblom & Selin, 2023).

Moreover, intrinsic viscosity (IV) is the main indicator for quality regarding PET (*Polymers; Intrinsic Viscosity Measurements for Quality Control of PET*, n.d.). The IV value reflects the material's melting point, tensile strength and crystallinity related to the polymer's molar mass. The value of IV depends on the polymers chain length, the higher the IV value is, the longer chains meaning more entanglements between chains. The preferred IV value depends on the application.

3.1.2. Material flows and market

On a global scale, there has been a steady increase in both plastic production and consumption, with 360 million tonnes produced in 2018 (Lindahl et al., 2022). By 2019, global plastic production had already surged to 460 million tonnes (OECD, 2022). If the current rate of plastic consumption continues, it is anticipated that fossil fuel consumption will rapidly rise, accounting for up to 20 percent of total resource usage. This escalation in plastic production is also expected to result in an increase in GHG emissions, which will rise from their current level of one percent of the global CO_2 budget to 15 percent by 2050 (Lindahl et al., 2022).

The fluxes of plastic waste that are currently predominantly incinerated or sent to landfills consist of polymers suitable for both mechanical and chemical recycling (Lassesson et al., 2021). Nevertheless, the substantial quantity of plastic polymer mixtures, along with additives, poses a challenge when there is a desire to recycle the plastic material at the end of its lifecycle as a part of the circular economy. The difficulty arises from the need to segregate various fractions, given the numerous distinct material-specific qualities possessed by the plastic. Even if the material can be successfully separated, the volume from each fraction is seldom adequate to create a profitable business. Consequently, the ensuing consequences include the continued flow of virgin material within the system, resulting in an increase in the amount of non-recyclable plastic waste and heightened CO_2 emissions, both during production and waste management (Lassesson et al., 2021).

Figure 1 displays the demand by segment and polymer of plastics in Europe, showing that the demand for plastics is the greatest within the packaging sector accounting for approximately 40 percent (Rumetshofer & Fischer, 2023). Furthermore, the longevity of the product, depending on the plastic application, the product lifespan differs affecting the generated and collected plastic waste. The lifespan of packaging and textiles for consumer usage is predominantly shorter than for products such as electronics, transportation, buildings, or industrial machinery because the rate of production and the waste generation differs because of the longer lifetime of the product. Hence, the correlation of the annual demand does not always match the amount of plastic waste. However, by 2050 it is estimated that 12,000 Mn tonnes of plastic waste will have ended up in the environment or the landfill (Shonnard et al., 2019).

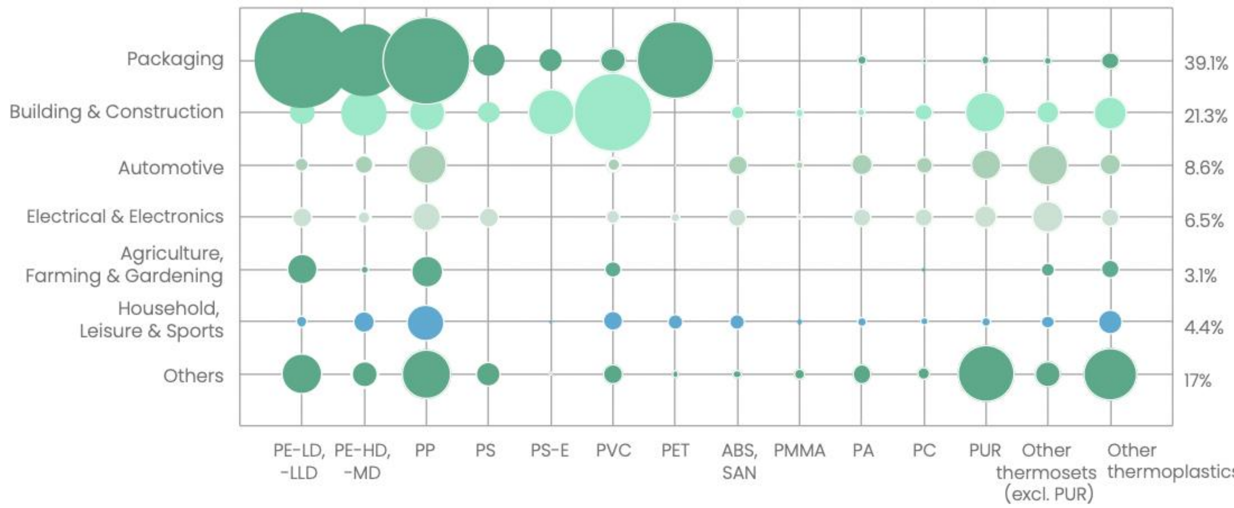

Figure 1: *Demand by segment and polymer of plastics in Europe.* ('Plastics - the Facts 2022 - Plastics Europe', n.d.) *Reprinted with permission.*

Furthermore, the amount that accumulates during a year can vary immensely between the different sectors and does not always correlate with the annual demand on plastics. Globally the flow of plastic of the short lived packaging products results in approximately more than 80 percent of plastic waste whilst the middle- and long-life products stand for less than 35 percent (Shamsuyeva & Endres, 2021). With the international value chain as it is today it also makes it hard to ensure the recyclability of products due to the import and export of materials during different stages of the value chain. Data collection is a challenge between countries and is another barrier because of the different system structures within the societies. Implementation of new regulations and goals therefore is not only a national interest, hence requiring many different stakeholders within the entire value chain to collaborate. These stakeholders range from collection companies to plastic manufacturers to consumers to authorities as well as waste managers and standardisation organisations (Shamsuyeva & Endres, 2021).

The global market for vPET has over the past years increased in both capacity and demand as seen in Figure 2, demonstrating that the capacity is much higher than the demand. Moreover, the figure below presents the entire market for vPET, meaning both for consumer and industrial usage. As seen in Figure 2, much of the material is used for packaging in Europe, a general consensus globally as well. For reference 6917 tonnes of PET was purchased in 2022 for production of foamed PET at DIAB (M. Malmström, personal communication, October 27, 2024).

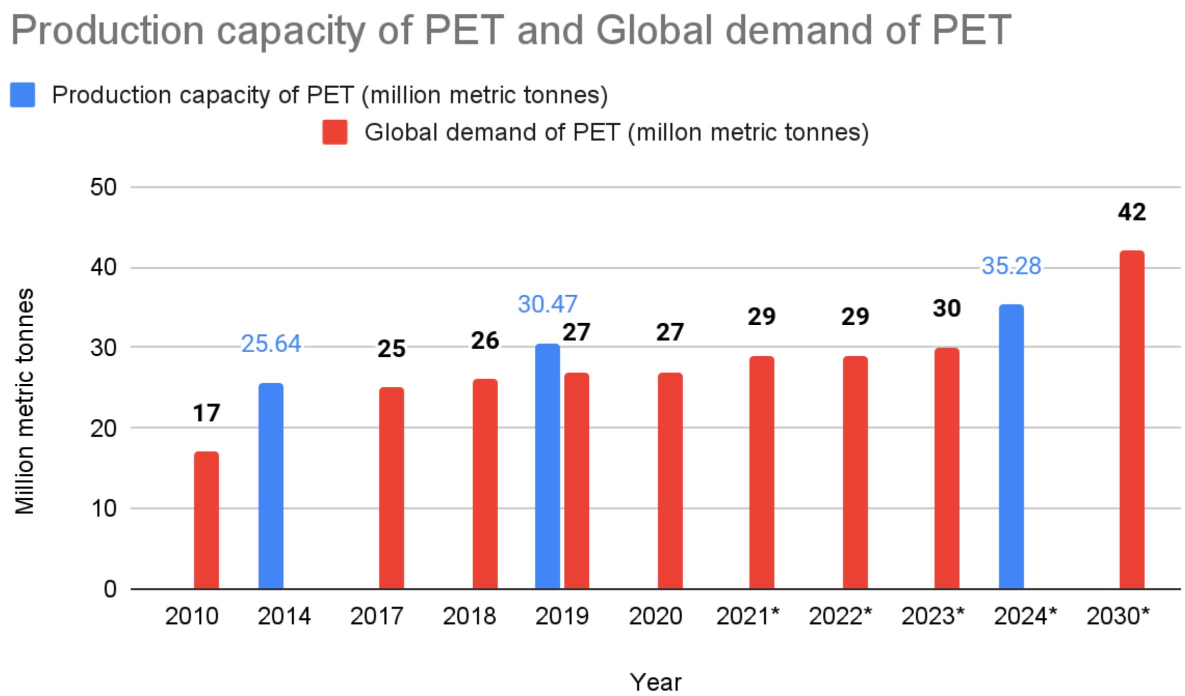

Figure 2: *Global production capacity of PET, in million metric tonnes (GlobalData, 2020). The global demand for PET (Indorama Ventures, 2021). * refers to a calculated forecast, in million metric tonnes.*

Recycled content of recycled PET (rPET) on the market for all rPET streams stems from PET bottles sources as a consequence of very low recycle rates from non-bottle PET applications (Garant et al., 2022). Out of the recycled fraction by 2019 approximately 1.8 million tonnes of flakes came from bottled PET, 31 percent constituting pellets for bottles. The rest (69 percent) appears in other products concluding that there is a big leak from the closed loop streams of bottled PET. However, the collection and recycle rate is hard to estimate according to Garant et al. (2022) due to several reporting issues. Recycling companies in Europe make up a total of 600 facilities with an installed capacity of 8.5 million tons, where 30 percent of the capacity is just for PET (Rumetshofer & Fischer, 2023).

3.1.3. Recycling methods

For plastic to be incorporated into a circular economy, one focus for enabling a sustainable integration is to develop a recycled plastic global supply chain as well as to establish efficient and effective recycling approaches. Mechanical and chemical recycling are two different general methods for recycling plastics, explained further below. Explanations for how they work and positives and negatives that can be found for respective methods, are summarised in Table 2 at the end of this chapter.

Mechanical recycling

The most common recycling method today is mechanical recycling that entails waste collection, sorting, washing, grinding/shredding, and extrusion. Mechanical recycling does not change the chemical structure of a given polymer (Rumetshofer & Fischer, 2023). Additional steps can sometimes be necessary when recycling mechanically. For example, such steps can be separation of magnetisable metals, sieving the material as well as an air-separation unit to remove the biological waste. The separation process is crucial to provide good plastic recycling. By minimising the concentration of contamination raw material gains a higher economic value. Moreover, when reprocessing plastic waste via the techniques such as extrusion and injection moulding the product properties can be deteriorated due to degradation effects and molecular weight reduction. However, the general process for mechanical recycling of PET, melt extrusion, does not significantly affect the chemical structure of the polymer chain. PET in the form of film or fibres are on the other hand not as easy to recycle as the bottles. As the mainstream of recyclate of PET originates from packaging i.e. PET bottles mainly, applications that use recycled PET from bottles are increasing, because of the high quality of the recylate from the closed loop (Bobek-Nagy et al., 2023).

Current barriers for the mechanical method are that the material flows that are available for recycling mechanically are too small to become potential for external use. Therefore, the demand for recycled plastic is not enough, entering an insufficient incentive for the recyclers to increase the collection of material. Moreover, as the concept of recycling plastic is relatively new, current policy and incentives as well as the infrastructure is based on fossil plastic production. There is an emphasis on the lack of a long-term vision and clarity entailing means of control aiming to move away from the need of fossil fuel commodities and from incineration, towards an increasing amount of recycled plastic (Lassesson et al., 2021).

Another barrier with mechanical recycling is that the material, depending on the sort of polymer, only goes through the recycling loop a certain amount of times (Shamsuyeva & Endres, 2021). This is because the materials quality of the molecules deteriorates caused by shear during the extrusion processing. This is due to high pressure and temperature and this deterioration of the material downcycles the material. However, the recycled material can be improved by using additives to reduce the number of plastics that are downcycled. When lengthening the polymer chain during extrusion of PET, reactive copolymers such as styrene, butyl acrylate and glycidyl methacrylate can be used which results in an increase of tensile strength. Nevertheless, the mechanical properties are improved but this also increases the cost of the plastic recyclates. Compared to virgin plastic the recyclates of mechanical recycling however do not always have the same quality that is necessary for certain applications, nor necessarily lower cost for the material. Virgin plastic low cost puts a high pressure on the recycled plastic to live up to the same price range as well as maintaining a high quality. Sourcing enough recycling plastic with the right quality is difficult and can therefore hinder the ability of the recycling business to improve and develop better techniques for a more circular economy (Lee, 2021). In order to increase the amount of plastic that is recycled to improve the sustainability of plastics, an introduction of designing for recycling and an improved sorting of the mixed waste has to be implemented (Shamsuyeva & Endres, 2021).

Overall, the main advantage with mechanical recycling is that the approach is suitable for decentralised implementation. Moreover, the method is also simple and therefore not costly nor needs a high energy demand. However, the quality of mechanical recycling can vary due as it depends on the purity of the input plastic stream (Shamsuyeva & Endres, 2021).

Chemical recycling

Chemical recycling is conducted through controlled processes such as depolymerisation, solvolysis, or pyrolysis, aiming to recover plastic and facilitate its continuation within the circular economy (Lassesson et al., 2021). In contrast to mechanical recycling, the quality of the recycled material is achieved at the end of the chemical recycling process and can be comparable to the quality of virgin plastic. Currently, this method is applied to post-consumer PET, PE, and PP, albeit on a small scale. Thermolysis and solvolysis constitute the main groups of chemical recycling, encompassing several processes. However, the overall process is known for its energy intensity and complexity, which contributes to its limited usage (Shamsuyeva & Endres, 2021).

Looking at the environmental aspect, chemical recycling is better than incineration but worse than mechanical recycling. However, there are factors such as the energy source, chemicals used and the quality and percentage of the recycled material of the output of the recycle process. Chemical recycling has the potential of returning more material back into the loop in addition to mechanical recycling. Moreover, chemical recycling of plastic could be argued to have more potential when dealing with a significant flow of material, especially recycling plastics that are less suitable for mechanical recycling. Specific waste streams mentioned as beneficial include polyethylene and polypropylene from mixed waste, polystyrene, PET-polyester, composites, and other plastics originating from vehicles (Lassesson et al., 2021).

While chemical recycling has the potential to target lower-value materials, mechanical recycling is generally more environmentally and economically suitable, especially for relatively pure waste streams. Downcycling often results from mechanical recycling, leading to lower-quality recycled materials. Efficient sorting increases the potential for high-quality mechanical recycling. This process creates opportunities for both mechanical and chemical recycling, ultimately benefiting the environment and the economy (Lassesson et al., 2021).

Moreover, the technique of chemical recycling of polymers is improving but still needs to improve on an energy, economic and environmental level to be seen as efficient as mechanical recycling and to be scaled to industrial manufacturing. Within this improvement there is also the need to look at the sustainability aspects of the process (Shonnard et al., 2019).

Aspects of recycling

Moreover, the current recycling models are complex and looking at it with today's perspective the main obstacles are the lack of information shared between all stakeholders within the value chain as well as the increasing complexity within it. The demand for higher recycled fractions is partly because of the increasing pressure from the EU and their increased recycling targets. Furthermore, the industry is also missing clear guidelines, technologies and definitions for recycling and recyclability as well as quality criteria (Rumetshofer & Fischer, 2023).

Additionally, the quality is largely determined by the sorting and collection systems that constitute the material for recycling. According to Pinter et al. (2021) mono-collection-systems are more efficient where the input to the rPET was shown to have a higher quality compared to a co-collection-system. Moreover, sorting of the material means that removal of undesirable substances or material that can also be considered as contamination is polyolefins, additives, coloured PET flakes, metals, or labels. However, it has also been shown that contamination of rPET is not always negative. Discoloration for example is not affecting the mechanical, physical, or chemical qualities, but is seen as an undesired colour (Pinter et al., 2021).

According to Lee (2021) there are primarily two reasons for low recycle rates: first, recyclers have high-quality standards for the plastic they handle, and second, the recycled plastic's quality is questioned due to contamination, leading to its downcycling. Standardising and mainstreaming the recovery process is therefore desirable to increase the supply base of recyclates, stimulating the circular economy (Lee, 2021).

Table 2: *Overview of the positives and negatives with mechanical- and chemical recycling.* (Lassesson et al., 2021; Lee, 2021; Shamsuyeva & Endres, 2021; Shonnard et al., 2019)

Attributes	**Mechanical recycling**	**Chemical recycling**
Cost	Low	High
Current environmental assessment (Lack of data)	More advantageous	Less advantageous
Energy requirement	Low	High
Maturity of industry	High	Low
Multiple recycling loops possibilities	Limited	Possible
Process material flow demand	High	High/Low
Technical aspects: infrastructures, process	Low	High
Quality of material; output	Depends	Very high
Quality of material requirement; input	High	Low/can be discussed

3.1.4. Policies and means of control

Work towards a more sustainable and circular economy for plastic has been on the agenda for a while. Therefore, there are already incentives that aim to guide the development in the right direction. Following a presentation of current policies, different means of control and regulations regarding plastic and industrial PET within EU and Sweden will be introduced in this chapter.

EU

The new Circular Economy Action Plan (CEAP), adopted by the European Commission in March 2020, is part of Europe's agenda towards sustainable development, known as the European Green Deal. CEAP introduces initiatives throughout the life cycle of products, encompassing design, usage, and end-of-life measures, with the goal of promoting the circular economy process. Objectives within the action plan seek to standardise the production of sustainable products, including resource-intensive sectors such as plastics, to ensure less waste and encourage more sustainable practices. Through this action plan, various measures, including legislative initiatives and complementary regulatory or voluntary approaches, are presented to enhance and supplement existing instruments (European Commission, 2020).

Moreover, as part of the CEAP, the EU has adopted a strategy for plastics within Europe. The plastic strategy's objectives include mitigating GHG emissions, reducing dependence on fossil fuels, protecting the environment, and promoting the shift towards more sustainable production and consumption patterns of plastics. However, it is noteworthy that there are currently no specific incentives targeting plastics on the industrial side. The existing incentives and directives primarily focus on single-use plastic products, fishing gear, plastic packaging, and recycled plastic for food security. Additionally, measures to address plastic waste include efforts to restrict the use of microplastics in products and a focus on the integration of new bio-based, biodegradable, and compostable plastics (*Plastics Strategy*, n.d.).

The regulation of waste management in Europe has an overall legal framework called the Waste Framework Directive. Overarching the directive is the aim of protecting the environment and the public health with the descriptive waste hierarchy, Figure 3, in the centre directing the regulations regarding the waste management. The waste hierarchy as a regulatory framework provides a general guide for a sustainable way to look at material usage, including industrial PET.

Figure 3: *The European Waste Hierarchy. The higher up in the hierarchy the better.* (Directive 2008/98)

To reach higher up in the waste hierarchy, product design plays a crucial role in ensuring the long-term and sustainable use of plastics within the circular economy. As mentioned above, more than 80 percent of a product's environmental impact is attributed to the design phase in product development (European Parliament, 2023). The EU is currently exploring ways to expand the Ecodesign Directive beyond the existing requirements for energy-related products, with a particular focus on including plastic in the extension. The initiative considers several aspects, including the necessity for products to be durable, reusable, upgradable, repairable, free of hazardous chemicals, and to enhance energy efficiency. Additionally, there is a proposal to increase regulations related to recycled content, aiming to improve recycling quality and incentivise models such as product-as-a-service, where the producer retains responsibility for a product throughout its lifecycle. Measures such as mobilisation and digitalisation of product information, such as tagging, watermarks, or digital passports, are also suggested (European Commission, 2020). Designers bear significant responsibility in making conscientious choices for both the product and its packaging during the development process. Factors such as reparability, reusability, and recyclability must be taken into consideration at the design phase, as they directly influence the product's and materials' lifespan. Developing an understanding of a product's life cycle is, therefore, advantageous for designers (Ljungkvist Nordin et al., 2022).

Sweden

Apart from the regulations that come with the directives from the EU implemented in all member legislations, Sweden has also implemented further measurements to try to mitigate the climate impact from plastics. There are no legal frameworks regulating industrial PET, however there is a deposit return system for ready-to-drink bottles in addition to the packaging Extended Producer Responsibility (EPR) including plastic bottles made from PET. The collection system for PET bottles is specific, as the consumer pays a deposit upon purchase and upon return gets it back. It is regulated depending on the beverage that the bottled container withholds and is thereafter decided if it is mandatory within the return deposit system. If it is not included in the deposit and return system, EPR for packaging applies. The incentive to introduce the system in the first place was due to littering. 2018, 83 percent of the PET bottles that entered the market were collected (The Swedish Environmental Protection Agency, 2020).

3.2. Standards as governance of plastics and industrial PET

Standards can be created for broadly anything, not only handling products but also for example services and processes. They can range from being broad and general to more niche and specific in all its bearings. This chapter explores the concept of standards and their applications in the context of plastic, industrial PET and a circular economy.

3.2.1. Definition of a standard

According to the European Committee for Electrotechnical Standardization (CENELEC) (*European Standards*, n.d.) a standard is defined as:

"*...a technical document designed to be used as a rule, guideline or definition. It is a consensus-built, repeatable way of doing something. Standards are created by bringing together all interested parties such as manufacturers, consumers and regulators of a particular material, product, process or service. All parties benefit from standardization through increased product safety and quality as well as lower transaction costs and prices*."

The ultimate purpose of standards is to establish uniform and transparent procedures that garner stakeholder consensus. It is in everyone's interest to enhance quality, prevent misunderstandings, and eliminate the need for reinventing the wheel. Standards find applications across a broad spectrum of business sectors and industries, and while their implementation and usage are voluntary, they can also serve as obligatory references mandated by public authorities (SIS, n.d.).

Moreover, a standardisation promotes a more effective and resource efficient production (SIS, n.d.). It also facilitates processes within procurement, trade, and communication, looking at the broader aim. The advantages of standardisation are concluded as follows (Schuyler et al., 2022; SIS, n.d.):

- Establishing precise guidelines to ensure uniform functionality and high quality
- Enhancing procedures to boost efficiency
- Fostering transparency and simplifying comparability
- Strengthening safety measures and accessibility
- Implementing resource conservation practices to minimise the environmental footprint promoting sustainability
- Encouraging and supporting development initiatives
- Providing policymakers and governments with guidance, frameworks of specifications
- Enhancing the market for recyclable and reusable products

- Better communication and transparency in the exchange for information facilitating trade and reducing information asymmetry
- Providing assurance to the consumers and the manufactures
- Increasing the social acceptance for recycled products/materials
- Advancing the infrastructure to provide less costly recycled plastics

According to Shamsuyeva & Endres (2021), standardisation plays an important role in the transition to a circular economy and the establishment of the plastic recyclate global supply chain. Prerequisites that are mentioned to develop a functioning market for plastic recyclates are; clear responsibilities for both the supply guarantee as well as the properties and the material quality. Furthermore, that means that there needs to be a traceability and a standardised sampling and characterisation method for the material while at the same time keeping in mind the application and product-specific requirements. In order to prevent greenwashing, the standards also need to cover updating and concretise definitions of terms so that they are not misused.

3.2.2. Categorisation and levels of standards

Standards can be classified into areas - international, European, national, function or purpose. However, the subdivisions are not always clear-cut, one standard can be used in multiple fields, hence a compilation of various standards is illustrated in Figure 4.

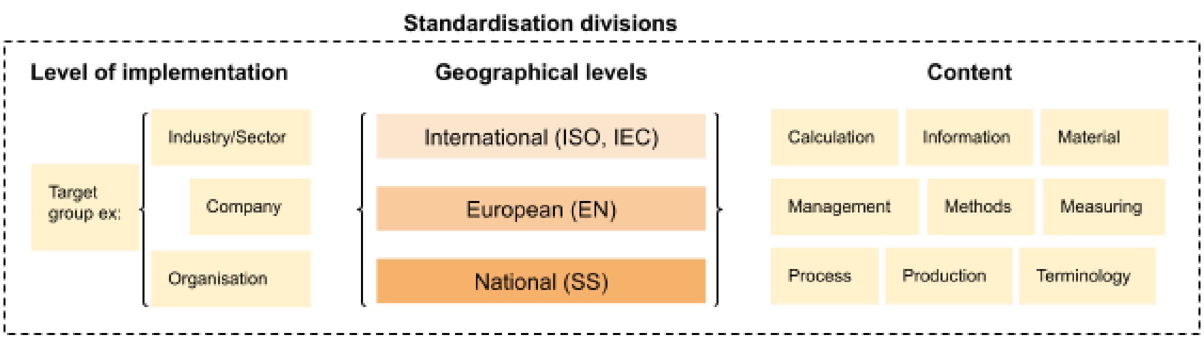

Figure 4: *Example of division of standards.* (Boverket, 2015; Jakobs, 2016)

Geographical levels

Determination of geographical level depends on the development of the standard origin, hence the standard organisations. Global standards are denoted ISO or IEC, with respective organisations International Committee for Standardization (ISO), International Electrotechnical Commission (IEC) or International Telecommunications Union (ITU). Global standards are used generally in the same way on a national level. European standards are denoted EN created by following standard organisations European Committee for Standardization (CEN), CENELEC or European Telecommunications Standards Institute (ETSI). Furthermore, a European standard can be referred to within a directive and is then called a *harmonised standard*. Moreover, national standards in Sweden are denoted SS with the Swedish Standards Institute (SIS) are respective standardisation organisations. All the members within the EU must adopt the European standards on a national level. If there is a national standard that contradicts the European standard it will automatically be suspended (Boverket, 2015).

Subdivision of content
Standards can be further categorised parallel to the international, European or national standards regarding the area that it covers and its content. However, there are no unambiguous subdivisions seen, the categorisation shown in Figure 4 is therefore one example of a division of standards and is not to be seen as complete (Boverket, 2015).

Level of implementation
Moreover, standardisations have different target groups. Regarding for example terminology standards spans over a wider group whilst measuring standards targets institutions for scientists or sampling (Boverket, 2015). That also entails that standards can be carried out by an industrial or trade association. However, standards can be generated by industries as a general standard but are not necessarily recognised by the state (Jakobs, 2016).

3.2.3. Current standards relevant for industrial PET

Summarising the total amount of all standards regarding industrial PET depend partly on the application and the mechanical aspects required. Table 3 represents the general standards that exist or are under development relevant for industrial PET.

Table 3: *Overview of existing and coming standards in the field of PET and industrial PET. Types of standard organisations: ISO - international, EN - European standard.* (European Committee for Standardization, 2014, 2024; International Organization for Standardization, 2012, 2019)

Type of standard	**Area of use**	**Name**
Criteria for testing	*Standard outlining the criteria and testing procedures applicable to non-oriented PET or copolymer sheets produced from vPET- or rPET-resin, or their combinations. The standard is specifically designed for sheets with a thickness below 2.0 mm, excluding foamed sheets and shrinkable films.*	ISO 13636:2012 Plastics -- Film and sheeting -- Non-oriented poly(ethylene terephthalate) (PET) sheets *(Under review)*
Designation system and basis for specification	*Specifications established in a system of designation for thermoplastic material including PET. Application specific and/or method of processing information is provided to a certain extent.*	ISO 20028-1:2019 Plastics Thermoplastic polyester (TP) moulding and extrusion materials

Plastics recycling and recycled plastics	*Projects associated test methods and important characteristics for assessment of PET recyclates helping the purchaser and buyer to agree on specifications.*	FprEN 15348 Plastics - Recycled plastics - Characterization of poly(ethylene terephthalate) (PET) recyclates *(Under development)*
Methods	*This test method determines the inherent viscosity of poly(ethylene terephthalate) (PET) by dissolving it in a specific solvent mixture and measuring viscosity with a glass capillary viscometer. It provides comparable results to a differential viscometry method.*	ASTM D4603-18 Standard Test Method for Determining Inherent Viscosity of Poly(Ethylene Terephthalate) (PET) by Glass Capillary Viscometer
Characterisation of sorted plastic wastes	*Scheme for sorting plastic depending on characteristics, laying out properties. Information regarding "Required Data" and "Optional Data" division is provided.*	prEN 15347-4 Plastics - Sorted plastics wastes - Part 4: Quality grades of sorted poly(ethylene terephtalate) (PET) wastes and specific test methods *(Under development, not released)*

Overviewing the current standards through the lens of a circular economy and plastic it can be concluded that there is a lack of industrial PET standards apart from recycling and recovery/disposal. There is an overall lack of plastic standards in the early stage of the plastic value chain regarding design or feedstock relegating the plastic standards to the bottom of the waste hierarchy (Schuyler et al., 2022). Currently the total number of standards does therefore not necessarily represent the best metric of standards effectiveness, they rather show the current top-down prioritisations. The waste hierarchy is seen as disconnected from the implementation of standards as of today. Moreover, the reason being the understanding in circular economy principles has mainly understood the recycling phases and are therefore reflected in the number of standards within the area. However, the interest in a circular economy is growing and the current interest already shows that standards have a future potential (Schuyler et al., 2022).

4. Thematic analysis

This chapter includes a presentation of the result of the semi structured interviews that were conducted to deepen the knowledge regarding standards in the context of the industry of industrial PET. From the thematic analysis, the results are presented in the respective themes that were found within the study, see Table 4.

Table 4: *Overview of results from the thematic analysis of the semi structured interviews. Green marks equals that they have mentioned something within the theme. Numbers represent the interviewees presented in Chapter 2.3.*

Category/Interviewees	1	2	3	4	5	6	7	8	9	10	11	12	Total number of interviewees
Implementation of a standard	✓	✓	✓	✓	✓			✓	✓		✓	✓	9/12
Composition variations	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	10/12
Design for recycling	✓		✓	✓	✓				✓	✓	✓		7/12
Engagement	✓		✓		✓		✓						4/12
Infrastructure and waste management system	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	11/12
Chemical recycling		✓	✓			✓					✓		4/12
Understanding and dissemination of knowledge	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	10/12
Quality of the plastic material and recyclate	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	10/12
Price/cost	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	10/12
Rules and legislation	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓	10/12
Time	✓	✓	✓		✓				✓				5/12
Volumes	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	11/12

The thematic analysis covered aspects of benefits and challenges and respective barriers/factors that are correlated to the implementation and system of standards regarding industrial PET. Moreover, it covered correlations between standards and governance as a complementary measurement for the development of a more circular economy for industrial PET. Understanding and dissemination of knowledge among stakeholders was also brought up pointing at the importance of easy access to tools that can be utilised for progress.

4.1. Correlations between standards and policy

Firstly, ten out of twelve interviewees accentuated the correlation between legislation and the role of standards in governing plastics and PET, Table 5. Standards alone are voluntary to implement creating the need for development of standards simultaneously with governance of industrial PET (6). Policymakers play a crucial role in enforcing rules that guide the market towards a more circular economy for industrial PET, given the strong global interest in the virgin PET market, requiring regulations to ensure the reliability of rPET (11).

Table 5: *Overview of result from the thematic analysis of the semi structured interviews regarding rules and legislation.*

Category/Interviewees	1	2	3	4	5	6	7	8	9	10	11	12	Total number of interviewees
Rules and legislation													10/12

Standards are viewed as essential tools for policy and governance (3, 12), offering a framework for information and measurement that is recognized and accepted by industries. These standards simplify the policymaking process by providing guidelines and criteria for the intended area of application. In the absence of standards, the absence of industry-defined quality or product criteria creates a gap in the potential for standard creation. Additionally, existing standards can serve as benchmarks or guidelines to align with implemented laws (3).

Currently, significant developments are taking place at the EU level. Following a revision of existing harmonised standards within packaging legislation, deemed insufficient, the commission has issued a standardisation request (3). Within the framework of the EU's Plastic Alliance initiative, new standards have been introduced, with two specifically addressing PET at a more general level, thereby impacting industrial PET. These pertain to the classification of solid plastic waste (PET) and quality recommendations for consumers or users of recyclate. However, the primary focus remains on packaging, as the Circular Plastic Alliance is a voluntary engagement, with the packaging industry showing the most enthusiasm in developing these standards (3).

Moreover, standards for the calculation of mass balance are currently in progress on a broader scale, encompassing various products beyond plastics or PET. Mass balance serves as a method for determining the recycled amount in a product (*Recycled Content in Plastics*, n.d.). Nevertheless, efforts towards achieving an acceptable standard for transparency regarding recycled content have faced resistance (3). The calculation of mass balance for plastics also varies based on the recycling method employed. Chemical recycling, an area of interest for the fossil fuel industry, is contingent on meeting mass balance criteria. However, Interviewee 3 notes that if the criteria for mass balance are too stringent, the entire concept of chemical recycling could collapse. In essence, this underscores the industry's hesitancy to divulge transparent details about their processes. Advocacy by legislators could potentially apply pressure to encourage transparency, benefiting the development of a more circular plastic industry (6).

Moreover, because of the multitude of users of PET and PET's existence in the broader plastic system, it is challenging to establish effective and targeted governance. This difficulty arises from the need to divide the material among a reasonable number of waste streams, as further discussed in Chapter 4.2 (3). Establishment of a recycling quota, indicated by Interviewee 5 and 11, as an effective measurement to stimulate the market for recycled plastic and enhance material quality. The proposal entails products containing a specific amount of recycled material, though it raises questions about how the mass balance should be calculated (3, 6). This is a subject of matter that has come across companies as a tool for greenwashing as the rules are currently developed too loosely. Products can be said to contain recycled material regardless of their true content. This negatively impacts the credibility of the recycling industry and the incentives for improved recyclability (3, 6).

Differentiated fees, mentioned by Interviewees 1, 5, 10, and 12, were proposed as a complementary measure to standards. Increasing fees on harmful compositions, additives, and materials used in plastic production incentivises the use of alternative plastics, thereby increasing the demand for specific materials and reducing the price of accepted plastics (5). Furthermore, Interviewee 7 highlighted that legislation should offer guidance to make it easy to do the right thing and not to complicate the process further. Legislation and regulations are deemed necessary to accelerate the pace of change. The industrial PET sector holds the capacity to set higher demands on distributors for a more sustainable product (9). However, placing the entire responsibility on the market for driving change is viewed as impractical (5). Overall, there was a consensus among interviewees, particularly 2 and 5, on the need to implement governance for plastic, encompassing both legal and economic aspects, alongside industry actions and standardisation measures.

4.2. Benefits and challenges of standards regarding industrial PET

Conducting the thematic analysis constituted many aspects and factors regarding the implementation of industrial PET. Below, a presentation of aspects such as the materials composition to system factors around the material, application, waste management, infrastructure and structure of the system are presented.

4.2.1. Composition variations

As mentioned previously in the literature review, the many different sorts of plastics within the system creates a big challenge at the stage of reuse and recycling of the material, which was also emphasised by the interviewees. Ten out of twelve, Table 6, talked about the vast number of different plastics that today exist on the market creating challenges when handling the product at the stage of end-of-life. Aspects on how a standard on industrial PET are presented from the standing points of the product's composition and its life expectancy, the mixtures associated with the waste stream during collection of the material, quality, and design for recycling.

Table 6: *Overview of result from the thematic analysis of the semi structured interviews regarding composition variations.*

Category/Interviewees	1	2	3	4	5	6	7	8	9	10	11	12	Total number of interviewees
Composition variations													10/12

The composition of a product involves numerous parameters that hinder today's progress towards a circular economy of reusing and recycling materials. Depending on the product's application, even if it is made from the same polymer, it can possess different characteristics based on the production method used (4). For example, extrusion, injection, or foaming of the plastic all behave differently in the recycling process. Whether the PET is amorphous or crystalline (structure of the material) poses challenges in the recycling process, impacting the potential value of the material (10). Furthermore, the various additives such as colours mixed with the plastic to confer the desired product characteristics create another obstacle to recycling, introducing barriers when selling material to recycling facilities. Currently, additives within DIAB's foamed industrial PET constitute approximately 5 percent, 95 percent being PET (8). Transparency within the industry is lacking, and the additives are believed to vary among companies in the same field. Industrial PET is consequently unattractive to recyclers due to its unknown additives and foamed structure (2). Cross-links, a specific type of chemical bond linking polymers together, present for example in DIAB's foamed industrial PET, is mentioned as a factor that recyclers often avoid. Post-consumer PET is argued by Interviewee 2 to be more attractive because its products meet higher production standards, such as suitability for food, making it easier to recycle. However, post-consumer PET recyclate can potentially emit an unwanted smell when reused in production, considered unattractive by some major companies. Nevertheless, the PET bottles' flow was especially noted as a successful example of a pure material stream. Today's rPET comes from bottled PET due to high demands on material composition and purity, leading to increased interest in the recyclate and a desire to use more rPET (3, 10, 12). Therefore, substantial material losses within the intended closed loop of bottles occur. The industry's ability to find its own resources is very limited (3). Overall, the consensus is that the higher the degree of purity in the material, the more appealing it becomes for recyclers and producers, meaning there is a significant deficiency in transparency today. However, producers often specify the qualities and additives required to meet customer needs creating a question for flexibility of the composition of the products.

Moreover, life expectancy further complicates our understanding of the material's composition. In contrast to consumer packaging products, which have a brief lifespan, the industrial realm of PET entails products that can endure anywhere from a couple of years to multiple decades, depending on the application. Nevertheless, current information on material composition is elusive, and the combination of materials within industrial plastic can be exceedingly intricate (10). Plastic manufactured decades ago may contain materials now prohibited. Although additives may be essential to achieve desired characteristics, they pose a significant challenge for recyclers and impact the demand for recyclates from the industrial sector. Interviewee 12 suggests that implementing a standard for products or a reporting system to collect data could enhance transparency and traceability, proving beneficial, provided the information is accessible during and after the expected lifespan.

Effect of a standard for industrial PET

Concerning product composition, the diverse nature of plastics in the system currently poses a challenge for reuse and recycling, particularly at the end-of-life stage. A standard could streamline the material's composition, focusing on characteristics such as structure, additives, and colours, making it more appealing for recyclers and reducing barriers in the recycling process. Overall, a standard has the potential to increase the transparency and the traceability of the material requested today and wanted in the future system of handling plastic recyclate such as industrial PET. However, variations can be required in certain applications to attain certain qualities.

4.2.2. Hinders concerning infrastructure

Not only does the composition of production pose barriers to increased use of recycled materials, but there are also challenges in the current management of plastic as waste including industrial PET. Table 7 demonstrating that eleven out of twelve interviewees underlined the factor of current system and flow of plastic and industrial PET.

Table 7: *Overview of result from the thematic analysis of the semi structured interviews regarding infrastructure.*

Category/Interviewees	1	2	3	4	5	6	7	8	9	10	11	12	Total number of interviewees
Infrastructure and waste management system													11/12

There are two aspects currently hindering the implementation of a standard for industrial PET and limiting its recycling potential. Firstly, present waste streams mix various types of plastics and polymers, creating a complex logistical chain with contaminated waste streams (3). Contamination can occur due to improper sorting and the presence of impurities or non-clean elements. Material collected from, for example, a construction site can often be received by the sorting facilities mixed with material such as concrete and metal (1). Occasionally, the material is crushed into smaller fractions to facilitate more efficient transportation, although this practice makes the material unattractive for recycling. Moreover, on the industrial side, the sizes of collected objects can vary significantly requiring manual sorting often proving costly and time-consuming when conducted at waste management facilities. The variety of plastics does not simplify the process manually and requires good knowledge of the materials composition. Interviewees 1 and 4 also commented that the quantities of industrial PET received at the recycling facilities are very small at present. Hence, there are no well-established systems for collection of industrial PET, nor current incentives to implement one. Moreover, even if industrial PET products and materials adhere to a design-for-recycling standard, the current system of collecting everything in a mixed manner and sorting afterwards hampers the incentive for establishing such standards (3,7).

Secondly, at the end-of-life stage, the product owner lacks control over where the material ends up. Even if the companies using industrial PET would want to take back their material, there are no current collection systems established for industrial PET, nor other plastic types (3). More homogeneous fractions are typically sorted at the production site, something that can be done at post-industrial or construction sites (2). Achieving a streamlined flow like that of plastic bottles depends on logistical factors such as the number of producers and a consensus among them regarding the benefits of implementing the collection system. However, product producers often receive requests from customers that drive the demand for knowledge about their product's composition. A thorough understanding of the collected products enhances the potential for finding new uses for the material entailing the benefits of implementing standards or system increasing incentives for industrial PET to increase circularity of the material (10, 12).

Furthermore, after the material has been collected, numerous steps are necessary for it to reappear in a new application. Hence, there is a requirement for new appropriate infrastructure, ideally located near to each step within the recycling and collection process (1, 2). Currently, distances can create unprofitable solutions, hindering the material from advancing further in the recycling process. Transportation of the material can be costly and navigating international and national legislation adds complexity. For industrial PET in the form of composites for example, there is currently a lack of technology that enables recycling (4). Chemical recycling is seen as the solution and is something that is under development. This is something that a standard cannot solve specifically, but improved waste streams with material design for recycling could potentially increase the incentive. Furthermore, regarding composites in windmill blades there was also the emphasis on the reuse of the material instead of recycling (12). This means elevating the material one further step in the waste hierarchy.

Effect of a standard for industrial PET

In terms of waste management and infrastructure systems, a standard could contribute to more efficient recycling processes, addressing issues in waste streams and ensuring better knowledge and control over material handling. However, either the system must adapt to the standard, or the other way around, for the standard to be effective. Factors such as number of stakeholders affected determines the size of the project for implementation of standards regarding industrial PET. Nevertheless, standards for industrial PET will not get past all the barriers in the process towards a more circular economy.

4.2.3. Inconsistent recyclate quality

Quality of the recyclate was highlighted by ten out of twelve interviewees to be crucial to increase the demand for the material Table 8.

Table 8: *Overview of result from the thematic analysis of the semi structured interviews regarding quality of recyclate.*

Category/Interviewees	1	2	3	4	5	6	7	8	9	10	11	12	Total number of interviewees
Quality of recyclate													10/12

Historically, the quality of recyclates has failed to meet producers' demands, resulting in material downcycling and, in some cases, incineration (11). The inconsistent quality of recycled plastic poses challenges for producers, as virgin material maintains a consistent quality that is challenging for recyclates to match (4, 9). Material inconsistencies can impact production, making it difficult to identify whether the issue lies with the material or the machinery. This uncertainty, absent in current vPET production, is undesirable for producers due to the costly nature of production standstills.

The quality of the recyclate is a crucial aspect for material users. Unfortunately, traceability is lost throughout the various steps in the process, making it challenging to acquire the necessary knowledge to ensure high quality (12). The current industry scepticism and reluctance to incorporate recycled materials into products stem from the perceived risks associated with their use, indicating a lack of trust within the sector. The implementation of a standard for industrial PET could potentially address these concerns, providing recyclers with assurance regarding composition and lowering the requirements for the material or informing producers about material expectations (3).

Over the past five years, there has been rapid development in the manufacturing of industrial PET, particularly in its application for foamed PET used in windmill blades (8). Unlike other markets for plastics, industrial PET foam is not as mature, and the industry is continually refining the production process for this foam. The incorporation of rPET into their production has only recently commenced, and ongoing efforts are in place to increase the recycled rate of resin. Currently, foamed industrial PET utilises the raw material "bottle grade" vPET, the same material used for PET bottles. According to Interviewee 8, this is a standardised raw material employed by the entire PET industry. Characteristics specified to distributors include the IV and COOH-content (a factor influencing the reaction within the process), with the COOH-content value calculated in accordance with the ISO 16281 standard. As long as the rPET meets these specifications and satisfies the buyer's demands, no hindrances are seen to incorporating more recycled material. The recipe and process adjustments are made in accordance with the development of increased recycled content requests (8).

Effect of a standard for industrial PET
The aspect of quality improvement is another significant outcome that can be addressed with the help of a standard. The standard addresses industry scepticism by assuring recyclers of composition and potentially lowering material demand, preventing the material to be incinerated or end up in a landfill.

4.2.4. Aspects of standards regarding design for recycling

In the context of the linear economy, products are not designed to remain in the material loop and be reusable or recyclable. Standards and legislation for design for recycling regarding products of industrial PET was mentioned as one solution for the material to hold value at the end-of-life stage, Table 9. Producers must assume responsibility or be incentivised to introduce products with a longer life cycle perspective (4). The complexity of disassembling products can be avoided with the implementation of a standard (5), following the same reasoning outlined in Chapter 4.2.1 regarding compositions.

Table 9: *Overview of result from the thematic analysis of the semi structured interviews regarding design for recycling and chemical recycling.*

Category/Interviewees	1	2	3	4	5	6	7	8	9	10	11	12	Total number of interviewees
Design for recycling													7/12
Chemical recycling													4/12

Establishing standards in this area could bring about significant changes by imparting value to the material (1, 9, 10). Firstly, designing for recycling necessitates thinking beyond conventional boundaries to create circular links (3). With respect to industrial PET that entails the need for the industry to collaborate and find a general aim posing a complex question according to Interviewee 8. The overall idea is good but there is uncertainty regarding how this should be done. Secondly, determining what design for recycling truly entails is not evident (3). For instance, the current design for a product of industrial PET generally comes with a lengthy lifespan involving a prolonged retention time for the material to return to the producer, i.e. possibly around 20-25 years for a windmill blade. This poses conflicts for the industry of industrial PET when specifying what design for recycling should entail. Design for recycling could be effective in many ways, both for loss of material in production, reuse, and recycling at end-of-life. Requiring multiple standards for industrial PET, extends beyond design for recycling as a material, encompassing specifications for products, specific vocabulary, and more. Additionally, the design is contingent on the recycling method to be employed—a task made difficult by the swift evolution of techniques. Moreover, chemical recycling also imposes higher design demands compared to mechanical recycling (3). Furthermore, the concept of chemical recycling, with its current misleading presumed ability to recycle any material, does not encourage design for recycling. This is due to the industry's misconception that this technique will resolve the issue. The crude oil industry, keen on retaining its market share against the recycling industry, has the potential to foster false promises for plastic-using producers, perpetuating the mistaken belief in the linear economy as the ideal path. Hence, it is easier for the industries, including the industry of industrial PET, to just continue as before rather than put time and effort in standards for design for recycling (3).

Effect of a standard on industrial PET

Standards on industrial PET would have multifaceted effects on various aspects, addressing challenges and enhancing the circularity of the material. For example, a standard can influence design for recycling, encouraging a shift towards products designed for longer lifespans and facilitating a more streamlined recycling process and an increased value. Overall, Chapter 4.2.1-4.2.4 shows that a standard on the industrial PET composition has the potential to bring positive changes, addressing current challenges and fostering a more circular approach for the material.

4.2.5. Insufficient volumes

Volumes are closely interlinked with current problems regarding quantities recycled. With today's global industries, supply and demand is closely interlinked with volumes. Eleven interviewees out of twelve, Table 10, emphasised the importance and effect of insufficient volumes concerning both the availability of the recyclable and recycled material on the market not meeting the request from the recyclers and producers regarding PET.

Table 10: *Overview of result from the thematic analysis of the semi structured interviews regarding volumes.*

Category/Interviewees	1	2	3	4	5	6	7	8	9	10	11	12	Total number of interviewees
Volumes													11/12

Most of the polymer PET is today used in packaging or in textiles meaning that the volumes on the industrial side are very small (6). This was also emphasised by the collectors and waste handlers 1, 2 and 10. Volumes are affected by factors such as supply and demand and certain volumes are requested for the recycling processes. Firstly, there ought to be an adequate amount of material that is recyclable. Moreover, concluding from what has been mentioned before, that also requires that the material is clean, has sufficient quality and pureness. Secondly, the amount of recyclate must match the demand on the market where the PET supply today is limited, both on the consumer and industrial side (7, 8). The forecast is that there will probably be a deficiency of rPET on the Europe market implying a demand for import from outside of Europe (8). Moreover, this is due to the circumstances of insufficient collection rates of PET in correlation with the increasing demand for rPET on both the consumer and industrial side. Interviewee 11 also argues that it further revolves around the lack of infrastructure that is required for the system to have optimal performance. This is both regarding the quantities of facilities being insufficient today as well as lack of infrastructure. This was also emphasised by Interviewee 1 and 2, highlighting the demand for sufficient volumes for profitable transport of the collected material to the recycler. Furthermore, this demand for certain volumes is expressed by the recyclers because they need a certain volume of material for one batch for it to be profitable. Thus, there is often a gap between the amount needed and the amount present in new products available for recycling on the recycling market (12). By implementing a standard that streamlines the industrial PET for a product or category, it could potentially increase the volumes of the same material as well as the demand for the industrial PET (5, 9). Furthermore, standardisation within an industry increases the demand for certain additives and PET creating a potential for a drop in price. Post-industrial spill as an example can therefore gain value and be attractive to other competitors to buy (9).

Streamlining the demand with standards could potentially affect the general flow of material on the market. However, the amount of recyclable material also highly fluctuates on less manageable factors such as the production rate, for example post-industrial spill (2), and seasonal variations (4). Production volumes are moreover determined by the demand for the product that often follows the inflation (10). If the market is good, production increases as companies are ready to invest and the other way around. Recession entails that less material will be available for recycling as fewer companies are willing to invest, whether it is the construction sector or the windmill sector the tendencies are the same, hence affecting industrial PET (1,9). Volumes can also rely on directives affecting the incentives of production of certain products. For example, the demand for renewable energy incentivises investments in windmill blades. This implies that more than just a standard is needed to steer the industrial PET to become more circular. Currently, there is often the need to find multiple suppliers to find the same amount of material required for production compared to the virgin supplier that can meet demanded volumes. This requires more from the companies in terms of labour, requiring new solutions for facilitating the availability to use rPET. Overall, all of this poses a challenge for the recycler to ensure consistent and substantial flows because of the fluctuating volumes of PET (12).

Another dimension to the fluctuating volumes is the longevity of the product. For illustrative purposes windmill blades containing industrial PET were mentioned by Interviewee 3. Apart from the many difficulties of recycling composite materials, that has more to do with design for recycling as mentioned in Chapter 4.2.4, the volumes of material in the blades can potentially be interesting as the blades contain a substantial amount of material. Nevertheless, that brings us back to the fact that the material that is mounted in the windmill blades today, containing industrial PET, is material that will not be available in the next 20 years approximately (3). Value of the material is still aimed for, whether it is now or in 20-25 years, stressing the need for measurements, like a standard on different levels within the industry of industrial PET, to be implemented (9).

Effect of a standard on industrial PET

The implementation of a standard for industrial PET and PET is intricately tied to the issue of volumes within global industries, as highlighted by eleven out of twelve interviewees. The scarcity of volumes significantly impacts material availability and the demands of recyclers and producers. The predominant use of polymer PET in packaging and textiles results in limited volumes on the industrial side, a concern emphasised by collectors and waste handlers. Adequate material for recycling requires cleanliness, quality, and purity. The current limited supply of PET poses a challenge, and foresight predicts a potential deficit of rPET in the European market, necessitating importation. The insufficiency of PET collection rates, coupled with increasing rPET demand, is further compounded by a lack of infrastructure. Streamlining industrial PET through standardisation could boost volumes and demand, potentially leading to a drop in prices. The fluctuation in recyclable material depends on production rates, seasonal variations, and market conditions, posing challenges for recyclers to ensure consistent flows. The longevity of products, exemplified by windmill blades, introduces another dimension to fluctuating volumes, as materials used may not be available for recycling in the next 20 years.

4.2.6. Cost, Engagement and Time

Throughout the interviews there has been an emphasis on costs, time and engagement as factors looking at the implementation of a standard for industrial PET, Table 11. Interviewee 1, 3, and 9 all emphasised on the resentment existing regarding change in the industries innovation towards a more circular economy and its different mindset compared to current used linear economy.

Table 11: *Overview of result from the thematic analysis of the semi structured interviews regarding engagement, price/cost and time.*

Category/Interviewees	1	2	3	4	5	6	7	8	9	10	11	12	Total number of interviewees
Engagement													4/12
Price/cost													10/12
Time													5/12

Stakeholder engagement plays a pivotal role in the creation of standards. The development of a standard requires active industry involvement to ensure that it addresses their specific needs and demands (3). Interviewee 3 highlights a lack of industry understanding regarding their role in innovating new standards. Looking at the historical perspective, during the development of linear standards, each company had a dedicated standard expert positioned to align with the industry's economic interests in standard development. Post-implementation, standards required only periodic revisions, leading to the removal of the standard position. Presently, standardisation processes are predominantly influenced by legislators, shifting the responsibility to industries, which are compelled to subsidise standard development without clear knowledge of its eventual incorporation into policies or directives. Additionally, apart from the requirement of engagement by the industries in the innovation of new standards, the legislators also need to have the intentions for development (5). Furthermore, there is a notable emphasis on the complexity of implementing a standard, with resentment stemming from the perceived difficulty level of the task (1, 7). The sector of industrial PET, with its numerous distributors, producers, and diverse applications, signifies a more intricate undertaking (8).

Time adds another layer to the dimension of implementing a standard for industrial PET. Given that the development of a standard typically spans three to five years, clear intentions must be agreed upon (3, 5). However, in the current situation, the process of recycling plastic and industrial PET faces prolonged lead times, necessitating greater transparency. For instance, when analysing the material content, desired material samples are sent to a lab for testing due to a lack of knowledge about the materials' composition (2). Timewise, there can be delays of up to several months before the test samples return. Standardising the material or product has the potential to reduce the time spent on understanding material composition, thereby potentially increasing the amount recycled.

Furthermore, the pricing aspect is closely interconnected with engagement and time and frequently emerges as a pivotal consideration, serving as a compelling factor to incentivise participation in the change. Price of the vPET versus rPET and the overall price of material, price of the investment in resources creating a standard and the price of change, new and developed infrastructure etc, were mentioned by the Interviewees as delicate factors for the industry (1, 3, 4, 5, 7, 8, 9, 10, 11 & 12).

Effect of a standard on industrial PET

The implementation of a standard for industrial PET is influenced by key factors such as price, time, and engagement, as highlighted in various interviews. Stakeholder engagement is crucial, and there is a noted lack of industry understanding, with the historical perspective revealing a shift in standardisation processes from industry-driven to legislator-influenced. The complexity of implementing a standard, coupled with the intricate nature of the industrial PET sector, adds to the challenges. Time is a significant dimension, with the development of a standard typically spanning three to five years, requiring clear intentions. The pricing aspect is closely tied to engagement and time, influencing industry considerations.

4.2.7. Dynamics of the market structure

Interests in the market influence the pricing dynamics of vPET and rPET. Over the past two years, the price of rPET has consistently remained slightly higher than that of vPET (10, 11). While price fluctuations are generally anticipated, this trend does not hold for rPET due to its sustained demand, indicating a higher demand than supply and encouraging recyclers to invest. However, the global capacity of vPET significantly exceeds the current market demand, creating a challenging environment for rPET competition (8). Interviewee 8 argues that the price of rPET is slightly lower than vPET. Overall, the price of vPET is relatively low, providing fewer incentives for the production and purchase of rPET, given its perceived lower reliability (4, 8, 11). Interviewee 4 emphasises that recycling of PET can be costly, especially if the composition of the material is complex, giving the example of composites that must be recycled chemically for good results, such techniques that do not exist currently. The glass fibre within composites harms the equipment when mechanically recycling the material. Overall foamed PET was mentioned as unattractive by the recyclers (2, 4). During a recession, price becomes a more significant consideration than environmental concerns, which held greater importance two years ago during times of prosperity (10). Additionally, the price is influenced by the fossil fuel industry's interests in maintaining market share (11). A surge in demand for recycled material could potentially disrupt their current distribution of vPET, posing a challenge to the circular plastic economy.

The development of a standard for industrial PET has the potential to stimulate interest in the material, thereby increasing demand, which recyclers perceive as profitable (7). Innovating a standard for a specific product within the industry could also boost demand for the standardised materials agreed upon for the product's composition, potentially leading to lower material prices and increased margins (9). Furthermore, embracing a circular economy involves adopting a new market perspective (9, 12). According to Interviewee 9, a standardised product may not be the primary income generator; rather, it creates opportunities beyond the product itself, spawning new business prospects that are not only profitable for the producer but also for others. Standardising a product shifts the focus from the product's profit to services and products complementing the standardised items.

Effect of a standard on industrial PET

The market dynamics, particularly regarding vPET and rPET, reveal a sustained demand for rPET, impacting its pricing dynamics. Developing a standard for industrial PET could stimulate interest and increase demand, potentially impacting material prices and margins positively. Embracing a circular economy entails a shift in market perspective, with standardised products generating opportunities beyond the product itself, contributing to profitable outcomes for various stakeholders.

4.3. Understanding and dissemination of knowledge among stakeholders

Finally, yet importantly, the overall process of going from linear to circular economy creates the demand for knowledge. Out of the twelve interviewed, ten interviewees mentioned knowledge or understanding as a barrier among stakeholders within the industry regarding standards and the shift towards a circular economy, Table 12.

Table 12: *Overview of result from the thematic analysis of the semi structured interviews regarding understanding and dissemination of knowledge.*

Category/Interviewees	1	2	3	4	5	6	7	8	9	10	11	12	Total number of interviewees
Understanding and dissemination of knowledge													10/12

Concerning standardisation, there is much to grasp to effectively implement a standard. For instance, there is a misconception that a standard is both a general expression and an intricate process with several steps (12). There is a need for clarification and agreement on what a standard entail in the context of discussion. Moreover, even though the implementation of a standard could potentially offer a more transparent market, facilitating traceability and measurability, creating a standard requires substantial knowledge. This involves not only understanding how to create a standard but also comprehending the system where the standard is to be implemented. The recycling process itself is perceived as intertwined and complex, constituting just one step in the entire chain, and the lack of understanding about different parts of the value chain creates gaps, posing barriers when implementing something new (1). Moreover, the general perception that waste is merely waste and not a resource affects product design priorities. Various stakeholders along the value chain possess different knowledge, necessitating communication between different process steps (2). Recyclers must share information about what works and what does not work in the recycling step, and producers need to communicate their demands. Furthermore, knowledge is intertwined with the willingness and ability to engage in the process, as discussed in Chapter 4.2.6.

In the narrow mindset of today's industry, driven by a focus on money, it is challenging to envision how a standard will lead to a higher uptake of plastic in the near future (3). This can influence the decision by the commission on whether the standard will be approved or not. Moreover, the lack of understanding of the broader perspective is also evident at the level of for example salespersons, motivated primarily by financial considerations and routines currently (9). The incentives for salespersons are strongly interlinked with a performance-oriented salary structure, meaning their actions and behaviour depend on how the bonus is formulated. Moreover, educating the sales staff about why they should promote a new product and the arguments relevant in the new context takes time and engagement but is yet an essential measure. With the consistent rapid development of products, maintaining awareness demands effort—a factor observed in the sale of industrial rPET (8, 9). Additionally, this was emphasised by Interviewee 7, highlighting that communicating the benefits of increased recycled content in products can contribute to climate benefits and, consequently, the sustainability of the product.

4.4. Consensus of a standard between interviewees

Regarding the final question on whether a standard would enhance the circularity of the material, it was directly posed to the interviewees. The results indicate an overall consensus among them that standardisation is a measure with the potential to facilitate the transition from a linear to a more circular economy, as illustrated in Table 13. This chapter delves deeper into the interviewee's uncertainties regarding the practical aspects of implementing a standard.

Table 13: *The interviewees responses to the question; "if a standard would increase the circularity of industrial PET", summarised per consent.*

Yes	**Maybe but how?**	**Uncertain**
1. Yes, absolutely, it would be easier 3. Yes, a tool to achieve circularity 5. It is a key factor 6. It is an aid 9. Yes, an important factor, helps to think broader 11. Yes, necessary but will not solve the problem on its own. 12. Yes, if one succeeds to implement standards on a sufficient level. There is much that can be gained.	2. If one succeeded well, is it feasible? It would be easier 4. If one could implement standards it could provide, but it's so difficult, how should one do it? 8. Interesting, must be global because there are so many manufacturers 10. Maybe, if one becomes more aware of what one puts on the market, facilitating recycling	7. Spiral economy, sceptical of the circular economy

Interviewees 1, 3, 5, 6, 9, 11 and 12 are convinced that a standard is a step towards a more circular economy. However, interviewees 2, 4, 8 and 10 express hesitations regarding its practical feasibility, extent, and the level of standard that could be implemented. Interviewee 7 was the most hesitant, mentioning that the circular economy can often be perceived as too complicated to eliminate vPET on both sides of the industries. They specified that the industrial PET sector faces high demands from customers regarding quality and technical mechanical properties (7). Interviewee 7 suggested a spiral economy as a more achievable and simpler goal, referring to the idea that materials can change product flow, removing the material from the closed loop, as currently done with rPET from bottles to other applications to be accepted. Further, the factors regarding implementation of a standard are discussed. Nine out of twelve interviewees commented on the issues specifically, Table 14.

Table 14: *Overview of the result from the thematic analysis of the semi structured interviews regarding implementation of a standard.*

Category/Interviewees	1	2	3	4	5	6	7	8	9	10	11	12	Total number of interviewees
Implementation of a standard													9/12

4.4.1. How to design standards

The thematic analysis underscores the complexity of standard implementation. The process of designing a standard, as confirmed earlier, is intricate but not counterintuitive. Various trade-offs between broad and narrow standards were identified, reflecting the diverse interests of different sectors and industries (3, 10, 12). Given that standards can operate on different levels, there are numerous alternatives in terms of their aims. Standards for industrial PET are perceived as general and must remain sector-neutral, highlighting the challenge of generalising the standard to be applicable across all sectors. It is acknowledged that the standard cannot have identical technical specifications at a general level, such as those needed for windmill blades for example (3). This observation also holds for plastic waste and recyclate, given their mixed composition of different plastics. However, this underscores the necessity for multiple standards that span the entire life cycle of products and operate at different levels (12), as exemplified in Figure 5.

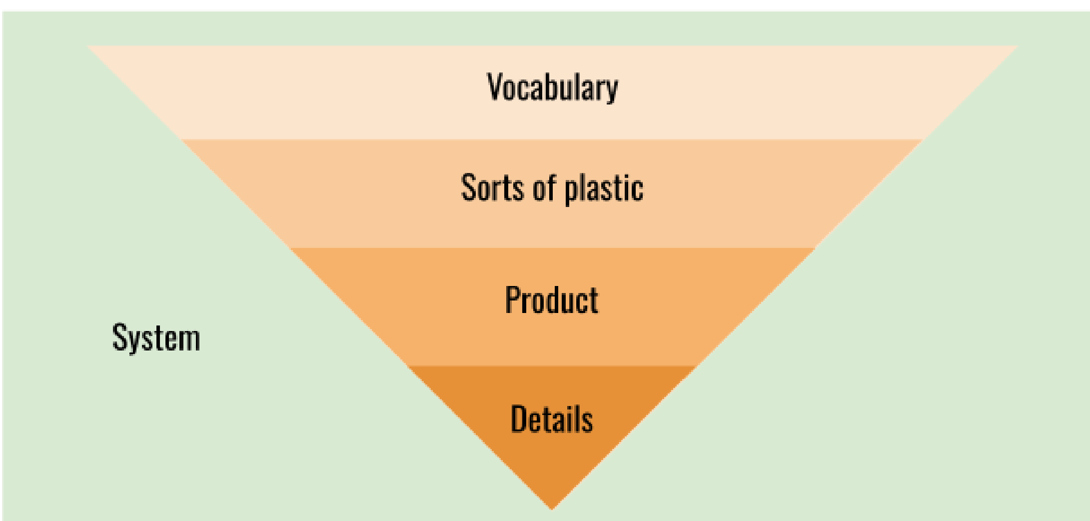

Figure 5: *Levels of standards regarding a product within its system. (12)*

The interconnected nature of standards may appear counterintuitive, yet it is essential due to the complexity of the global production system. This intricate web of standards is crucial, as it ensures comprehensive coverage of the entire value chain, enabling standards to function as intended (3). Industrial PET represents just one of these levels that must be considered collectively, complementing standards at both industry and product levels. This approach ensures a holistic and effective implementation of standards across diverse sectors and products.

4.4.2. From intent to action

While standards are continually developed, the extent of their utilisation remains unknown to the organisation (3). Information available is limited to the number of standard buyers, and the actual usage—whether it involves just a small paragraph or the entire document—is unclear. The indication of standards being cited in a certification program or directive reflects the level of use, but the process heavily relies on users to contribute information for the development of current and future standards. Even with measures like harmonised standards, there is a persistent question of how to encourage companies and industries to initiate or increase their use of existing standards. As stressed by Interviewee 9, the industry struggles to discern where and how to begin. The determining factors for the implementation or development of a standard, as concluded by Interviewee 12, include the number of actors involved, a general consensus within the industry regarding the benefits of standards, such as reclaiming or reusing materials, and the existing system's favourability for standard implementation. An illustrative example is the current PET bottle industry, which was previously part of a deposit and return system incentivised by the value of metal cans for beverages from the beginning (12).

From Table 13 one can see that Interviewees 1, 3, 5, 6, 9, 11, and 12 operate at a more general level, dealing with systematic views and addressing broader sustainability and climate-related issues. In contrast, interviewees 2, 4, 7, 8, and 10 are involved in the recycling sector of the industry, holding more hands-on positions. This leads to the conclusion that there are varying perceptions of how the question is understood, depending on the sector in which one works.

5. Conclusions

The aim of the project has been to investigate advantages and challenges of introducing standardisation within the field of industrial PET as a measure to get past hindrances and barriers towards a circular economy. From the collected material and analysis done within this thesis, multiple conclusions can be drawn.

From Question 1 posed regarding *the current status of governance regarding industrial PET*, the results show that industrial PET represents a more specific yet still diverse sector within various industries, lacking direct and precise current standards or government regulations for the material. Additionally, industrial PET as a material is intricately connected to the consumer side, blurring the distinction between these two sectors. This thesis highlights the emergence of post-consumer PET, particularly in bottled PET packaging, even though the value chain's packaging side was not explicitly explored. The market is intricate, with PET bottles serving as a nexus between the industrial and consumer realms. Currently, PET bottles dominate the market, necessitating a universal adjustment where all PET sectors must adapt to the dominance of the PET bottle industry, whether willingly or not.

As the volumes of industrial PET reaching the recycling facilities are insignificant in comparison to other plastic polymers, Question 2; *What are the advantages and challenges associated with recycling of industrial PET*, needs further research both on a material and a product level to answer the question. To fully understand the recycling method's detailed advantages and challenges for industrial PET, an application-specific examination is essential. Furthermore, current recycling methods, both mechanical and chemical, do not eliminate fossil resource usage, indicated both by the literature review and interviews. For instance, windmill blades containing industrial PET in the form of glass fibre composites exemplify the potential for chemical recycling due to their complex composition. However, reuse of industrial PET in the form of composites has also been brought up, fostering an additional step in the waste hierarchy that is not to be forgotten when talking about moving towards a circular economy. Longer material lifetimes contribute to extended industry retention but also open avenues for new businesses around standardised products, offering potential solutions to reduce plastic overconsumption in society. Knowledge that the Swedish NAO should consider when developing measures within the field.

Regarding Question 3, *benefits and challenges of implementing standardisations for industrial PET,* the result showed an intricate relationship between both. Implementing a standard for industrial PET has the potential desired advantages such as streamlined material composition, increased transparency, and enhanced traceability resulting in increased volumes, addressing key concerns for recyclers, and improving the recycling process. While standards can potentially boost confidence among recyclers and producers, but at the same time facing challenges of lacking incentives requiring comprehensive measures addressing market dynamics, seasonal variations, and product longevity. The success of industrial PET standards depends on overcoming challenges related to industry and policy engagement, time constraints, and cost considerations, with potential benefits including reshaping market dynamics, stimulating interest, and fostering a circular economy. Proper infrastructure and waste management are crucial for the effective implementation of standards, and the interplay between legislation, standards, and governance is essential for shaping the trajectory of industrial PET towards sustainability. Ongoing developments at the EU level present potential strategies for guiding the industry in this direction, emphasising the need for both voluntary standards and comprehensive legislation. The complexity of design considerations, the requirement for interconnected standards, and uncertainties surrounding adoption underscore the challenge of achieving widespread acceptance and utilisation of standards within the industry.

Furthermore, potential for further investigation exists within the field concerning the implementation of tools for measuring standard usage. This information could be valuable for both the industry and standardisation organisations to understand how current standards operate concurrently with the implementation and development of future standards. It is particularly interesting for the industrial PET industry and its numerous stakeholders. Additionally, conducting further research on the implementation of standards for windmill blades is of interest. Both the industry and the municipality have expressed interest in a shared goal, benefiting the development of a standard. Determining which standards, how they should be implemented, and at what level is an aspect that requires further exploration.

In conclusion, standards constitute a complex and intricate realm of information, guidelines, and tools to get past hindrances towards a circular economy. However, considering the overarching objective of this study, delving too deeply into specifics is not feasible. After completing the semi-structured interview study, a prevailing consensus emerges; standards are not universally comprehended. There is a lack of consistent understanding and knowledge necessary for navigating the system of standardisation effectively. While expectations abound, there is no straightforward or shared understanding of how a standard can or should be implemented. This leads to considerable uncertainty regarding what real-world issues a standard might solve. The shift from a linear to a circular economy demands a profound comprehension and widespread dissemination of knowledge among stakeholders, emphasising the need to demystify the intricacies of standardisation. One can argue that *standards need to be standardised,* implying improved simplification.

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7. Appendix 1 - Literature review protocol

Search protocol

Date: 20/9
Subject: PET as a part of a circular economy, implementing standardisation
Search engines: LUBseach
Search strategy and keywords **(PET or polyethylene terephthalate or "industrial PET") AND (Standard* or guideline* or target or framework or policy) AND ("Circular economy" or sustainable or "sustainable development" or CE) AND (Recycl* or reus* or reprocess* or reclaim or recover) AND (Waste or misspend or misuse or "left over" or debris or remains) NOT ("plastic bottle*" or "consum* plastic")**

Search result:

Search:	**Search stratgy:**	**Number of hits:**	**Relevant hits:**
1.	PET or polyetentereftalat or "industrial PET"	1,132,255	
2.	AND Standard* or guideline* or target or framework or policy	282,550	
3.	AND "Circular economy" or sustainable or "sustainable development" or CE	146,982	
4.	AND Recycl* or reus* or reprocess* or reclaim or recover	144,971	
5.	**AND Waste or misspend or misuse or "left over" or debris or remains**	144,844	
6.	**NOT "plastic bottle*" or "consum* plastic"**	305	
7.	**2013-2023**	281	
8.	**Peer reviewed**	225	To manny in order to

Date: 20/9
Subject: standardisation of plastic/PET, a tool for implementation of a circular economy
Search engines: LUBcat
Search strategy and keywords **(PET or polyetentereftalat or “industrial PET”) AND (Standard* or guideline*) AND ("Circular economy” or CE) NOT ("plastic bottle*" or “consum* plastic”)**

Search result:

Search:	**Search strategy:**	**Number of hits:**	**Relevant hits:**
1.	PET or polyetentereftalat or “industrial PET”	1,132,255	
2.	Standard* or guideline*	236,479	
3.	"Circular economy” or CE	145,449	
4.	Peer reviewed	824	
5.	**NOT ("plastic bottle*" or “consum* plastic”) Date: 2013-2023, english**	609	Way to manny in order to screen

Date: 20/9
Subject: standardisation of plastic/PET, a tool for implementation of a circular economy

Search engines: LUBcat
Search strategy Searched around and tried to get the number of hits down to under 50 and then I checked for relevance. I then sorted by titles and abstract. Possibly added the removal of some words that I didn't want included in the search, like DNA for example.

Search result used in the final literature review:

Search:	**Search strategy and keywords :**	**Number of hits:**	**Relevant hits:**
#1	(PET or polyetentereftalat or plast* or “industrial PET”) AND Standard* AND ("circular economy" or circular*) NOT ("plastic bottle*" or “consum* plastic” or “beverage cup*” or DNA or disease or cancer or patients or packaging waste or bio-based or biodegradable) AND (Recycl* or reus*) Limiters - Peer Reviewed; Date Published: 20130101-20231231; Available in Library Collection Narrow by Language: - english Search modes - Find any of my search terms	35	5 1.Circularity Study on PET Bottle-To-Bottle Recycling 3.Ease of disassembly of products to support circular economy strategies 4.Information-Based Plastic Material Tracking for Circular Economy—A Review. 5.Plastics in the context of the circular economy and sustainable plastics recycling: Comprehensive review on research development, standardization and market 6.Towards a Circular Product (Re)Design Methodology: Proposition of the Unlinear Method to Foster Circularity.
#2	(PET or polyetentereftalat) AND Standard* Find all my search terms	1	1 Kemisk återvinning av plast: Teknik, flöden och miljöaspekter
#3	TI (PET or polyetentereftalat or “industrial PET”) AND (Standard* or guideline* target or framework or policy) AND ("Circular economy” or CE or Circula*) NOT (DNA or nano* or consum*) AND (Waste or misspend or misuse or “left over” or debris or remains) Limiters - Peer Reviewed; Date Published: 20150101-20231231; Available in Library Collection Search modes - Find any of my search terms	41	5 - Only read the titles 1.How introduction of deposit-refund system (DRS) changes recycling of non-drinking bottle PET wastes 2.Systems Analysis for PET and Olefin Polymers in a Circular Economy. 3.Circular economy: Preserving materials or products? Introducing the Resource States framework 4.Material efficiency to measure the environmental performance of waste management systems: A case study on PET bottle recycling in Austria, Germany and Serbia. 5.A multi-method approach to circular strategy design: Assessing extended producer responsibility scenarios through material flow analysis of PET plastic in Jakarta, Indonesia

#4	TI Standard* AND ("circular economy" or circula*) AND (plastic* or PET or polyetentereftalat) Limiters - Peer Reviewed; Date Published: 20130101-; Language: English; Available in Library Collection Search modes - Find any of my search terms	26	3 1.Plastics in the context of the circular economy and sustainable plastics recycling: Comprehensive review on research development, standardization and market 2.Standards as a Tool for Reducing Plastic Waste. 3.Plastic pollution mitigation – net plastic circularity through a standardized credit system in Asia.

8. Appendix 2 - Interview questions

Manufacturers

- Who are your main customers (private/public sector)?
- Which properties are important for industrial PET?
- What are the main performance and property requirements you impose on the plastic you purchase?
- What performance and property requirements do you have from the customer you supply?
- What is the external demand for the future of plastics?
- Play with the idea that a standard would be introduced for industrial PET and its composition. How do you think this would affect your business?
- What would be the challenges and opportunities of the above idea?
  - What do you see as barriers to using (more) recycled material?
  - What opportunities would standardisation bring? Is it possible that it would lead to overcoming the barriers?
- Do you have the interest to push for standardisation?
- Do you think standardisation would affect price and demand?
- How are you affected by Swedish/EU regulations, current and future?
  - Industrial PET
- Do you think standardisation would lead to an increased circular economy?
- Is there anything you would like to add? Anything we missed or didn't ask about?

Sellers

- How much PET do you buy, what type, how much is sold and to whom is it sold?
  - Industrial PET, what quantities are we talking about there?
- What performance and property requirements do you place on the PET you purchase?
- What performance and property requirements do you have from the customer you deliver to?
- Play with the idea of introducing a standard for PET and its composition. How do you think this would affect your business?
- What would be the challenges and opportunities of the above idea?
  - What do you see as barriers to using (more) recycled materials?
  - What opportunities would standardisation bring? Is it possible that this would lead to overcoming the barriers?
- What requirements would you impose on rPETs?
- Are you interested in pursuing standardisation?
- Do you think standardisation would affect the price and demand?
- How would this affect EU and Swedish regulations?
- Do you think standardisation would lead to an increased circular economy?
- Is there anything you would like to add? Anything that we missed or didn't ask about?

Purchasers

- What are the most common forms of PET that you purchase? What quantities are we talking about?
- What are your performance and property requirements for the PET you buy?
- Play with the idea of introducing a standard on PET and its composition. How do you think this would affect your business?
- What would be the challenges and opportunities of the above idea? Do you think it is feasible from the beginning?
    - What do you see as barriers to using (more) recycled materials?
    - What opportunities would standardisation bring? Is it possible that it would lead to overcoming the barriers?
- What requirements would you impose on PET?
- What regulations would be needed to enable this idea?
- Do you think standardisation would lead to an increased circular economy?
- Is there anything you would like to add? Anything we missed or didn't ask about?

Industry organisations

- Where is PET used? In which products (both consumer and industrial)?
- What are the volumes in Sweden, EU?
- How much is recycled PET?
- How come we do not use more recycled PET?
- Which performance requirements that you consider important are not met by recycled PET?
    - What do you see as barriers to using (more) recycled material?
- If recycled PET were guaranteed to have the same properties as virgin PET, do you think its use would increase? By how much?
- What performance and property requirements for PET do you consider important?
- What would be required to introduce a standard for PET?
    - What barriers do you see being encountered?
    - What opportunities would standardisation bring? Is it possible that it would lead to overcoming the barriers?
- Which products and actors would you start with?
- What legislation and other barriers would need to be overcome/changed?
- Technologically, could this affect production, use or recycling?
- How would the industry be affected by the introduction of standardisation?
- Would this be affected by e.g. EU and Swedish regulations?
- Do you think standardisation would lead to an increased circular economy?
- Is there anything you want to add? Anything that we missed or didn't ask about?

Recyclers/collectors

- How many different types of thermoplastics and variants of additives do you handle? What is the share of PET?
- What are the most common PET products you collect? From which sector?
- What are the requirements for the plastics you receive for recycling?
- Play with the idea of introducing a standard on PET and its composition. How do you think this would affect your business? Do you think it is feasible?
- What would be the challenges and opportunities of the above idea?
    - What do you see as barriers to using (more) recycled materials?
    - What opportunities would standardisation bring? Is it possible that it would lead to overcoming the barriers?
- What would increase the incentives to increase recycling of PET?
- Which regulations could contribute to an increase in recycled material?
- Do you think that standardisation would lead to an increased circular economy?
- Is there anything you would like to add? Anything we missed or didn't ask about?

Researchers and experts

- Where is PET used? In which products (both consumer and industrial)?
- What are the volumes in Sweden, EU?
- How much is recycled PET?
- What performance and property requirements for PET do you consider important?
- Why don't we use more recycled PET?
- What requirements does recycled PET not fulfil that you consider important?
- If recycled PET was guaranteed to have the same properties as new PET, do you think its use would increase? By how much?
- Play with the idea that a standard would be introduced for PET and its composition. How do you think this would affect businesses? Do you think it is feasible?
    - What would be required to introduce a standard for PET?
    - Which products and actors would you start with?
    - What legislation and other barriers would need to be overcome/changed?
- Technologically, could this affect production, use or recycling?
- How would the industry be affected by the introduction of standardisation? Is it different between different actors?
- Would this be affected by, for example, EU and Swedish regulations?
- What would be the challenges and opportunities for the above idea? Speculate freely.
    - What do you see as barriers to using (more) recycled materials?
    - What opportunities would standardisation bring? Is it possible that it would lead to overcoming the barriers?
- Do you think standardisation would lead to an increased circular economy?

- Is there anything you would like to add? Anything that we missed or didn't ask about?