Mapping the Dutch textile recycling system through the Butterfly Framework

KB34 Report

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1 Introduction

Textile waste is a major global challenge, exacerbated by fashion overproduction and overconsumption. The textile industry, specifically fast fashion, is put under increasing pressure due to its negative environmental impacts, ranging from heavy use of non-renewable resources to polluting waterways and ecosystems (Sandin and Peters, 2018). Since 2000, fast fashion has intensified the flow of materials in the fashion industry, producing almost twice the amount of clothes nowadays (Niinimäki et al., 2020). One of the viable trajectories to tackle this issue is to increase circularity in the textiles and clothing industry (Ellen McArthur Foundation, 2017; Harmsen et al., 2021). Circularity aims at reducing the input of virgin non-renewable resources while satisfying societal demands. The Netherlands, per the Dutch government, plans to transition from a linear to a fully circular textile chain by 2050, where waste is minimised, and materials are continuously reused (Ministry of Infrastructure and Water Management, 2024). This can be achieved by applying circular strategies to reduce the consumption of natural resources and waste generation, one of which is recycling. Recycling is the process of recovering and converting waste materials into reusable forms to conserve resources, reduce environmental impact, and minimise landfill waste (Netherlands Environmental Assessment Agency (PBL), 2017). In the textile industry, reuse and recycling (in the form of downcycling)[1] is already commonly practiced (Sandin and Peters, 2018). However, the current state of recycling is insufficient to meet ambitious circularity goals, either at the national or global level. Globally, recycling figures for textiles indicate that around 30-35% of all textile waste is collected, and less than 1% is recycled into new clothing (European Commission, 2023). Hence, effective textile recycling has become increasingly critical for achieving a circular transition.

The European Union (EU) has taken steps to address these challenges. From 2025, all EU countries are required to set up procedures for collecting textile waste separately. Key policies, such as the EU Strategy for Sustainable and Circular Textiles and the Waste Framework Directive, aim to create a greener textile sector with durable and recyclable products. However, despite various regulations and initiatives, progress remains slow, particularly in reducing fossil feedstock dependency and developing truly circular products (Charnley et al., 2024). The Netherlands is known for being one of the circular frontrunners in Europe, particularly in the textile sector (Netherlands Enterprise Agency, 2024). It has taken several steps to ensure progress towards a circular textile economy by putting forward multiple legislations, regulations, and measures targeting the adoption of circular practices and processes (Netherlands Enterprise Agency, 2024).

Recycling alone, however, cannot achieve circularity. Circularity requires managing material flows holistically and reducing dependency on fossil resources. Yet, recycling practices often remain siloed within waste management systems, and stakeholders hold varying interpretations of recycling. Generally, there is a lack of data and insight on what is collected, what should be collected, and what could be recycled. Hence, there is a huge discrepancy in the amount which is recycled not only from a societal but also from technological perspective (Kazancoglu et al., 2022). For example, recycling as a technical process differs from consumer behaviours such as donating or selling used clothing. Despite the necessity of tackling this issue, poor harmonisation of regulations, limited data on collected and recyclable materials, and technological constraints—such as down-cycling and material safety concerns—pose significant bottlenecks (Reike et al., 2023). These are serious bottlenecks of circular economy as the circular economy should reduce environmental pressure in a safe way. This reflects the multifaceted challenges of transitioning toward a circular economy, highlighting the urgency of recycling and reusing textiles. Therefore, to increase circularity, effective recycling is increasingly critical and needs to be explored from a multidisciplinary perspective.

[1] The recycling of waste where the recycled material is of lower quality than the original material.

Transforming the textile sector into a circular system requires an interdisciplinary approach that integrates technical, ecological, and socio-economic dimensions. The objective of this report is to fill in the gaps and identify the bottlenecks hindering the expansion of textile recycling. It aims to do so by applying the Butterfly framework (Bos et al., 2022) as a tool to map textile recycling systems and their bottlenecks from a multidisciplinary perspective. By identifying key challenges and addressing gaps in knowledge, this report intends to guide researchers, policymakers, and local governments in supporting the transition to a sustainable and circular textile economy. The report first introduces the Butterfly framework by providing a short explanation (Section 2). In Section 3, the applied method for the framework is described. Section 4 then presents answers to the framework's assessment questions for each element. Lastly, a short conclusion is offered in Section 5.

2 Butterfly Framework

The presented framework aims to facilitate understanding and decision-making in transitions toward a circular and climate-neutral society by examining the interconnections, synergies, and trade-offs between ecological, technical, and socio-economic systems. The Butterfly Framework presents an overview of system relations on the level of the technical system, ecological system, socio-economic system, and their interrelations (Figure 2.1). According to Bos et al. (2022), the objective of the framework is 'to assess the role of circularity (as a means) in relation to circularity and climate neutrality (as an objective)', highlighting the interconnected flows across systems.

The framework emphasises three systems: the technical system (human-driven processes interacting with nature), the ecological system (physical and biological processes), and the socio-economic system (social, economic, and cultural dynamics). It incorporates societal goals (e.g., Sustainable Development Goals), planned interventions (e.g., policies, strategies), and external driving forces (e.g., technology, climate change) to analyse system dynamics. Thus, the framework has a systems perspective that helps in an interdisciplinary context to understand the interlinkages, synergies, and trade-offs between different aspects. By integrating local actions with broader ambitions, it serves as a comprehensive interdisciplinary tool for monitoring and guiding bioeconomic transitions.

The framework can be used as a checklist or as a map: a scope is selected to define system boundaries, influenceable and uninfluenceable processes (drivers), then questions are posed concerning (problems in) the state of the system, goals (aimed at the preferred state of the systems), interventions, and impacts (on the system). Thus, it is applied by formulating questions for each of the elements in the framework and describing how these elements can be interpreted. Notably, the Butterfly Framework does not provide solutions but assists to face questions on how to find opportunities, approach problems and their solutions, and deal with trade-offs in an integrated way. Bos et al. (2022) created the framework to deal with stakeholders' action perspectives and integrate their lower-level objectives to higher-level societal objectives. Therefore, the framework can be used by any kind of stakeholder as it integrates aspects relevant for the system as a whole.

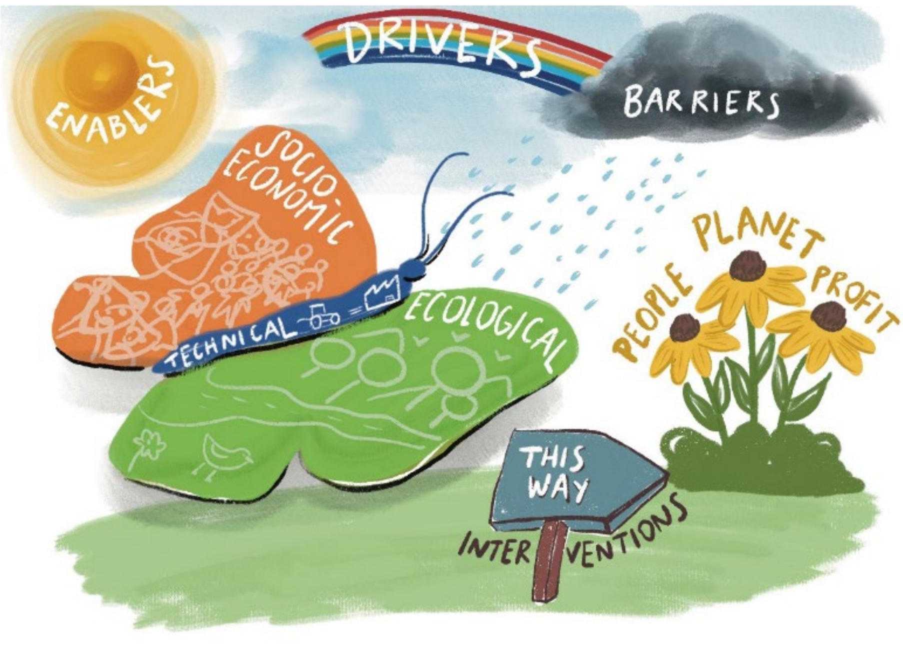

Figure 2.1 *The Butterfly Framework*
Source: Bos et al. (2022).

3 Application of Framework

The report uses the Butterfly Framework as a mapping instrument to identify gaps and hotspots that affect textile recycling. The focus of the report is on the downstream of recycling to better understand the processes that are involved in these processes. Having such an overarching framework encourages the collaboration across all relevant disciplines.

We used the framework to formulate questions and provide an overview on the current (Dutch) textile recycling system including its gaps/bottlenecks to be able to optimise re-use of materials and components and achieve circularity.

The questions were formulated based on the diverse expertise of the team from different science groups and underwent two rounds of revisions before completion. The assessment questions are listed in Table 3.1. A main desk-literature search was applied to address the formulated questions along with the team's expertise. The desk literature search covered two databases: Web of Science and Google Scholar. The literature search and selection were carried out based on keyword search that consisted of a combination of the following words:

- Textile OR cloth* OR garment OR apparel OR fibre OR fabric
- Waste OR recycling OR closed loop
- Europe OR Netherlands OR Dutch
- Sustainab*OR circular OR
- Driver OR barrier OR challenge
- Intervention OR strateg* OR consumer OR stakeholder
- Environment* OR econom* OR social OR socio-economic*

Additionally, snowballing from relevant literature was performed to provide a full overview of literature.

Table 3.1 *From the Butterfly framework to assessment questions for Dutch textile recycling system*

Butterfly Framework Elements	Assessment Questions
1. System Boundaries/scope	1.1 What are the boundaries of the Dutch textile recycling system that must be addressed? 1.2 What are the primary components of the Dutch clothing recycling system?
2. Goals	2.1 To what extent must circularity and recycling contribute to achieving the Sustainable Development Goals (SDGs), and how is this contribution be assessed? 2.2 What are the overarching goals for the clothing recycling system in the context of circular economy, considering environmental, social, and economic sustainability?
3. Drivers	3.1 What driving factors (socio-economic, technical, ecological) are involved in the recycling system? 3.2 How does consumer behaviour influence recycling activities? 3.3 How does the availability of garments from fossil, recycled, or biobased origin influence current status of textile recycling and expected developments?
4. Interventions	4.1 What interventions from the different stakeholders are needed to support the recycling system? 4.2 How can we quantify and measure these recycling intervention initiatives of stakeholders?
5. Technical System	5.1 Are the existing infrastructure and technologies capable of handling increased recycling/scalability? 5.2 What is the effect of contaminants (dyes, finishes) on the textile recycle quality, i.e. is their presence a problem? 5.3 Does the current legislative framework properly assess textile safety concerns? 5.4 Are there quality standards or specifications that recycled materials must meet for use in new products?
6. Ecological system	6.1 What are the environmental implications of textile recycling methods and recycled materials commonly used in clothing? 6.2 What are hotspots for improving recycling taking into consideration resources?
7. Socio-economic system	7.1 What are the potential social impacts of transitioning to a more circular recycling system? 7.2 How can we ensure that recycled materials are used as feedstock for new textile products?

4 Answers to the Assessment Questions

4.1 Element 1: System Boundaries

4.1.1 What are the boundaries of the Dutch textile recycling system that must be addressed?

To map and understand the Dutch textile recycling system, boundaries must be set. In this assessment, textile recycling is focused on the end-of-life phase, specifically post-consumer waste stream – consumers' worn out, damaged, or unwanted clothing. Therefore, the system boundaries are set only from textile collection phase to the recycling process.

4.1.2 What are the primary components of the Dutch textile recycling system?

The primary components of post-consumer textile recycling include collecting, sorting, and processing various textiles to reuse or create new materials or products (Charnley et al., 2024). Generally, there are six steps for textile recycling. The first step is the collection of used textiles, which can be done in several ways such as collection bins, drop-off points, or collaborations with organisations and retailers. Once collected, textiles are sorted based on their material composition and condition. Different types of materials require different recycling processes, so materials are commonly sorted into natural fibres (e.g., cotton), synthetic fibres (e.g., polyester), and blended fibres. Hence this step also separates textiles that can be reused or repurposed from those that cannot, making it an important phase to maximise the value of used textiles and reduce waste. After sorting comes inspection where the quality of textiles is assessed and graded based on aspects like their fabric type, colour, and condition to determine their potential for recycling. Those in good condition can be reused or resold, while those in poor conditions are processed through recycling. Step four, recycling, involves breaking down the textiles to their individual fibres usually through mechanical or chemical methods. The recycled fibres are then further refined to improve their quality and remove impurities using processes such as combing or spinning. Finally, in step six, the yarn or thread-like material is created and can be used for different applications such as clothing, furniture, insulation material, or as raw materials (e.g., in construction).

4.2 Element 2: Goals

4.2.1 To what extent do circularity and recycling contribute to achieving the Sustainable Development Goals (SDGs), and how is this contribution be assessed?

Circularity and recycling are transformative means for sustainable development. Circularity and recycling can address several of the current issues by promoting sustainable resource management, fostering economic development, and reducing environmental impact (Ellen McArthur Foundation, 2017; United Nations Environment Programme, 2023). Such processes increase resource efficiency with environmental and economic benefits that aim at 'closing the loop' (Koszewska, 2018). The contribution towards Sustainable Development Goals spans several goals (Figure 4.1): SDG8 by job creation and economic growth; SDG9 by innovation and sustainable infrastructure; SDG11 by waste management and economic opportunities; SDG12 by waste reduction and resource efficiency; SDG 13 by emission reduction and climate resilience; and SDG15 by biodiversity protection.

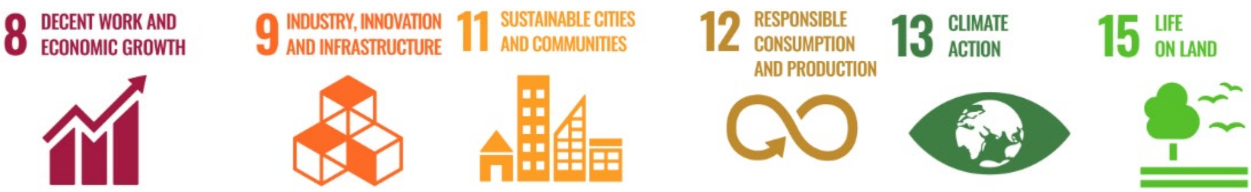

Figure 4.1 *Textile recycling contribution towards Sustainable Development Goals*

Evaluating the impact of these contributions can be done through a combination of metrics and indicators that measure environmental, economic, and social effects. Quantitative metrics focus on specific aspects such as recycling rates, resource efficiency, and emission reductions. For example, Material Flow Analysis (MFA) is used to measure the efficiency use and reduction in raw material utilisation. Whereas Carbon Footprint and Lifecycle Assessments (LCAs) quantify reductions in greenhouse gas emissions due to recycling and circular practices (Sandin and Peters, 2018). Moreover, qualitative methods can include economic performance indicators that evaluate the contribution of recycling initiatives to green economic growth through job creation and economic value of recycled materials and social impact indicators that assess the sustainable livelihoods and quality of jobs (Suarez-Visbal et al., 2023). Lastly, qualitative metrics such as policy implementation, public awareness, and consumer engagement are also tools to measure the contribution of circularity and recycling to achieve sustainable development (United Nations Environment Programme, 2023).

It is worth noting that these assessments can also face challenges hindering their accuracy or applicability due to data availability and standardisation across regions and system boundaries that can impact the results such in the case of LCAs (Sandin and Peters, 2018). Such challenges need to be recognised and optimised to achieve the 2030 Agenda for Sustainable Development.

4.2.2 What are the overarching goals for the clothing recycling system in the context of circular economy, considering environmental, social, and economic sustainability?

The aim of the Dutch clothing recycling system in the context of circular economy is to create a more sustainable and resilient clothing industry by integrating social, environmental, and economic sustainability. The environmental goals include (1) Waste and landfill use reduction by diverting textile waste from landfills, minimising of clothing waste incineration, reducing toxic emissions; (2) Resource conservation by reducing the demand for virgin non-renewable materials like polyester and promote efficient use of resources during recycling processes; (3) Prevention of microplastic pollution by innovating technologies that recycle synthetic textiles without leaching of harmful elements into the environment (Netherlands Enterprise Agency, 2024; United Nations Environment Programme, 2023). As for the social sustainability goals, there is a large focus on promoting ethical practices such as fostering safe and fair working conditions within the textile recycling industry and empowering communities; consumer awareness and participation by educating and engaging the public and facilitating involvement (Suarez-Visbal et al., 2023; United Nations Environment Programme, 2023).

Economic sustainability goals include maximising material value retention by designing systems that retain high values of materials through multiple cycles of reuse and recycling; incentivise innovation by supporting development of innovative recycling technologies and encouraging sustainable designs; and implementation of supportive policies such as the Extended Producer Responsibility (EPR) which holds producers accountable for the disposal management of clothing, incentivising the production of recyclable garments, and funding recycling systems (Netherlands Enterprise Agency, 2024; United Nations Environment Programme, 2023). Improving resource efficiency in the recycling system could provide financial viability through cost efficiency and profitability.

4.3 Element 3: Drivers

4.3.1 What driving factors (technical, ecological, and socioeconomic) are involved in the recycling system?

The Dutch textile recycling system is influenced by a complex interrelation of technical, ecological, and socioeconomic factors. Technically, innovations in sorting and recycling technologies are critical in enhancing the efficiency and scalability of textile recycling (Sandin and Peters, 2018). Recent advancements in automated sorting systems have improved the ability to separate textile waste by fibre type and colour, which is essential for high-quality recycling (Baloyi et al., 2024). However, challenges persist, as there is no standardisation for sorting of textiles in the Netherlands and the dominant sorting process is still done by hand with only a few locations offering near-infrared identification technology (Koszewska et al., 2018). Additionally, sorting and recycling blended garments, which constitute a significant portion of textile materials, are complex and often require advanced separation technologies such as chemical recycling, which are not yet cost-effective or widely available (Peters et al., 2021). Due to this, low-quality recycled materials fill the recycling market and strain commercial recycling technologies (Reike et al., 2023). Furthermore, design for cyclability during production offers a great advantage for achieving a circular textile loop (Leal Filho et al., 2019).

Ecologically, the Dutch textile recycling system is driven by the need to reduce environmental impact of current recycling processes such as high energy consumption and chemical use which can offset the ecological benefits of recycling (Roos et al., 2021). Additionally, the contamination of textiles with dyes and chemicals complicates recycling and reduces the quality of materials (Sandvik and Stubbs, 2019). Life cycle assessments (LCAs) of textile recycling processes highlight the potential environmental benefits, such as reduced carbon footprints and resource conservation, but also underscore the need for optimising recycling technologies to minimise secondary environmental impacts (van der Velden et al., 2022). As a leader in circular economy initiatives, The Netherlands emphasises the importance of closing material loops, minimising resource extraction, and promoting recycling as part of its national sustainability agenda (European Environment Agency, 2021).

Socio-economic factors also play an important role in textile recycling. The high costs of recycling infrastructures and lack of economic incentives act as hindrances for stakeholders to partake in recycling (Hole and Hole, 2020). Also, public awareness and engagement, influenced by awareness campaigns and policy measures, is critical for increasing participation in textile collection schemes (Reike et al., 2023). Usually, this poses a challenge as there is low consumer awareness and participation in textile collection schemes; however, recently, the Netherlands is experiencing an overflow of used textiles available (see NRC, 2024). Yet, there is still a limited demand for recycled textiles since the market prices for virgin textile materials are low. This also corresponds to the insufficient accessibility and availability of recyclable textile materials (Leal Filho et al., 2019). However, legislation schemes such as the Extended Producer Responsibility (EPR) and governmental subsidies for recycling initiatives can drive industry engagement (WRAP, 2021). Collaborations between industry, academia, and policymakers can also foster innovation and knowledge sharing (Kazancoglu et al., 2022).

There are also cross-cutting factors such as traceability in circular supply chains, digitalisation and data management, and market dynamic that also influence the textile recycling system (Islam et al., 2022). Together, these factors and other ones not covered in this scope create a multifaceted ecosystem for textile recycling in the Dutch context, requiring integrated approaches to tackle limitations and encourage optimisation.

4.3.2 How does consumer behavior influence recycling activities?

Consumer behaviour has a vital influence in shaping the effectiveness and scalability of recycling activities by acting as both a barrier and an enabler as aforementioned. Consumer behaviour can positively impact recycling through active participation in recycling programmes, proper sorting of garments, demand for recycled and/or recyclable materials, purchase of second-hand clothing, and through applying pressure on company brands to change their corporate practices. For example, the success of textile recycling initiatives in the Netherlands relies heavily on consumers returning used garments to designated collection points (WRAP, 2021). Additionally, growing consumer awareness of environmental issues and the demand for sustainable fashion are driving brands to adopt circular economy practices (e.g., incorporating donation boxes, incentives, or secondhand sections), thereby creating a market pull for recycled textiles (Koszewska, 2019).

However, consumer behaviour can also have negative impacts when there is a lack of awareness or misinformation about the impact of different kinds of materials as well as recycling processes. This often leads to improper disposal of textiles, such as mixing recyclable items with general waste or contaminating them with dyes or paint (Sandvik and Stubbs, 2019). This not only lowers the quantity of usable materials but also increases the costs and complexity of sorting and processing. Furthermore, the fast fashion culture, characterised by frequent purchasing and disposal of low-quality garments, exacerbates the amount and quality of textiles, overwhelming existing recycling infrastructures (Niinimäki et al., 2020). Moreover, consumer reluctance to pay higher prices for recycled or sustainably produced textiles limits the economic feasibility of recycling initiatives, as it disincentivise companies from invest in advancing recycling technologies (Kazancoglu et al., 2022)).

Additionally, other aspects of consumer behaviour also impact textile recycling including but not limited to urbanism, income levels, age categories, awareness levels, social norms, peer influence, ethical considerations, adoption of technology (e.g., online marketplaces, recycling apps) (Koszewska, 2019). Therefore, consumer research is essential to understand the underlying drivers and barriers behind consumer behaviour and provide insights on how to positively influence consumers' recycling behaviour.

4.3.3 How does the availability of garments from fossil, recycled, or biobased origin influence current status of textile recycling and expected developments?

The availability of garments derived from fossil-based, recycled, and bio-based materials is an important matter in the current status and future prospects of textile recycling. The dominant availability of fossil-based materials on the market due to their low costs and durability poses a significant challenge for recycling (Baloyi et al., 2024; Harmsen and Bos, 2020). Fossil-based garments are commonly made of a virgin blend of natural and synthetic fibres that make the sorting process of these garments complicated and difficult to separate. Also, the recycling of fossil-based garments often performed by mechanical recycling results in reduced quality fibres. This causes a bottleneck for recyclers to produce good quality recycled materials which further exacerbates the scalability limitation in the Netherlands (Netherlands Enterprise Agency, 2024). Expected developments include advancements in recycling equipment and implementing more sustainable policies and regulations that rely less on fossil-based materials.

Recycled materials, such as recycled polyester or cotton, are gaining attention as a sustainable alternative to fossil-based since they reduce the demand for virgin resources and allow for closed loop systems (Charnley et al., 2024). Demand for recycled products is increasing due to initiatives like the Dutch Circular Textile Valley and the Textiles 2030 programme (WRAP, 2021). Although demand is growing, the quality and durability of recycled fibres are still a concern impeding widespread implementation (Harmsen and Bos, 2020). Despite these challenges, the Dutch government commitment to a circular economy, outlined in the Circular Economy Action Plan, aims to improve the viability of recycled textiles (European Commission, 2020). This would open opportunities for future developments to scale up the research and development of recycled materials, innovation in sorting technologies, and consumer involvement.

Lastly, bio-based materials, such as hemp or linen, are emerging materials that provide a renewable and bio-degradable alternative to fossil-based materials. Even though such bio-based garments are still not widely available on the market, their availability is increasing because of consumer preferences for sustainable and natural materials (Roos et al., 2021). Currently, the recyclability of such materials is challenging because they require specialised recycling streams that account for the risk of contamination during recycling processes (Sandvik and Stubbs, 2019). Further research and development are needed to understand the effect of such materials on recycling. Thus, future developments in policy and regulation targeting sustainable and circular innovations would provide an outlet where research and innovation on biodegradable materials to flourish expanding market and circular models.

4.4 Element 4: Interventions

4.4.1 What interventions from the different stakeholders are needed to support the recycling system?

To address recycling challenges, multiple stakeholders should be engaged in recycling interventions such as fashion industries, non-profit organisations (NGOs), consumers, and governments. Fashion or textile industries can act by incorporating circular design strategies in their product innovations. Designing products with the end-phase in mind would improve the recyclability of products including the product's life cycle such as Design for the Environment or Design for Disassembly (Leal Filho et al., 2019; Netherlands Enterprise Agency, 2024). Likewise, highlighting transparency and accountability in their supply chains would also improve recycling by identifying the origins of fibres and the resources utilised in textile production (Kazancoglu et al., 2022). These stakeholders can also partake in collaborative initiatives where knowledge and resources from multiple stakeholders are shared and developed. Lastly, investments in recycling infrastructures are key in backing collection and recycling initiatives.

Non-profit organisations can also support the recycling system by engaging and supporting communities through local initiatives and capacity building (e.g., knowledge on recycling). Interventions that highlight consumer awareness and education, and policy advocacy are needed to foster the knowledge for citizens to take action. Similarly, targeted interventions are needed to influence consumer behavior positively. Educational campaigns and awareness programmes can help bridge the knowledge gap, encouraging consumers to adopt sustainable practices such as repairing, reusing, and recycling textiles (Roos et al., 2021). Furthermore, governments through policy measures, such as extended producer responsibility (EPR) schemes and deposit-return systems, can also incentivise consumers to return used textiles by offering financial rewards or discounts on new purchases (European Commission, 2020). Moreover, fostering a cultural shift towards valuing quality over quantity in fashion consumption can reduce the overall volume of textile waste, making recycling systems more controllable and effective (Zamani et al., 2021).

It is important for stakeholders align their goals towards a common vision of promoting textile recycling and achieving sustainability targets. Thus cross-sector collaborations can leverage complementary skills and resources to collectively overcome barriers to recycling and have greater impact. Furthermore, interventions aim at continued improvement. So it is crucial for stakeholders to have assessments and feedback systems in place to ensure interventions remain effective and adaptable to evolving challenges.

4.4.2 How can we quantify and measure these recycling intervention initiatives of stakeholders?

Recycling intervention initiatives can be measured in several methods through combinations of metrics and methodologies depending on the inputs available and the desired outcome. In terms of methodologies, questionnaires, MFA, LCA, and key performance indicators (KPIs) are some of the suitable methods. For instance, to analyse intervention impact on textile collection, metrics can include the volume of textiles collected, participation rates, and geographical coverage. As for sorting and processing, the efficiency, quality of textile materials, and rate of non-recyclables can be among the aspects that should be measured for an intervention. Examples of economic metrics can include cost efficiency, monitor market demand, and tracking investment in infrastructure. Environmental metrics could focus on the carbon footprint of the recycling process, use of resources, and waste reduction. Whereas social metrics can measure public awareness through consumer behaviour, quantifying consumers' attitude levels to recycling and tracking changes over time. Lastly, the effectiveness of policies can be measured through its impact such as rate of compliance to recycling. Furthermore, it is crucial to mention that these are all separate metrics that allow for measurements of interventions at a local scale but do not provide large-scale impact. In order to assess impact at a large scale such as on a country level, there is a need for a more integrated measurement system with appropriate and reliable databases.

4.5 Element 5: Technical System

4.5.1 Are the existing infrastructure and technologies capable of handling increased recycling/scalability?

As mentioned earlier, the lack of innovative technology is a barrier in the transition to circular textile (Kazancoglu et al., 2022). Effective recycling is highly dependent on proper infrastructure and availability of technologies. Sorting technologies play an important role in the first stages of textile recycling with automated sorting systems such as near-infrared spectroscopy and artificial intelligence (AI)-driven classification, being better at classifying textiles according to fibre type, colour, and composition (Netherlands Enterprise Agency, 2024). However, the dominant sorting process is still done by hand with only a few locations offering near-infrared identification technology (Brouwer et al., in progress; Koszewska et al., 2018). Currently, existing sorting methods cannot separate dyes and other contaminants from the original fibres (Leal Filho et al., 2019). Furthermore, aspects such as zippers, buttons, and chemical contaminations render effective sorting and separation as difficult (Kessler et al., 2021). Although current sorting technology is not highly capable, an increase in the quantity of textiles suitable for recycling, automated sorting is promising. Thus, there needs to be improvements in the separation and sorting technologies to support higher amounts of recycling (Kazancoglu et al., 2022).

Regarding post-consumer waste streams, one of the biggest technical issues is material complexity, garments made of blended materials, natural and synthetic fibres, such as cotton, polyester, and elastane. Since each fibre has its own suited recycling process, blended textiles are difficult to sort and recycle properly (Harmsen and Bos, 2019; Harmsen et al., 2021). This makes recycling of post-consumer garments complicated and challenging. Nonetheless, recycling options for some materials is still possible, but it can be quite energy-consuming and expensive (Harmsen and Bos, 2019). A detailed description of existing technologies is outside the scope of the report, but Harmsen and Bos (2019) provide an overview of the recycling methods available for different types of materials.

Typically, textile recycling routes involve two classifications: mechanical or chemical recycling. Mechanical recycling is the most prevalent and mature in The Netherlands (Rieke et al., 2023). However, mechanical recycling processes (i.e., downcycling) such as shredding and grinding often result in reduced quality materials restricting their applicability in products, for instance, to insolation material purposes. In combination with the low market demand for low quality materials, this further limits the potential to scale mechanical recycling facilities without sufficient investments (Rieke et al., 2023). Chemical recycling is another form of recycling that uses solvents and enzymes to break down synthetic materials into equal quality material as virgin materials (Juanga-Labayen et al., 2022). This type of technology is sensitive to the input composition requiring non-blended and uncontaminated material such as pure cotton as post-consumer input. This makes chemical recycling be only viable to specific waste streams (Brouwer et al., in progress). Currently, this type of recycling is only in pilot-scale facilities in the Netherlands. So, it is still in its infancy in terms of post-consumer garments, which will take time to adopt at a large scale. Therefore, in terms of scalability, the current recycling infrastructure is not equipped to handle increased recycling at a commercial scale with existing technologies (Leal Filho et al., 2019). Moreover, the size of the markets is not large enough yet to absorb the capacity of materials that would come from scaled recycling of clothes. Similarly, the cost of using virgin materials is still more economic than recycling of textile fibres (Reike et al., 2023). Therefore, advancements and investments in research and infrastructure is required to achieve higher scalability.

Another method of systematising recycling routes can be done based on the type of processes involved or based on the level of disassembly of the recovered material (see Harmsen et al., 2021; Sandin and Peters, 2018), namely: fabric recycling (fabric recovered and reused in new products), fibre recycling (original fibres are preserved from dissembled fabric), polymer/oligomer recycling (polymers are preserved from dissembled fibres), and monomer recycling (monomers are preserved from dissembled polymers). This systematisation of recycling routes resembles the classification presented by Ellen Foundation (2017).

4.5.2 What is the effect of contaminants (e.g., dyes, finishes) on the textile recycle quality? Are there technologies or methods for removing contaminants from textiles prior to recycling?

Contamination of garments in the form of dyes, finishing agents, and additives or with other types of fibres is a bottleneck for recycling. These contaminants can degrade the mechanical and chemical properties by changing the properties and structures of fibres, reducing fibre strength, and causing discolouration in the recycled material output (Baloyi et al., 2024). Hazardous chemicals such as heavy metals further complicate recycling by posing environmental and possible health risks rendering recycled materials not suitable for all applications (Undas, Sijtsema, & van Dooren, 2023; Undas et al., 2023). Contamination could also be an issue in physical recycling of non-textile materials such as PET bottles with recovered coloured plastic being a challenge to use for recycled textiles (Baloyi et al., 2024). However, chemical recycling with the use of chemical solvents is a possible method to overcome this challenge, making removal of contaminants easier in this recycling method but costly (Harmsen et al., 2021).

The challenge with these recycling methods is that their effectiveness in removing chemical contaminations can vary causing potential bottlenecks to arise. The first possible bottleneck is that the recycling method fails to properly remove impurities; second is unintentional creation of new Non-Intentionally Added Substances (NIAS) which result from inadequate recycling processes or cleaning of reused materials could pose further environmental and safety concerns; lastly, the lack of adequate analytical tools to assess the chemical safety or recycled materials (Undas et al., 2023).

Furthermore, there are developments in technological methods that can remove contaminants from textiles prior to recycling using chemical treatments, enzymatic treatments, or solvent-based processes (Charnley et al., 2024). Though the use of such methods can be harsh and may damage the fibres reducing their quality and reusability. Therefore, future research and further data are needed to optimise the value, quality, and safety of recycled textiles as well as the use of such technologies in terms of profitability, scalability, and environmental sustainability.

4.5.3 Does the current legislative framework properly assess textile safety concerns?

The legislative framework for textile safety in the Netherlands is aligned with the European Union regulations. Across the EU, there are strict legislations for labelling, chemical safety, and environmental impact, however, these legislations do not cover the full spectrum of safety concerns in textile, specifically for textile recycling practices. EU regulations on chemicals such as REACH (Registration, Evaluation, Authorisation, and Restriction of Chemicals) aim to improve the protection of human health and the environment from the risks that can be posed by chemicals (European Chemicals Agency, 2025). It ensures that textiles put by companies on the market comply with the safety standards, but it does not consider the multitudes of post-consumer textile recycling where contaminants can pose risks during recycling. In 2020, the EU took further steps implementing new legal norms on setting strict limits on dangerous chemicals in clothing and footwear (Joint Research Centre, 2023). The new norms, part of the EU strategy for sustainable and circular textiles, also address the resource efficiency and environmental impact of hazardous substances by regulating these substances through restriction or substitution of concerning substances.

There are national policies set in place such as the Circular Economy Action Plan sets requirements for recyclability of textiles and addresses the presence of hazardous substances and substances that limit recyclability. This initiative can promote the use of safe chemicals that correspond with recycling technologies, yet it focusses more on waste management and recycling targets rather than on the safety of recycled textiles. Currently there are no specific standards for measuring the potential presence of hazardous substances in post-consumer textiles or non-intentionally added substances (NIAS) in recycled textiles (Heens & Eliesen, 2023; Undas, Sijtsema, & van Dooren, 2023). These are significant gaps in legislation that raise safety concerns about recycled textiles. Hence, new legislation should explicitly discuss their presence, impact, and testing methods.

Little is known about hazardous chemicals in garments made from recycled textiles since information regarding substances present in textile materials and traceability of those materials are not presented to potential recycling companies (Heens & Eliesen, 2023). Methods used for virgin materials could potentially be applied to recycled materials as well. However, available data on hazardous substances in post-consumer textiles is very limited and more research is needed to evaluate this potential bottleneck. Strategies such as the EPR could also fill these gaps by including stricter safety requirements for recycled textiles (Undas et al., 2023) while technological advancements such as blockchain technology could offer traceability on the presence of chemical substances in a textile's lifecycle.

4.5.4 Are there quality standards or specifications that recycled materials must meet for use in new products?

Currently there are no harmonised quality standards for the use of recycled materials in new products (Netherlands Enterprise Agency, 2024). The need for standards or analytical tools to monitor newly recycled materials is urgently evident with new legislative ambitions. Based on the new measures under the EPR for textiles (2025 and beyond), producers have to report on the volume of textiles recycled making sure that at least 50% of the textile that is sold is prepared for reuse or recycle and at least 25% of the recycled textile is fibre-to-fibre recycled (Ministry of Infrastructure and Water Management, 2023). Accordingly, collaboration together with other producers is encouraged to comply with these new measures and create coordinated testing methods and tools to provide safe recycled textile products.

4.6 Element 6: Ecological System

4.6.1 What are the environmental implications of textile recycling methods and recycled materials commonly used in clothing?

Textile recycling is often promoted as a means of concurrently tackling resource scarcity and the negative environmental effects of textile production by reducing the need of virgin material inputs and generated waste (Kessler et al., 2021). Generally, recycling of textiles reduces environmental consequences compared to incineration and landfills yet reuse of textile is more beneficial than recycling (Sandin and Peters, 2018); however, this is often based on the assumption that production of new products is avoided, or consumption is reduced (see 'rebound effect'; Siderius and Poldner (2021)). Recycling methods pose environmental benefits and challenges with mechanical recycling consuming less energy compared to virgin material production, yet it can produce substantial amounts of microfibre pollution contaminating wastewater and endangering aquatic ecosystems (Ribul et al., 2021; Sandin and Peters, 2018). Similarly, chemical recycling enables the production of high-quality recycled fibres but possibly at the cost of high energy consumption and use of chemicals (Ribul et al., 2021). Since chemical recycling is still in the adoption stage, it is tricky to assess its environmental impact reduction.

Environmental implications of textile recycling are mostly explored using climate change and energy use as impact indicators. This provides a rather narrow perspective on the relevant impact categories associated with textile recycling. For textiles, utilisation of resources is shown to have the highest ecological footprint followed by energy consumption (Juanga-Labayen et al., 2022). However, environmental implications of recycling methods could result not only in reductions, but also environmental intensifications as shown in the review of Sandin and Peters (2018). There are situations where the environmental benefits of recycling are eliminated by the low replacement rates of virgin materials. Climate impact can also increase if the recycling method is powered by fossil fuels. Hence, to tackle critical assumptions on the environmental implications of textile recycling, there is a need for research on realistic replacement rates for textile recycling and product types (Sandin and Peters, 2018).

In terms of recycled materials, the environmental implications are dependent on the origin of materials (Ribul et al., 2021). For instance, recycled polyester from PET bottles can reduce the demand of virgin polyester lowering the climate impact; yet its recycling process can produce microplastics that accumulate in the environment. As for recycled natural fibres such as cotton, they result in low-quality fibre but can mitigate the high-water consumption and pesticide use linked to cotton cultivation (Sandin and Peters, 2018). Therefore, we ought to prioritise more sustainable alternatives utilising ecofriendly textile fibres such as jute and hemp in production. They have significant ecological benefits due to having a smaller environmental footprint compared to conventional synthetic fibres (Juanga-Labayen et al., 2022). This emphasises the importance of shifting to and investing in research and development of innovative materials that result in a reduced ecological impact.

4.6.2 What are hot spots for improving textile recycling taking into consideration natural resources?

Hot spots represent critical opportunities where intervention is needed to enhance the efficiency and sustainability of textile recycling. Natural resources such as raw materials, water, and energy are possible areas where improvements can be explored. In the case of raw materials, complex fibre blends and contaminants complicate the recycling process. Thus, advanced sorting technologies can provide an opportunity for more efficient separation of various fibre types and chemicals (Baloyi et al., 2024). This goes hand-in-hand with designing for recycling/circularity where mono-material textiles are promoted over blended textiles enhancing the quality of the recycled output (Harmsen et al., 2021). As for water, traditional mechanical recycling is a water-intensive process which can benefit from water-efficient technologies such as advanced filtration and implementation or closed-loop water systems (Ribul et al., 2021). Lastly, for energy, both mechanical and chemical recycling can be energy intensive. So, investing in energy-efficient technologies and renewable energy sources can alleviate the climate impact of recycling routes. Additionally, integrated approaches that stimulate circularity such as closed-loop systems can lead to major improvements in resource efficiency (Charnley et al., 2024). Collaboration among stakeholders is also key for scaling up sustainable and innovative recycling solutions (Netherlands Enterprise Agency, 2024). Furthermore, policies and legislation that support textile recycling system and initiatives are detrimental to the success of textile recycling.

4.7 Element 7: Socio-economic System

4.7.1 What are the potential social impacts of transitioning to a more circular recycling system?

According to the European Commission’s Circular Economy Action Plan, circular economy practices could create up to 700,000 jobs across the EU by 2030, with the Netherlands expected to benefit significantly due to its advanced infrastructure and commitment to sustainability (European Commission, 2020). Another potential social benefit is the empowerment of local communities. Circular economy initiatives can raise social unity and provide opportunities for skill development and education. For example, the Dutch government’s Circular Textiles Valley initiative encourages collaboration between local businesses, municipalities, and citizens, promoting a sense of shared responsibility and community engagement (Government of the Netherlands, 2021).

The national ambition of the Netherlands for circular economy is highlighted in its policy program for Circular Textile 2020-2025 (Ministry of Infrastructure and Water Management, 2024). The potential social impact for circular economy is mostly associated with job creation, however, other social aspects such as the health and wellness of workers and the quality and quantity of jobs are unspecified. Based on a social-impact framework for circularity that explore multiple social indicators spread over quality of jobs, sustainable livelihoods, and gender equality and inclusivity (Suarez-Visbal et al., 2022); there exists a large gender pay gap with women being paid less than men in Dutch recycling facilities. Hence, there is more capacity incorporating pay equality for economic opportunities within the recycling.

Generally, there are ample opportunities to improve the social impact of a circular recycling system including participating in trade unions or creating committees for workers, ensuring female and male workers receive decent working conditions and equal pay, prioritise fixed contracts over short-term contacts, and provide knowledge and skill reproduction for workers through skill training and education (Suarez-Visbal et al., 2022). Furthermore, legislation such as the Corporate Sustainability Due Diligence Directive (CSDDD) requires companies to report on the social impact (and environmental risks) associated with their activities (Government of the Netherlands, 2021; Netherlands Enterprise Agency, 2024). Such developments will hopefully lead to the socio-economic benefits in local employment, new business opportunities, and the strengthening of local supply chains.

4.7.2 How can we ensure that recycled materials are used as feedstock for new textile products?

There are feasible opportunities for post-consumer textiles. For instance, sorting processes for collected textiles yields a large number of low-quality textiles that are inappropriate to recycle or reuse in new textile products. Currently, there are no markets for such textiles though prospects are feasible to channel these textiles to be used as feedstock in chemical recycling processes currently under development (Leal Filho et al., 2019). Moreover, mechanical recycling routes generate downcycled materials that can be used for other industries such as construction hence creating local employment in local supply chains. Thus, further research is required to find more opportunities to reduce waste fractions from post-consumer textiles.

Largely, ensuring that recycled materials are used as feedstock for new textile products in the Netherlands requires a multi-faceted combination of public engagement (e.g., awareness and demand), technological advancements in recycling, development of closed-loop recycling systems, collaboration and partnerships among stakeholders through initiatives (e.g., Circular Textiles Valley), policy support through regulations and financial incentives (e.g., EPR and subsidies), and standardisation of recycled materials through certifications and standards (e.g., EU Ecolabel, Global Recycled Standard (GRS)).

5 Conclusion

The present report highlights the bottlenecks and gaps in the current state of textile recycling with a specific focus on the Dutch context. The Butterfly Framework facilitated the mapping of the Dutch textile recycling system highlighting the bottlenecks that should be overcome. Applying the framework showcased the interlinkages and the unintended spillovers that occur across systems. The report underlined the different elements including the technical, ecological, and socio-economic systems that ought to be addressed and presented several aspects in each system. The framework facilitated the formation of the groundwork to appropriately approach problems and find solutions and opportunities in an integrated manner showcasing the importance of applying a system lens approach. It should be noted that the report covered each system, though, the economic aspects are interwoven throughout the answers, in hindsight, an explicit economic question could have been added to the socio-economic system.

Overall, the report concentrated on the challenges facing recycling, however, recycling is only one facet of the supply chain. Changes across the supply chain are also required to realise substantial transformations in the current linear methods (Kazancuglu et al., 2022; Sandvik and Stubbs, 2019). Such changes also entail ample economic, technical, and ecological considerations that surpass the scope of this report but are equally crucial in a successful transition to circular economy. Circular economy should prioritise environmental impacts over economic opportunities to allow for a proper reduction in material flows or else such streams are more likely to grow (Kessler et al., 2021). Above all, to achieve set targets and ambitions, reduction in terms of production and consumption should be prioritised over recycling. Textile recycling is a multifaced topic where a lot is going on in the technical, ecological, and socio-economic front, yet still a great deal needs to be studied to position recycling as an effective part of a transition towards more circular textile system.

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