Measuring Textile (Un)sustainability to Raise Purchasing Choices Awareness: Theoretical Background

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Abstract The textile industry is ranked amongst the top four sectors, which impact to the environment the most, and the European Union has enacted several strategies to strengthen competitiveness, sustainability, and resilience of the sector by promoting circular economy. On the global scale, the textile sector generates over 1,715 million tons of waste. In Europe, the clothing consumption has been estimated at 26 kg per person, and their environmental impacts have been evaluated at 650 kg of CO_2eq per consumer. Considering the importance of measuring macro-level material flows to assess the sustainability of a consumption model and raise awareness on consumers' purchasing choices, the present chapter deals with the unsustainable production and consumption of textiles in the European Union highlighting the lack of effective schemes aimed at recording material flows in the textile and clothing market to assess their potential effect on the environment. Under the managerial perspective, the chapter highlights the main challenges to improve the sustainability and the circularity of the textile sector, discussing the adoption of measuring and assessment tools for more sustainable production processes and the enhancement of circular economy actions in Europe. Under the theoretical perspective, common European recommendations must tackle the linear economy paradigm and the fast fashion by encouraging and providing schemes and tools for the tracking and traceability of the textile supply chains.

Keywords Textile industry · Circular economy · Material flow analysis · Life cycle assessment · Environmental sustainability

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1 Introduction

The textile and clothing industry has a complex value chain and covers a wide range of products. The main processes occurring are fibre production, spinning, weaving, or knitting, coloration, finishing, and manufacturing of made-up articles such as cloths (e.g. underwear, outerwear), furnishing and home textiles (e.g. curtains, carpets, bed linen), and industrial and technical textiles (e.g. ropes and nettings, parachutes, medical textiles, synthetic grass, sunblind, smart textiles) (EURATEX, 2022). Textile fibres can be distinguished into natural and man-made fibres and classified according to their chemical nature. As regards natural fibres, they refer to vegetable, animal, and mineral fibres. Vegetable fibres include bast, leaf, and seeds fibres, which are worth mentioning flax, jute, hemp, and cotton; animal fibres comprehend silk, wool, and other hair fibres like cashmere; whilst mineral fibres refer to asbestos (Mather & Wardman, 2015). Concerning man-made fibres, they relate to natural polymer, synthetic, and inorganic fibres. Natural polymers are cellulose rayon (e.g. viscose and modal), cellulose esters, and others like PLA (polylactic acid); synthetic fibres are many and include polyester, polyvinyl derivates, Teflon, nylon, polyolefin, and elastane; lastly, inorganic fibres are glass, carbon, and metal fibres (Mather & Wardman, 2015). On the global scale, polyester is the most produced fibre in 2019 (60 Mt. per year), followed by cotton (25 Mt.), whereas wool (1 Mt.) and silk (0.16 Mt.) are less consumed. Other synthetic fibres and polyamide record approx. 6.4 Mt. and 5.6 Mt. (Textile Exchange, 2020).

Several supply chain stages must be considered from the production of fibres to the consumption of finished products. When talking about spinning, it can be referred to polymer extrusion (melt spinning, wet spinning, and dry spinning), or to the conversion of staple fibres and filaments into yarns (twisting) (Lawrence, 2010). Based on the required performance, textile fabrics can mostly be manufactured through weaving and knitting or be nonwoven. Woven fabrics are characterised by two-dimensional or three-dimensional perpendicular interlacements of yarns, whereas in knitted fabrics, yarns are interloped in the horizontal (weft knitting) or vertical (warp knitting) way. On the contrary, nonwoven fabrics do not use yarns but are formed by bonding fibres through mechanical, chemical, thermal, or solvent processes. Woven and nonwoven fabrics have numerous applications and are produced for high-performance industrial and technical textiles, as well as for apparel and household products, whereas knitting fabrics are stretchable and ideal for garment production (Gong, 2018). Other subsequent processes are aimed at giving physical and aesthetic properties to the fabric by mechanical and chemical treatments (e.g. bleaching, mercerising, dyeing and/or printing, sanforising) and make it suitable for its end use (Bullon et al., 2017).

Resources and substances used during these value chain stages raise concerns about the negative influence on the environment and people well-being. Indeed, the textile industry represents the fourth most impacting business after food, housing, and transportation at the global level (European Environmental Agency, 2019). Under the environmental perspective, it is estimated that the clothing sector, which represents 65% of textiles production, consumes more than 80 billion m^3 of water and generates over 1,715 Mt. of CO_2eq worldwide, whereas the amount of its waste has been assessed at 90 Mt. each year (Uddin, 2019; European Parliament, 2020). Considering a business-as-usual scenario, the quantity of textile waste is presumed to increase by 46%, reaching more than 134 Mt. by 2030 (European Parliament, 2019). In Europe, the latest statistics (European Parliament, 2020) illustrate that a single consumer purchase approx. 26 kg of textiles each year, which correspond to 654 kg of CO_2eq emissions for each person. In the field of textile waste management, it is roughly calculated that over 37% of textiles are separate collected, but still 35% are incinerated with energy recovery and 28% landfilled (Watson et al., 2018, 2020). Specifically, out of the European countries, Germany shows the highest separate collection rate (75%), whilst the Netherlands and Denmark go behind (45% and 43%, respectively) (Watson et al., 2020).

In published literature, several authors (Amicarelli et al., 2022) examined the environmental impacts related to fibres, yarns, and fabric production by the life cycle assessment (LCA), which represents a standardised method (ISO 14040:2006) to evaluate the environmental impacts associated with the product life cycle and which at current is intended as one of the most promising tools to prioritise improvements towards increasing the environmental sustainability of textiles (Muralikrishna & Manickam, 2017). The application of the LCA methodology in the textile industry helps both tackling the production-consumption-disposal model and supporting circular economy strategies by highlighting the main hotspots under the environmental perspective (Wiedemann et al., 2021; Liu et al., 2020; Zhang et al., 2015). From these studies, it emerges that the textile industry is still more oriented towards the linear economy than to the circular one. Indeed, in recent years, public authorities have developed and promoted different strategies to pursue sustainability in the textile industry worldwide. Even in the 17 Sustainable Development Goals (SDGs), the United Nations promote sustainable production and consumption to achieve the zero waste in the textile sector (United Nations, 2019; Li et al., 2021).

Considering the premises above, the present chapter deals with the environmental sustainability of the textile sector in Europe. In particular, the chapter intends to highlight the main challenges to measure and improve the sustainability of the textile sector, discussing the lack of useful schemes for recording the material flows linked to the textile and clothing market and raising awareness towards the adoption of circular economy strategies and better purchasing choices.

2 Key Facts About the Textile Sector

2.1 Textiles and Clothing Market

In the global economy, the textile and clothing sector plays a leading role, being intrinsically linked to the needs of an ever-growing global population. Recent events severely hit the economies of the world countries, but despite the widespread fragmentation of supply chains, the markets reacted differently. Apparently, during the Covid-19 emergency, there was a decrease in market size due to disruptions in global supply chains, including those of textile and clothing products (Statista, 2021). Nevertheless, in 2020, textile and clothing items represented the world's seventh most traded product with a total value of 779 billion USD (OEC, 2023), maybe due to personal protective equipment demand (WTO, 2022). Textiles maintained high values and reached a relatively low growth (+7%) during the years of the post-pandemic recovery, while clothes saw an increase of more than 20% in exports (WTO, 2022). Today, roughly half of the textile and clothing market value refers to the clothing (outerwear, underwear, workwear, and accessories) production and trade, followed in the order by fabrics, industrial and technical textiles, home textiles, and yarns (EURATEX, 2020).

The clothing industry has approx. 95,000 companies operating in the European Union (EU) during 2021, showing a decrease compared to previous years (Statista, 2023a). Although the textile and clothing sector plays a relevant role in the European economy, it is predominantly based on small businesses (European Union, 1995–2023a). Many companies outsource production to cheaper locations, with 60% of clothing value produced elsewhere (European Commission, 2020a; Statista, 2023b). This involves a decrease in domestic production and a significant increase in imports from the producing countries. According to the latest statistics, the bigger exporter of textile and clothing items is China, whilst the larger importer are the United States, confirming the trends from previous years (WTO, 2022; EURATEX, 2022). During the pandemic, China experienced growth thanks to the PPE (personal protective equipment) textile trade, but a slight decrease after the emergency was over, leaving India marking a new trend with an increase in its exports by almost 50% (WTO, 2022). So that, developing countries like China, India, Bangladesh, Vietnam, and Turkey are gaining market shares to the detriment of developed countries (USA and Europe) which in recent decades were leaders in exports.

This leads to reflections of an economic, environmental, and social nature, since the growing market demand of developed countries determines an increase of the negative impacts in developing countries, where the production is mainly localised. In the period from 2000 to 2015, the production of clothes doubled to 100 billion units, whilst their utilization rate (indicating how many times a garment is used during its life cycle) dropped by 36%, meaning that more than a half of produced clothes do not last even a year. Moreover, it has been estimated that less than 1% of material is reused in new production processes corresponding to an associated value loss equal to 500 billion USD in the same observed period (Ellen MacArthur Foundation, 2017). The so-called fast fashion market has a size valued at 12,000 million USD in 2021, which will be increasingly linked to the demand for affordable clothing by youth population but also developing countries (Verified Market Research, 2022). Therefore, these growing trade flows of low-quality textiles and clothes cause alarming rates of resource consumption, emissions, and waste production, which need to be addressed urgently.

2.2 Textiles and Clothing Legislative Framework

Textiles and clothing fall into the scope of many legislations (European Union, 1995–2023b). Specific EU regulations related to textiles detail the rules concerning names, composition, and labelling (European Union, 1998–2023). As far as environmental aspects are concerned, EU Ecolabel standards and Green Public Procurement criteria for textile items are established (European Commission, 2014; European Union, 2017).

To date, the only binding measures on the topic 'textiles and sustainability' are essentially related to (i) the separate collection, launched with the Waste Framework Directive of 30th May 2018, and which must be ensured by the Member States by 2025; and (ii) the new legal norm to comply with targets regarding over 20 pollutants responsible for emissions to air and water, together with a chemical management strategy for the substitution of hazardous and harmful chemicals, both adopted under the Industrial Emissions Directive of 20th December 2022 (European Union, 1995–2023c). However, coherently with the recent Circular Economy Action Plan (European Commission, 2020a), the European Green Deal (European Commission, 2019), the Chemicals Strategy for Sustainability (European Commission, 2020b), and the Industrial Strategy (European Commission, 2020c), the EU is going to move towards greater sustainability in the textile sector. To this end, the sector is included amongst the 14 industrial ecosystems to be monitored through an annual analysis of the state of the market (European Commission, 2020c). Further, on 30th March 2022, the European Commission published a Strategy for Sustainable and Circular Textiles (European Commission, 2022a). Specifically, an action plan was stated with the aim to guide organisations in switching to more sustainable pathways. By 2030, the new policy is intended to pursue a production that allows to put on the European market safe, high-quality, durable, recycled, and recyclable textiles.

The key measures to achieve such goals basically concern the application of a new product framework and the implementation of regulations to provide incentives and support to the industry. As stated in the document, the EU has planned to (i) launch mandatory eco-design requirements, (ii) stop destroying the textiles not sold or returned, (iii) tackle the pollution caused by microplastics, (iv) introduce information requirements and a digital passport for products, (v) ensure green claims for the textiles that are truthfully sustainable, and (vi) institute extended producer responsibility and boost reuse and recycling of textile waste. Moreover, to accomplish that, the European Commission declares that enabling conditions must be created through (i) launching a transition pathway; (ii) implementing measures to reverse the overproduction and overconsumption; (iii) guarantee fair competition and accordance to guidelines for a well-operating internal market; (iv) promote innovation, research, and investments; and (v) spread the skills required by the green and digital transitions. The main limitation of this document is that it is configured more as a vision than a strategy. Whereas the principles, values, and aspirations that will guide the actions of the EU are illustrated, no measures aimed at setting up and coordinating these actions are mentioned. In addition, the EU strategy for textile guidance is focused on the implementation of circular business models applied to production, consumption, and waste management, completely ignoring all those aspects related to measuring and evaluating the sustainability of products, processes, and supply chains through the application of recognised assessment tools like the Material Flow Analysis (MFA) and the LCA. The only references to the development of science-based assessment tools for eco-design can be found in the regulation proposal of 30th March 2022 which establish a framework for the eco-design requisites (European Commission, 2022b) and in the Green Claim Initiative which will require companies to make claims reliable, comparable, and verifiable by using standard methods for quantifying their footprint (European Union, 1995–2023d).

3 Circular Economy and Sustainability

Circular business models could mitigate the environmental impacts. Contrary to the linear economic model, linked to the paradigm 'take-make-use-dispose', the circular one decouples revenues from virgin resource use, because materials keep flowing in a closed system economy, also preventing pollution and waste generation (Ellen MacArthur Foundation, 2021). The conventional circular economy concept, also referred to the 3R framework, which stands for 'reduce', 'reuse', and 'recycle', has gained growing attention. So that, more 'R' concepts have been introduced (Ang et al., 2021), giving shape to a hierarchy of strategies regarding smarter product use and manufacturing, extended lifespan, and functional use of materials, as follow: 'refuse', 'rethink', 'reduce', 'reuse', 'repair', 'refurbish', 'remanufacture', 'repurpose', 'recycle', and 'recover' (Kirchherr et al., 2017).

Looking at the textile industry, they result in four business models that should guide the transition of this sector towards more sustainable pathways: repair, remaking, rental, and resale (Ellen MacArthur Foundation, 2021). *Repair* allows bringing back to a good condition broken items instead of buying new also by brand programs; *remaking* at different levels can transform products or single components to adapt for the same use or for a different purpose; *rental* is intended both by private owners and platforms or brands; and *resale* mainly refers to selling and purchase of second-hand products in stores, marketplaces or through take-back programs (Ellen MacArthur Foundation, 2021). Apart from the potential of these circular strategies, it must be highlighted that there is no unequivocal relationship between circular design and reduction of environmental burdens. A product inspired by the circular economy principles should impact less to the environment compared to its conventional competitor; however, more users per product or recovering secondary raw materials may not generate benefits for the environment. There are critical issues related to handling and transformation of materials, as well as to the functionality and durability of the redesigned products and the effectiveness of new consumption models. For example, textile recycling and remanufacturing can prove challenging for items made with mixed fibres, which are difficult to classify and separate, as well as for those made from cotton fibres, which cannot be used without adding virgin cotton for new textile production and may result in products of lower quality and durability (Jia et al., 2020; Johnson et al., 2020). Likewise, collaborative consumption (i.e. rental, lease) can have rebound effects resulting in an extra consumption of clothes, which also implies additional transportation and care practices (Iran & Schrader, 2017).

It results that the circular economy strategies will never be effective if the enabling conditions are not created, such as designing high-quality products made to be repaired, disassembled, and recycled, creating supply networks to circulate the materials, and rethinking consumer experience (Ellen MacArthur Foundation, 2021). To then be sure that the strategies implemented are successful, it is essential to use measurement and assessment tools (i.e. MFA, LCA) that allow the identification of a net benefit for the environment. These tools are important not only at the micro-level and meso-level to support product redesign but also at the macro-level when considering the need to track and trace the products and materials circulating in a broader system with the aim to foster the sustainability of processes. First, detailed information about the amount of material entering, being stored, and leaving a system during a defined period of time and within a defined space is the basis to assess or improve the circularity through recycling and reuse practices (Corona et al., 2019), considering the quantity and losses related to renewable, virgin, and recycled materials (Elia et al., 2017). Secondly, to prioritise sustainable solutions based on evidence, evaluations from a life cycle perspective are needed, since implementing CE practices doesn't necessarily generate a benefit for the environment. Indeed, according to Sandin and Peters (2018), reuse and recycling are preferable to landfilling or incineration, but the benefits can be deleted if replacement rates are low. In this context, the quantity of materials stored in the system is an essential parameter to consider, as to determine the long-lasting of textiles.

4 Measuring and Monitoring Sustainability

4.1 Material Flow Analysis (MFA) and Life Cycle Assessment (LCA) Methodologies

Under the empirical perspective, amongst the challenges to address climate change, minimise waste generation, and extend the life cycle of products is data collection and analysis. Monitoring the levels of waste and emission generation within a system through the application of different tools is essential. Latest technical specifications, such as the UNI/TS 11820:2022 (UNI, 2022; Amicarelli & Bux, 2023), refer to inventory methodologies (i.e. MFA) and environmental impact assessment methodologies (i.e. LCA), highlighting their essential role in helping to lower the amount of waste and emissions and to adopt sustainable valorisation pathways amongst consumers.

In the field of the inventory methodologies, as outlined by Brunner and Rechberger (2017), the MFA represents a 'systematic assessment of the state and change of material flow and stock in space and time' and is currently considered as an essential tool, both in resource and waste management. The MFA is based on the principle of conservation of mass, and its goals are related to (i) the analysis of the conditional features of a metabolic system in space and time through the selection of the pertinent processes, the main material flows, and the indicative stocks; (ii) the analysis of the quantitative features of flows, processes, and stocks within a system; (iii) the analysis of the metabolic system over time, exploring past trends and predicting future opportunities related to resource consumption and waste generation.

As regards the environmental impact assessment methodologies, the LCA is one of the most used tools to assess the environmental impacts associated with products and processes. Different from the MFA, which has never been standardised but it is considered as an essential basis for conducting circularity or sustainability assessments (e.g. ISO 14051:2011, UNI/TS 11820: 2022), the LCA has been introduced as a standardised method by the ISO 14040:2006. Specifically, the ISO 14040:2004 defines the principles and the framework for conducting the life cycle assessment, including the description of the goal and scope, the life cycle inventory (LCI), the life cycle impact assessment (LCIA), and the interpretation of results. According to its definition, which states that the LCA 'is a compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle', such a method represents an appropriate tool to look into the environmental hotspots, as well as the environmental opportunities, at scientific and corporate level (Sala et al., 2016). In practice, there are limitations to the use of this tool, especially related to modeling choices; however, it has a strong potential towards circular and sustainable design, even in the face of the development of a pragmatic framework called Life Cycle Sustainability Assessment (LCSA) that allows to investigate all the three pillars of sustainability, incorporating also life cycle costing (LCC), and social life cycle assessment (S-LCA) (Valdivia et al., 2021).

4.2 Macro-Level Flow Estimation

As already stated, to enhance material and product circularisation, it is essential to have prior knowledge about the quantity, quality, and timing of materials and products within a given system (Franco, 2017). In this context, Information and Communication Technologies (ICT) can be useful (i.e. common identifiers combined with sensors and supported by Internet of Things) (Jia et al., 2020) at both micro-level and macro-level for product redesign and to evaluate the environmental sustainability from a system perspective. Indeed, to raise awareness on the environmental effects of consumption models and develop improvement strategies, environmental assessments should analyse the impacts of products and processes from a system perspective and not through isolated evaluations (Onat et al., 2017). However, in the literature, there is a paucity of studies regarding macro-level measurements to support policymakers' decisions (Guarnieri et al., 2023), and to date, no scheme is aimed at this purpose (Jia et al., 2020). Also, the latest technical standard UNI/TS 11820:2022 on 'Measurement of Circularity—Methods and Indicators for Measuring Circular Processes in Organizations' introduces a set of 71 indicators to be calculated both at micro- and meso-level, without providing an original and novel support for the macro-level, which still represents a challenge (Amicarelli & Bux, 2023).

In an attempt to evaluate the natural resource consumption, the waste generation and the environmental impacts at the macro-level, national statistics on production and trade can be used, as already reported in several studies on the accounting of textile flows by the European Commission Joint Research Centre (JRC) (Beton et al., 2014; Köhler et al., 2021). The community scheme ProdCom details national production and trade data information on an annual basis at EU level, considering both commodities and services. These statistics are compiled through a community survey based on ProdCom list, which reports product codes and descriptions. The products in the ProdCom list refer to an 8-digit code, where the first four digits designate the statistical classification of economic activities in the European community (NACE classification), whilst digits 5 and 6 are taken from the statistical classification of products by activity (CPA classification). Most codes refer to the combined nomenclature (CN) which connects the harmonised system (HS) at the international level, allowing a full comparability with data from foreign trade. Enterprises of the member states have to transmit true and complete information to Eurostat under the European Business Statistics (EBS) regulation, though some data can be confidential and therefore are processed according to the Statistical Law (European Union, 2022). This means that they shall be used for calculating the EU totals only, with EU aggregates rounded. In addition, some data might be missing or have low reliability. Data is freely accessible online through Eurostat's website, within the database 'statistics on the production of manufactured goods (prom)'.[1] Specifically, a drop-down menu allows access to ProdCom data sets, which provide data on total production, sold production, exports, and imports, and Comext data sets, which combine access to international trade and ProdCom data. The national production data comprises the total production and the sold production, the former referred to both the production sold, and the production reused as input to other manufacturing processes. From this data are excluded the productions done outside the national territory from enterprises with plants abroad. As regards trade data, only that relating to sold production is included in ProdCom data sets, whereas detailed statistics are available in Comext (European Union, 2022).

[1] http://ec.europa.eu/eurostat/web/prodcom/data/database

One of the main limits related to the ProdCom and the Comext data sets is that production data may not be aligned with trade data; thus, this heterogeneity can make data integration difficult for flow estimation purposes. In addition, aggregation codes utilised to record production and trade data do not allow to characterise the flows within multi-material products. For a more complete analysis, waste statistics data referring to waste generation, waste treatment, recovery, and disposal facilities collected under the Waste Statistics Regulation (European Union, 1995–2023e) could be integrated; however, in practice, only aggregate data relating to NACE classification codes on the manufacture of textiles, wearing apparel, leather, and related products is available.

5 Conclusions

The present chapter discussed the main challenges to improve sustainability and circularity in the textile sector in Europe highlighting the importance of measuring macro-level material flows to assess the sustainability of consumption models and raise awareness on consumers' purchasing choices. The growing trade flows of low-quality textiles and clothes cause alarming rates of resource consumption, emissions, and waste production, which need to be addressed urgently. The implementation of circular business models is considered a solution and therefore incentivised. However, there is no unequivocal relationship between circular design and reduction of environmental impact. The EU strategy for sustainable and circular textiles incentivises a production that allows to put on the European market products inspired by the circular economy principles but does not provide science-based assessment schemes to measuring and evaluating the sustainability of textile production and consumption at macro-level. Indeed, the use of measuring tools and standardised methodologies at macro-level is an essential requirement to foster the sustainability of products and processes. It is crucial to have detailed information about the amount of material flowing within a defined space and during a defined period to assess the related environmental effect and prioritise sustainable solutions based on evidence. MFA and LCA are suitable tools to address this need, but data collection of textile flows at macro-level is hindered by the lack of useful schemes and tools aimed at this purpose, leading to the use of methodological expedients that have many limits. National statistics on production and trade can be used to evaluate resource consumption, waste generation, and the related environmental impacts at macro-level by means of the community scheme ProdCom and Eurostat data sets. However, the aggregated and heterogeneous data available make the estimation of flows unreliable and thus not very effective for the purpose of estimating the environmental impacts of consumption models. Therefore, consumer choices can only be based on micro-level estimates, which can be misleading since they do not reflect the impacts along the entire life cycle of the product but stop at the production stage.

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