

Transition toward Green Economy: Technological Innovation's Role in the Fashion Industry

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Abstract

The consumption of unsustainable fashion and wasteful practices have recently attracted significant attention in practice and academia. The global fashion industry is expected to grow from \$1.5 trillion in 2020 to approximately \$2.25 trillion by 2025, indicating a continuous growth in demand. New technological developments are used to transition to a green economy and to promote an environmentally conscious fashion movement. Technology may seem counterintuitive, but becoming more sustainable is crucial for fashion, which is often an accelerant of waste. Sustainable fashion technologies significantly impact waste reduction through materials, products, and consumer experiences. Material changes made by environmentally conscious businesses improve longevity and reduce resource consumption. Fashion startup managers can use the proposed model to gain a deeper understanding of how technological innovations help achieve a successfully sustainable fashion, while simultaneously improving sustainability practices.

Keywords: Green economy; Sustainable development; Technological innovation; Fashion Industry; Fashion Technologies; Sustainable Fashion

1. Introduction

The fashion industry is an integral part of our economy, with a value of over \$ 1.5 trillion and employing over 75 million people. During the last decade, clothing production has doubled, as the sector has grown exponentially. In 2022, 25% more clothes were bought than in 2019; however, 98% of the clothes were used for half as long [1].

Fashion production contributes to 10% of the human carbon dioxide (CO₂) emissions, pollutes rivers and streams, and dries up water sources. As the fashion sector thrives, a growing number of environmental impacts are coming to light [2]. The UN reported that 85% of textiles end up in dumps each year [3], and washing certain types of clothes discharges significant amounts of microplastics into the ocean. Similarly, washing clothes releases 50 billion plastic bottles worth of

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microfibers into the ocean every year. Approximately 60% of garments are made of polyester, which is a plastic material. Additionally, polyester does not decompose in the ocean despite releasing almost three times more CO₂ than cotton [4]. In an attempt to keep up with fast fashion, clothes are worn only a few times before being thrown away, causing unnecessary environmental and social damage. According to the Soil Association (SA), non-organic cotton uses chemicals with acute toxicity, such as heavy metals, formaldehyde, and aromatic solvents, and 30 percent of cotton worldwide is genetically modified [5]. Manufacturers often pay low wages and workers work under hazardous conditions to keep the cost of garments low; this are a major contributor to environmental pollution. However, the trend is changing with the adoption of upcycling, downcycling, or reusing of textile fiber, as textiles have the potential to be 100 percent recyclable [6]. There is tremendous opportunity for innovation within the fashion industry at every stage, to contribute to the development of a green economy.

Since clothing requires large amounts of energy and water, the textile and apparel industry contributes highly to pollution. The fashion industry consumes approximately 79 billion cubic meters of water every year, making it the second most water-intensive industry worldwide [7]. Meanwhile, an average meter of cloth consumes 4,500-5,500 kcal of thermal energy and 0.45-0.55 kilowatt hours of electrical energy [8]. There has been increasingly blurred lines between the fashion ("high fashion") and clothing ("mass fashion") industries. However, fashion is generally defined as the style of clothing and accessories worn by people during particular periods [9]. The fashion industry's product lifecycles are short, product varieties are diverse, demand is unpredictable and volatile, and supply chains are long and rigid. Due to their complexity and interdependency, fashion supply chains require a change from the "take, make, waste" principle to a more sustainable approach. Gupta et al. [10] and Peters et al. [11] noted that the fashion industry

could reduce its carbon footprint by eliminating fossil fuel power supplies and fast-fashion business models. Therefore, fast fashion brands must develop initiatives to reduce the gap between fast fashion and sustainability. Fast fashion refers to inexpensive clothes that are quickly available to consumers who follow the latest fashion trends, often with little to no consideration for environmental and social impacts [12]. To make fast fashion more sustainable, fashion brands should be transparent about their supply chains, show their commitment toward sustainability, ensure that their packaging process is eco-friendly, engage in recycling programs, reduce the frequency of introducing new product lines, use offcuts of fabric and materials, and purchase raw materials from suppliers who support sustainability. These initiatives include reusing materials, reducing CO₂ emissions, or conserving water. Moreover, circularity must be demonstrated throughout the product life cycle of bio-based products to improve their sustainable performance [13],[14]. Therefore, green and circular bioeconomies can contribute significantly to the achievement of the sustainable development goals (SDGs) by improving the sustainability of the fashion industry [15]. Circular fashion can only be achieved with a clear vision of new strategies that are driven by motivation and smart technological application, as well as promoting circularity through education and knowledge exchange [16]. This study develops a sustainable fashion model for the fashion industry and contributes new theoretical perspectives on technological innovation and the green economy, which have been underexplored in literature. Moreover, this study develops a link between the green model, product design, and enabling conditions for transitioning to a green economy. This study suggests that to transition to a more eco-friendly fashion sector, the industry must focus on technical eco-design and collaborate with companies and governments across societies, as evidenced by the way consumer behavior and education have been integrated into value propositions and technical solutions. Finally, this study provides insight into how

different international management standard schemes can be used to improve sustainability performance in the fashion industry.

2. Sustainable Fashion and Green Economy

A green economy reduces environmental risk and ecological scarcity, while improving human well-being and social equity [17]. Sustainable and ethical fashion is crucial toward achieving a green economy. The aim of sustainable fashion is to make clothes more environmentally friendly through changes in design, production, distribution, and disposal [18]. By engaging in green activities that reduce, reuse, recycle, recover, and remanufacture resources, green and circular economies attempt to reduce resource inputs, waste, and emissions [19] [20], [21]. Digital innovations are expected to play a critical role in enabling and triggering green business models. This implies that technological innovation accommodates green business models and necessitates changes to business models, simultaneously, such that technology can be used [22].

Several studies have highlighted the importance of circular and green economies in the fashion industry. In the absence of scalable circular fashion research, the fashion industry has been unable to make significant progress toward the adoption of a truly circular economy [23]. To demonstrate the positive relationship between circular economy and sustainability, we must focus on the product life cycle. Developing a circular economy from a micro perspective has been one of the pioneering outcome in the second-hand fashion industry[24]. There is a need to separate from the principles of "fast fashion" production, which is not always a cheap process. Speed is required because tastes and trends are constantly changing; therefore, consumers are prone to treating such issues [25]. Additionally, the industry is responsible for its social responsibilities, as well as for caring for animals. The latter case concerns child labor and a lack of working conditions in developing countries [26].

In the last 15 years, global apparel production has doubled, resulting in greater CO₂ emissions from the textile industry than from both shipping and international travel. Eighty-five percent of the raw materials used in clothing production are cotton and polyester, both of which are not environmentally friendly [27]. The Global Fashion Agenda (GFA) 2020 involved 94 companies, representing 12.5% of the global fashion market [28]. Each company had a number of goals, including increasing water efficiency, developing sustainable fibers, and creating better systems. Different brands developed their own programs as well. One such initiative is Adidas' promise to use only recycled plastic by 2024 [29]. The H&M company aims to be 100% recyclable and environmentally friendly by 2030 [30]. Ralph Lauren and Tommy Hilfiger's parent company, PVH, plans to use raw materials from sustainable sources by 2025 and 2030 for cotton and viscose, respectively [31]. Moreover, in its G7 presidency, France (home to several popular fashion brands) led the charge in transforming the fashion industry into a more environmentally friendly model.

Although consumers generally claim to care about the environment, their sustainable consumption behavior has not reflected this view. Researchers have shown that humans consume products and services faster than nature can regenerate, process, or recycle them; however, most people still view the economy as primarily related to the production of physical products [32]. Consumer sustainability is related to increased environmental knowledge and risk perception, both of which are linked to increased environmental concern. However, in recent years, researchers have found a shift toward sustainable consumption. Consumers are more likely to consider buying second-hand clothing, reducing clothing purchases, and recycling clothing now than they did in the past [33] [34].

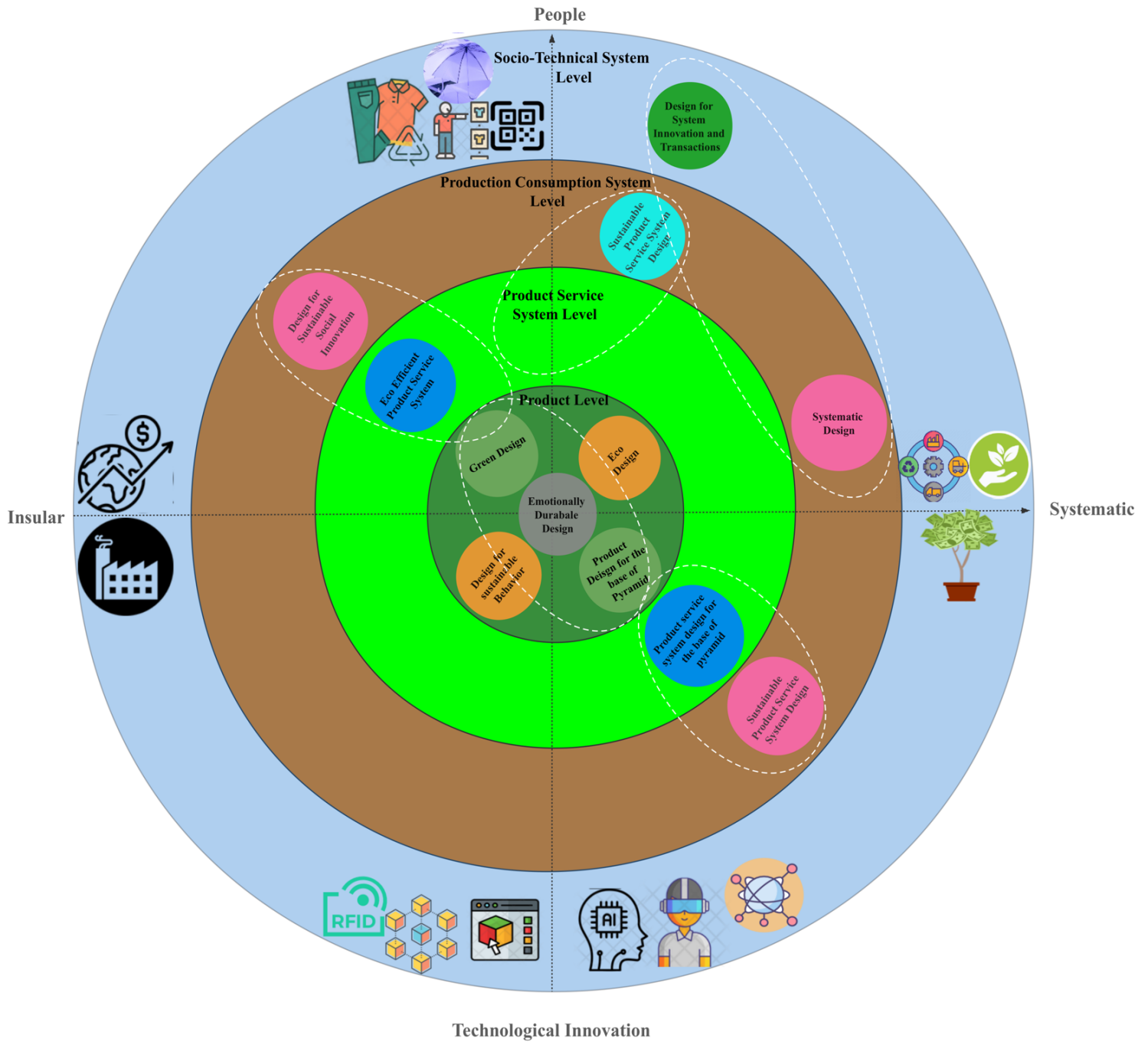
Prior studies, such as Paco et al. [35] and Cruz-Cardenas & Avrevalo-Chavez [36], investigated the significant relationship between the disposal of clothing behavior, and factors contributing to

development. Practitioners and policymakers acknowledged that the expectations were separate from reality when it came to wearing and disposing of fashion products.

Consequently, understanding the motivations behind good fashion consumption and monitor the social and environmental consequences of fast fashion waste disposal is becoming increasingly important [37]. Thus, consumer attitude and manner of clothing disposal must be addressed to achieve sustainable fashion. Sustainability in fashion encompasses the production of textiles, apparel manufacturing, distribution, post-purchase and disposal of clothing. Responsible consumption and post-consumer behavior play a significant role in the transition to sustainable consumption in the fashion industry supply chain [38]. Sustainability initiatives can foster positive associations with fashion brands related to responsibility, environmental stewardship, and social responsibility. Companies can gain a competitive edge by incorporating sustainability into their brands to attract more customers [39]. To reduce landfill waste over the long term, it is crucial to understand the most effective clothes disposal options. Sustainable fashion consumption occurs in three stages: production, purchase, and post purchase. Green economy and sustainability are moving toward a sustainable economy with proposals, initiatives, commitments, and innovations in which resources are used in an ecologically efficient and sustainable manner [37].

Consumers are required to engage in post-purchase sustainable fashion in the disposal stage, which includes reusing, reconditioning, and reselling clothes that they no longer need [41]. Cho et al. [42] reported that style-conscious purchases, sustainable disposal, and environmental concerns are interrelated. Consumers who are environmentally conscious, recycle or dispose of their clothes so as not to negatively impact the environment. Inefficient clothing disposal causes significant adverse environmental damage, which is why sustainably minded consumers recycle or redesign their unwanted clothes [9]. Additionally, consumers may donate clothes to charitable firms, pass

them on to needy people, resell them to used clothing online stores, or discard them. A sustainable fashion industry design relies on the latest technological innovations and a green economy. The fashion industry requires technological innovations, such as artificial intelligence (AI), virtual reality (VR), 3D printing, novel fabrics and material innovation, fashion applications and mobile commerce, blockchain, Internet of Things (IoT), virtual influencers, and bio-packaging to improve consumer experience and remain competitive. In the future, these technological developments may positively impact fashion, making it a more environmentally friendly industry.[43] Clearly, this latest development requires numerous more disciplines than engineering design. It requires an expansion from the technical and product-centric focus on large-scale system-level changes (considering both production and consumption systems) [44]. Unlike other studies, this study stressed that lower innovation levels are less important than systemic ones when discussing sustainable product design in a green economy. Future green and sustainable systems can be imagined only through innovation at the product and business model levels and through social practices and system transitions. A visualized explanation of technological innovation and the green economy in the fashion industry is summarized in Figure 1.



▼ **Figure 1.** Green economy, technological innovation in fashion industry

3. Linkages between Green model, Product Design and Enabling Conditions

In today's fast-moving fashion world, the pace of change continually increases [45]. By reducing resource consumption and extending the life of textiles, their environmental impacts can

be reduced to the greatest extent. A green product design strategy should encourage the long-term wear and value retention of clothing. The recycling and reuse of materials is an essential part of closing the loop, but strategies that extend the life of products, such as design for durability, ease of use, repair, and refurbishment, should be prioritized ("slowing down the loop") [46]. Green product design strategies and tools applicable to textile products, such as those related to toxic emissions, microplastic release, and prevention of hazardous chemicals in textile products, are being developed [47]. To ensure that these principles lead to a reduction in environmental impacts, innovation at different levels is required, as shown in Figure 2.

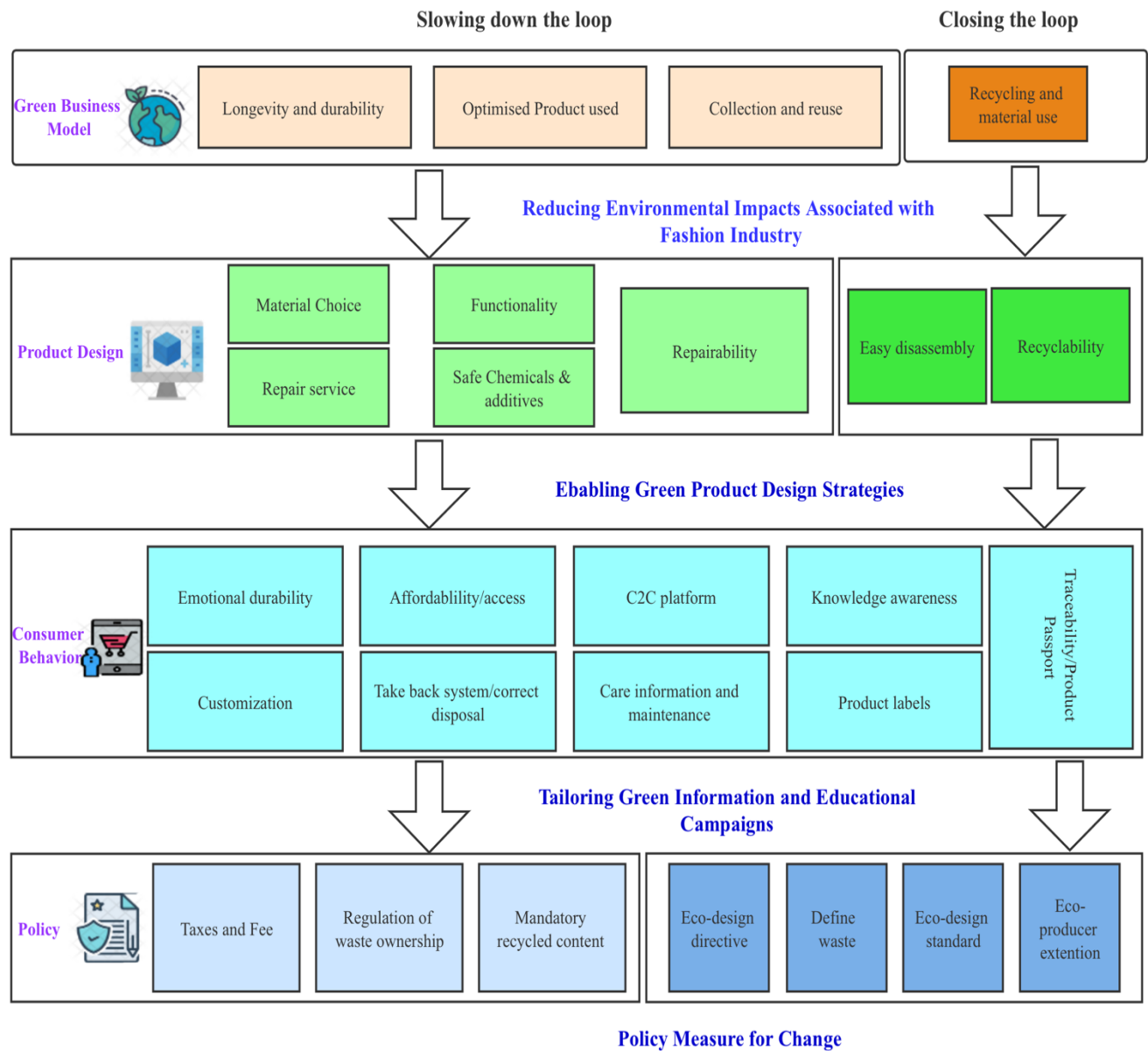


Figure 2: Linkages between Green model, Product Design and Enabling Conditions

To transition toward a green economy, the textile sector must focus on the technical and product-centric side of eco-design. Further, developing collaborative strategies across societies—including governments, businesses, and citizens—and suggesting technical and policy solutions is extremely vital. Businesses, organizations, and individuals can make significant changes toward a

green economy when they are facilitated, guided, and empowered by these essential collaborations and strategic programs in the fashion industry.

Businesses, governments, and consumers can gain a better grasp of the scale and scope of green economy enablers, as well as the issues surrounding their implementation and the wider effects of the transition toward circularity [48]. By acknowledging what goes into the manufacturing of products and services, we could be more conscientious of the importance of a green economy and sustainably designed textile products [49]. The design of green textile products and educational campaigns must go hand in hand. The applied green model behind specific textiles is often unknown to consumers, or not fully understood by them. Discovering the appropriate mix of enabling factors that will result in mainstream environmental design for textiles is challenging.

There are a number of sustainability standards and certification schemes within the fashion industry, such as Oeko-Tex standard 100, USDA organic, Cradle to Cradle, PETA-Approved Vegan, Ecolabel, Fair Trade, GCC Brandmark Bluesign, Consumer Product Safety Improvement Act, Global Organic Textiles Standard (GOTS), Better Cotton Initiative (BCI), Cotton Made in Africa (CMiA), Global Recycle Standard, ISO 14001, SA8000, ISO 9001, Responsible Wool Standard (RWS), Oeko-Tex 100, and Cradle to Cradle, which provide guidance and guidelines for brands to determine how to improve and communicate their sustainability efforts. Sustainability labels and certification schemes provide a roadmap and ensure sustainable consumption by suppliers and manufacturers [50]. Several international certifications and labels have already paved the way for optimized resource use as well as more transparent and improved communication about the environmental and social impacts of textile product. This includes the EU Ecolabel for textile products, the Blue Angel for Textiles, the Global Recycled Standard, the UPMADE, and the Organic Content Standard (OCS). OCS guarantees the traceability of

organically grown materials and prohibits the use of health-damaging chemicals, and regulates the consumption of water and energy. Additionally, the Better Cotton Initiative (BCI) and Nordic Swan pay attention to the health and environmental impact of the materials in their products, while implementing sustainability guidelines [51]. Standards and certification programs validate brands' responsibility to sustainability and provide guidance and credentialing. Figure 3 presents the most adaptable certification schemes for ensuring sustainability in the fashion industry.

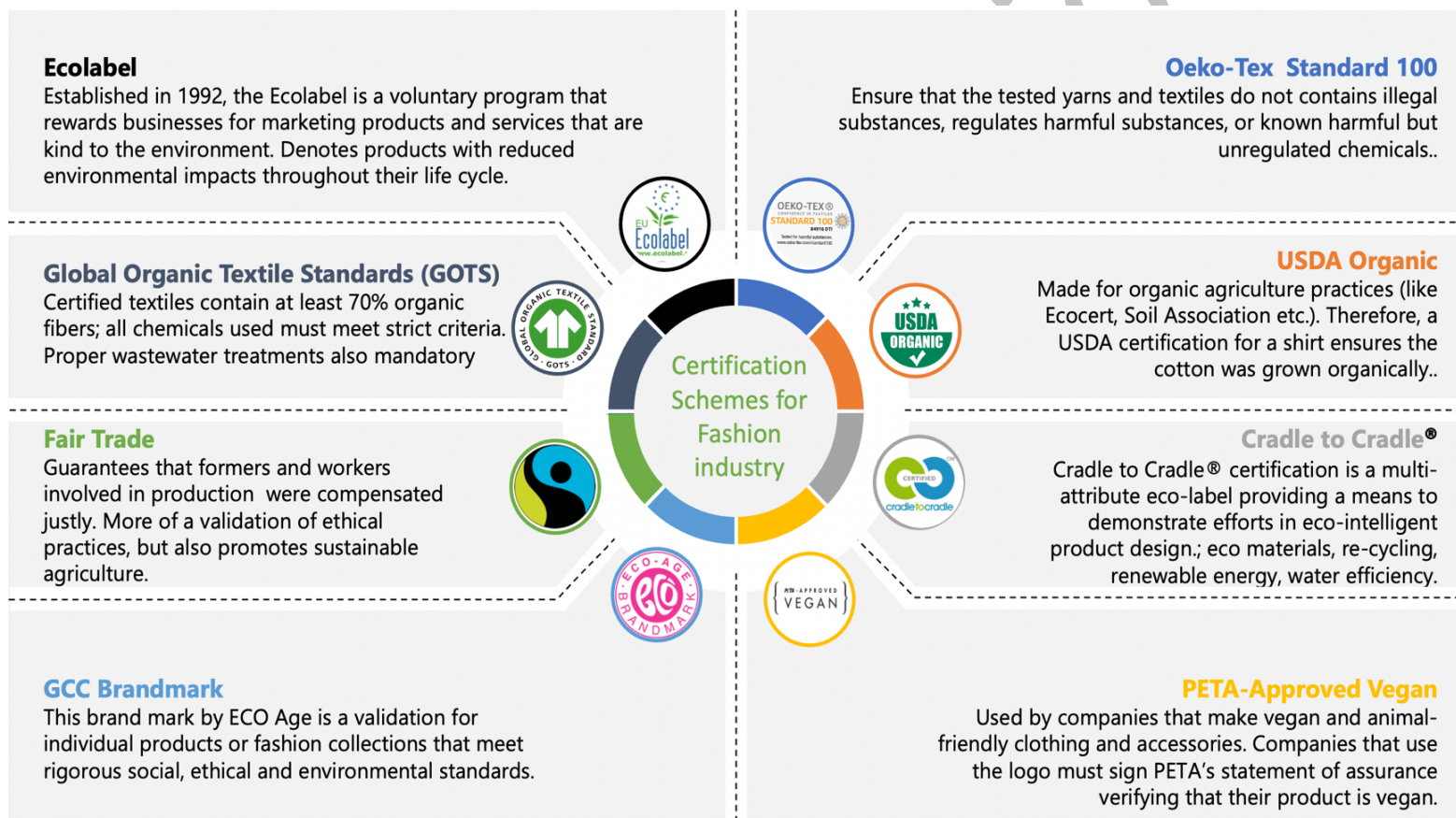


Figure 3: Certification schemes used in fashion industry

4. Role of Technological Innovation in Sustainable Fashion

Technological innovation in the fashion industry is important for creating a better experience for consumers and for ensuring a progressively sustainable future through green

economy [52]. After oil, the fashion industry has become the second-most polluting industry in the world; thus, it is not sustainable [53]. The ability of fashion technologies to improve sustainability performance is directly related to innovation, as these technologies help create more sustainable clothing items or develop more sustainable manufacturing processes. Innovation and sustainability help fashion brands gain customers' confidence and profit while lessening their negative effects on society and the environment [54]. Technological advancements have played a key role in advancing sustainability in the fashion industry.

The fashion industry has undergone several technological advancements, which are expected to improve fashion production and consumption over the next few years. Currently, artificial intelligence (AI) plays a major role across all industries, including fashion. A variety of fashion brands use AI to simulate human intelligence in various ways. AI fashion applications include improving customer experiences, analyzing and predicting future styles, understanding selling trends, and understanding the aesthetics in fashion. Retail stores use AI chat technology to offer personalized product advice to customers using touch screens. In addition to learning color preferences, synthetic intelligence can aid in learning textures and styles [55].

Virtual reality (VR), also known as augmented reality (AR), is gaining attention in the fashion industry. VR enables virtual environments to be fully simulated, whereas AR integrates interactive and simulated elements into the real environment. VR and AR have the potential to radically change the retail industry because they allow physical and digital elements to be combined. Customers can try clothes virtually using VR technology; it can even recreate an entire fashion store in VR [56].

Technological innovation and sustainability can be leveraged by brands using 3D printing, which continues to rise in the fashion space. 3D printing is a manufacturing process that converts

digital designs into real products using 3D printing technology. 3D printing helps to significantly reduce textile waste compared to traditional design technologies, as well as reduces air pollutant emissions, water contamination, and water usage [57]. Moreover, 3D printing opens a vast array of creative possibilities for designers. Although it has some limitations in terms of fabric, structure, and design, fashion designers can create more innovative and exciting designs using 3D printing technology.

Moreover, material selection is an important factor in the fashion and clothing industry for sustainable fashion. About 72% of garments in today's fast fashion industry are made from synthetic and non-biodegradable fibers, which is concerning. It may be possible to solve this problem using novel fabrics [58].

Designers enjoy the creative freedom offered by novel fabrics and gain a lot from the creation of sustainable materials. These possibilities are endless, regardless of whether they are lab-grown leather or seaweed fibers that can be knitted together. Apple pectin, a waste product of apples, is used to create vegan leather [59]. Such products have a wide range of implications. The fashion industry can decrease material waste by creating sustainable fabrics made from nonbiodegradable fibers and plastics. In addition to saving animals' lives, eco-friendly leather, fur, and silk will make the world more sustainable. The fashion industry has taken advantage of the use of smartphones and tablets, and have created all kinds of apps and mobile technology [60]. Thus, fashion brands can connect with consumers much more easily, with the help of apps. Fashion marketplaces, such as Depop and Vinted are examples of new kinds of applications that encourage sustainability, whereas some rating apps, such as By Rotation and On Loan, are new fashion applications that could encourage sustainability. Several apps, such as Good on You, rate companies according to how they treat people, the environment, and animals [61]. Therefore,

consumers can make more informed decisions using technology that promotes transparency in the fashion industry.

Blockchain technology plays a vital role in making businesses faster and more sustainable. In a blockchain, transactions and assets are recorded permanently. How can fashion industry professionals make use of the blockchain? It is an excellent tool for enhancing transparency in the logistics and safe transfer of data and documents between all parties. Fashion products can also be tracked using a unique digital ID provided by blockchain [62].

Internet of Things (IoT) refers to all products that have the ability to connect to the Internet by integrating technology. IoT technology can be applied to fashion products as well, and it can help companies meet modern-day consumer needs. Workout clothes that measure your heart rate, the weight of a baby, and recognize your sleeping pattern all provide data that can be automated using IoT technology [63]. Furthermore, IoT products do not just track health; they can also make design recommendations based on consumer demand.

The fashion industry can benefit from social media by attracting the attention of the younger generation, establishing a brand image, and promoting products. In addition to offering interactions between brands and consumers, social media platforms offer consumers the opportunity to gain insight into specific trends [64]. In response to consumers' increasing concern about the environment and social issues, numerous fashion brands actively communicate information about their environmentally and socially sustainable and fair-trade products, including Patagonia, Everlane, Reformation, Stella McCartney, Veja, Tretorn, and Allbirds [65]. The influence of social media has dramatically increased in recent years. Today, thousands of influencers partner with fashion brands to promote companies' products to their followers, which is a very effective marketing tactic. A virtual persona is created exclusively to sell clothing or other

products on social media channels. Brands do not need to worry about negative influencer behavior or lack of cooperation since virtual influencers do not have any such concerns [63]. Pictures can be "taken" and styled however they like, and brands do not have to worry about censorship or strict rules.

In the UK, one-fifth of total fashion sales are made through online shopping [60]. The packaging issue deserves serious consideration. Bio-packaging is a potential solution to the packaging of online shopping. Plastic packaging can often be discarded after just one use, which is one of the biggest environmental problems. The primary feature of bio-packaging is that it is biodegradable and made from renewable resources [66] [67]. A few companies have made use of bio-packaging. Maggie Marilyn uses ComPlast bags made of cassava, a compostable material.

5. Conclusion

There is no doubt that several sustainable technological innovations in the fashion industry will influence the future. We may be able to make fashion more eco-friendly, ethical, and sustainable. Through our own actions and consumption patterns, we play a role in making fashion brands ethical and sustainable, not just through technology. The government should encourage ethical and sustainable practice among fashion brands. Further, introducing fashion and the arts to children from all backgrounds is important. Increasing accessibility to fashion will encourage innovation and the transition toward a green economy.

Furthermore, achieving a green economy is proving to be theoretically profitable, economically feasible, socially desirable, and environmentally friendly. Therefore, this study proposes a sustainable fashion model for the fashion industry based on product, product service system, production consumption system, and socio-technical system levels. It contributes new theoretical perspectives on technological innovation and green economy. To transition to a green

economy, the fashion industry must focus on more than the eco-design, as evidenced by how consumer behavior and education integrated into value propositions and sustainable solutions. Therefore, this study is able to support to green economy transition through technology-driven innovation in the fashion industry. Moreover, decision-makers at all levels must take on this challenge and adapt to the complex dynamics of the closed-loop value chain to influence its structure and performance toward a green economy.

This study had some limitations. This study did not provide a green technology assessment in terms of the sustainability of a green model, as its complete implementation has yet to be fully established. Consequently, future studies could propose a more comprehensive green economy model for the fashion industry that understands how to optimize the closed-loop value creation process, put actions in place, and plan a schedule for implementing sustainable fashion. Conducting studies that compare the development stages of green economy in the fashion industry in developed and emerging markets is a possibility.

Conflict of interest statement

Nothing declared.

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Papers of particular interest, published within the period of review, have been highlighted as:

* of special interest

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***By using first application of Eora, a multiregional environmentally extended input output model, to assess the impacts of clothing and footwear value chains. As a result of the analysis, clothing and footwear consumption has increased its climate impact from 1.0 to 1.3 million tons carbon dioxide equivalent over the past 15 years. Social and environmental impacts per mass of garments have decreased in recent years; however, it would be feasible to significantly reduce the absolute carbon footprint of the fashion industry by eliminating fossil-fueled electricity supplies and by eliminating fast fashion as a business model.*

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