Sustainable Approaches and Sports Apparels

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Abstract Sports clothing is manufactured in large volumes for a shorter life cycle, leading to a huge waste, when disposed to earth. Synthetic fibres are used in sports apparels for better comfort properties and performances. The latest techniques and manufacturing processes are adopted to produce sustainable sports apparels. Digital concepts have been adopted to minimise material wastes, ensuring reduction in the resource exploitation. In this chapter, along with environmental aspects, social and economic aspects of sustainable development through triple bottom line study, effective material selection with digitalisation in the supply chain, and the influences of slow fashion in the waste reduction are also discussed.

Keywords sustainable manufacturing · Life cycle assessment · Triple bottom line · Digitalisation · Sports fashion

1 Introduction

Sports textiles bring better comfort and functions to clothing of sports persons. Sportswear industries not only include garment production, but also fibres, fabrics production including relevant chemical treatments. Manufacturers are challenged with the need of reducing the consumption of water and energy along with environmental impacts of waste disposal and gas emissions. Sustainable developments can be brought-in manufacturing sections through various approaches from raw materials to manufacturing processes, selection of intermediate supply chain management through digital environments and waste management. Consumers are aware of the

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sustainability and their imprints on environmental concerns, and are ready to spend more to ensure sustainable practices. Increasing concerns among consumers on the planet and environmental health emphasis the industries adopting sustainable manufacturing approaches and many brands of sports apparels create the interests among consumers through appropriate labelling, slogans and stories on the products and goods. However, sustainability practices are not being implemented consistently by the manufacturers due to limitation in infrastructure.

2 Sustainable Manufacturing: Strategy/ Framework Development

Sustainable manufacturing depends on infrastructure, workforce, management practices and technology levels. To implement sustainable strategies in an industry, the supply chain capability needs to be analysed through a framework (Fig. 1) to identify the potentials in terms of three levels, namely (i) capabilities—environmental aspects and standards, (ii) industrial practices and (iii) practical implementation of environment standards in the industry. Environmental aspects and standards deal with energy and water consumption, emission of greenhouse gas, wastewater and solid waste disposals, noise levels and nature of chemicals and usage (Haapala et al., 2013). Levels of environmental aspects and standards and the manufacturing

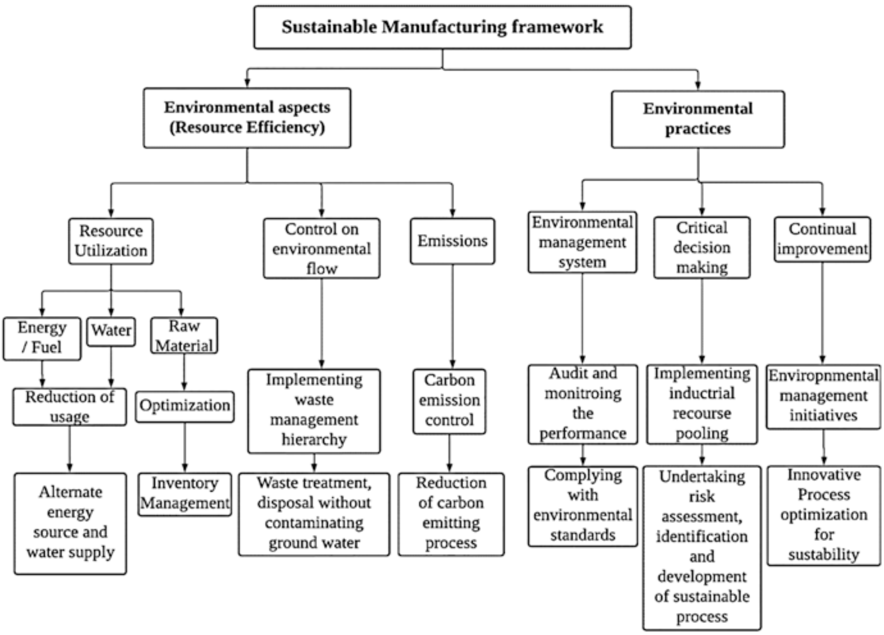

Fig. 1 Sustainable manufacturing framework (Dubey et al., 2015)

Table 1 Steps towards sustainable manufacturing

Area of focus	Expected impact (domain/process)
Resource utilisation and measurement	Energy and water
Hotspot analysis	Emission-intensive processes
Cause analysis	Reasons and resource for emission-intensive performance
Benefit / cost analysis	Social and economic factors to improve sustainable aspects
Targets setting	Selection of internal environmental targets and timelines
Critical decision-making	Establishing a decision-making system for achieving the targets
Auditing and monitoring system	Process to achieve environmentally sustainable process and verify performance with standards

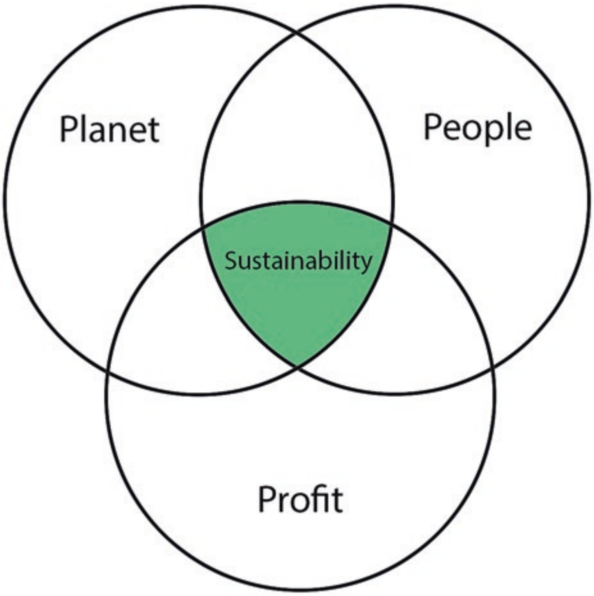

Fig. 2 Triple Bottomline Principle – a schematic representation (Abraham, 2006)

practices motivates the management to initiate sustainable approaches in the manufacturing processes. Achieving the consciousness in following practices lead to the beginning of sustainable manufacturing process (Table 1).

Hotspot and cause analysis involves certain questionnaire practice that includes (i) WHICH—identify emission-intensive processes, (ii) WHY—identify causes of the with reasons, (iii) WHAT—identify benefits and costs for environment concerned, alternates or modifications in the process, (iv) HOW—compare alternates, process modifications and selecting suitable options (Dubey et al., 2015).

Sustainable development can be achieved by imposing strategies for sustainable framework in entire sequence with social, economic and environmental dimensions (Fig. 2) – *Triple Bottomline*. But there are always conflicts among these dimensions and to be compromised when single dimension attains the higher focus, e.g. generating revenue to the industry (profit) (Jensen, 2010).

3 Sustainability Assessment for Enterprises

Sustainability assessment is often considered as an extension of general environmental assessment techniques like EIA (environmental impact assessment) or SEA (strategic environment assessment) or SIA (social impact assessment) (Pope et al., 2004). Assessment of sustainability competency involves collecting reliable evidences using assessment tools on sustainable competencies and it starts with two key questions (i) what to assess (knowledge, skills, attitude) and (ii) how to assess (strategy for assessment and interpretation and tools) (Remington-Doucette et al., 2013).

Approaches followed in the sustainability assessment are classified into (a) indicator / index-oriented approach, (b) product related approach and (c) integrated assessments or (a) monetary, (b) biophysical and (c) indicator-oriented approaches. It is often recommended to have a comprehensive and holistic assessment that may require participation from different domains / disciplines and stakeholders with system approach (Abraham, 2006).

4 Eco-Design

The concept of eco-design covers the *design for sustainability*, *design for environment* and *designs for recycling,* individually to influence the consumers in fashion industry. Eco-design lays emphasis on environmental aspects and plays a significant impact on the entire sustainable supply chain starting from material selection, designing, manufacturing process, and distribution systems (Köhler, 2013). Many fashion brands show interests in the elements of eco-designs for sports apparels with increasing awareness. Recycled, organic and traceable (in their lifecycle) materials are used in the eco-designs for environmental sustainability. The focus of eco-design is not only following aesthetic demands and trends to sustain in the market, but on eliminating harmful processes, resources and methods for sustainable practice. New product design, improvement in existing design and alternate materials for the design are key decision categories for the eco-design process (Pashkevych et al., 2020).

Manufacturers follow cradle to cradle model, applied in the eco-design process where they are encouraged to work with designers for sustainable fashion at every stage of sample production to final product, along the supply chain members especially at fabric selection. Eco-design further classified into functional and aesthetic, based on consumer lifestyle. Both aesthetic and functional performance of sportswear have greater impacts on the decisions in manufacturing process and supply chain in terms of sustainable measures (van der Velden et al., 2015; Cicconi, 2020).

5 Eco-Labels

Eco-labels are defined as the labels containing details of the raw materials used to create the product along with certification logos and slogans received for the product by following sustainable measures. Information available on eco-label guides the consumers on the care system of the product that helps in extending the lifespan of the products. Eco-label includes slogan or statement of stories telling the consumer about their sustainable inspirations on sustainability and how the products are occupying the stores with great concern on triple bottom line theory (Nimon & Beghin, 1999; Žurga & Forte Tavčer, 2014; Vadicherla & Saravanan, 2015; Dreyer et al., 2016).

6 Life Cycle Assessment and Sustainability Certification

Life cycle assessment is one of the major parts in sustainable approach in textile manufacturing. Where the emissions and carbon footprint can be evaluated and the outcomes will be useful to the designers and manufacturers to select appropriate sustainable materials in manufacturing. In eco-design, supply chain members consider the stages that a product undergoes during its life span. Stages of a textile product, post-retail include (i) frequency of washing and (ii) laundering conditions, while the life span of a textile sports clothing depends on (i) durability (wear and tear), (ii) aesthetic (boredom), (iii) garment fit (poor fit), (iv) cost of the product and (v) possibility of repair and recycle. To increase the life span, designers concentrate on functional quality with longevity in aesthetic and fashion trend supported by colour and style (Roy Choudhury, 2014; Muthu, 2015).

7 Sustainable Standards and Certifications

Although there is no compliance-driven mandate to get certification for sustainability, it helps in creating awareness among consumers and encourages the industry in terms of flexibility, and maintaining habitual buying among the consumers (Muthu, 2015; Warasthe et al., 2020). Certifications standards are categorised based on supply chain in which the industry practises the sustainability: (a) sustainable fibres (recycled, organic, and bio based) – Table 2; (b) environmental certifications – Table 3 (chemicals and reagents for cultivation and processing); and (c) complete business model (holistic certifications) – Table 4.

Table 2 Sustainable fibre standards (Senthil Kumar & Suganya, 2017)

Certification	Impact/outcomes
Oeko Tex	Arsenic, lead, phthalates, formaldehyde, pesticides are tested for certification and also the pH level that is acceptable for human skin. Testing products against 350 toxic chemicals present in the product from yarn to the end products
Organic Content Standard – OCS	Material contents and amounts in the final product that are organically grown are tracked and verified
Global Organic Textile Standard	Organic textiles contain minimum of 95% of organically grown fibres (with 5% synthetic fibres) and minimum 70% of fibres from organic agriculture (min. 10% of synthetic fibres and in case of footwear or sportswear min. 25%)
Regenerative Organic Certified	Has three levels gold, silver and bronze and focused on soil health and land management, welfare of the animal and fairness of the farmer and worker
OE 100	Organic Exchange OE-100 is provided to the products which are made with 100% organic fibres
USDA Organic	Requires production of agriculture products through USDA approved method; requires at least 95% of certified organic content or 70% certified organic content for certification 'made with' organic
Global Recycle Standard – GRS	Recycled materials present in the end products is tracked and verified
Woolmark	Woolmark licensing guarantees the fibre content and quality of the wool to consumer and supply chain, products with logo are made with 100% pure new wool

Table 3 Environmental certifications (Muthu et al., 2008; Lo et al., 2012)

Certification	Impact/outcomes
Better Cotton Initiative – BCI	Promotes better standard in cotton cultivation by multi-stakeholder governance group that impacts on environment and improves economic development
B-corp	Provided for the social and environmental performance of the company
Blue Sign	Standards for environmental safety and health. Chemicals are given three categories blue (safe to use), grey (special handling required), black (forbidden). Has five principles such as resource productivity, consumer safety, water emission, air emission and occupational health and safety
Cradle to Cradle – C2C	Based on global standards for safe, circular and responsibly made products—on five categories, material health, product circularity, water & soil protection, clean air & climate protection and social fairness. Five levels of certification of products such as basic, bronze, silver, gold and platinum
Ecocert	Certified in trade and environmental management system. The label 'Natural and Organic Cosmetics' has minimum 95% of formula with plant-based ingredients and minimum 10% of ingredients weight come from organic farming

Table 4 Business certifications (Lo et al., 2012)

Certification	Impact/Outcomes
B – Lab	Helps to translate the sustainable development goals into business processes
Fair Trade International	Multistakeholder group based on product oriented aimed to improve the life of workers and farmers through trade
NSF International	Product testing, inspection and certification
Solidaridad	Aims the development of socially responsible, environment friendly and profitable supply chain
Sustainable Apparel Coalition	Leading alliance for sustainable production to reduce the environmental and social impact on apparels, textile and footwear products.
Ethical Trading Initiative	Works to improve working status of the people who produce raw materials or consumer goods producer

8 Digitalisation

In sports apparel manufacturing and trading, digital methods increase the profit besides contributing sustainability through different ways. Digital scanning by RFID helps in tracking the supply chain and details of footprints and maintains transparency along the supply chain. The technology reaching metaverse world, fashion designing is possible in the digitalised world helping to reduce the resource utilisation for design creation and sample production specifically. Digital design reduces both utilisation of materials and engagement duration of skilled persons. Digitalisation in textile and fashion supply chain offers the following key advantages towards sustainability (Table 5) (Bertola & Teunissen, 2018; Martinez, 2019).

9 Sustainability in Material Selection for Sportswear

In textile and fashion, material selection plays major role as different fibre materials consume different levels of energy and water at different stages of processing.

As a part of sustainable practices, efforts are made to produce garments that are recyclable, reusable or biodegradable to reduce wastes. Recycled polyester (rPET). Polyester fibres are one of the preferred raw materials for active wear. Main advantages of using rPET in sportswear includes affordability, durability and more functional than many natural fibres. The polyester fibres can be produced three times finer than silk fibres and is blended with spandex or elastane to enhance the stretchability. Recycled polyester fibres are commercially made from industrial wastes, pre-used polyester garments and PET bottles. Recycling reduces landfills, energy consumption as well as the carbon emissions and saves products quality without negative impacts (Guppyfriend, 2022).

Recycled nylon is another commonly used in sportswear fibre, especially in swimwear. Similar to rPET, recycled nylon is blended with spandex or elastane for

Table 5 Digitalisation and advantages

Business process	Impact of digitalisation
Scalability	Digitalisation helps in reduction of manpower assigned
Transparency	Digitalised process information are fair statistics, connects all stakeholders
Customer satisfaction	Digitalisation aids communication from the business to the customers and supports healthier customer relationships
Virtual sample development	Helps fabric fitting in virtual reality that reduces physical sampling and carbon footprint. Manufacturing is carried out by digital machines for less error and identical quality
Sourcing / procurement	Reduces inventories and document storage
Circular logistics	Tracing and tracking
IoT smart wardrobe	Saves the time in arranging, using and blueprinting the wardrobe
Fast Fashion	Accurately tracking the stocks through the supply chain allowing the small shops to make reasonable market decisions

elasticity. Nylon fibres are recycled from the post-consumer and post-industrial wastes such as carpets, fishing nets, scraps from fabrics, etc. Properties of recycled nylon fibres find applications in sportswear that are durable, strong, soft, flexible and recyclable (Alex Assoune, 2022).

Bamboo is a substitute for cotton fibres. Naturally, bamboo fibre has wicking tendency with softness, and suitable for garments, yoga wear, after workout garments, trekking clothing (Imadi et al., 2014).

Cotton is the oldest and renewable natural fibre. It is soft and gives a pleasant feel to the skin, suitable to only limited extent as it dries poorly. This sustainable organic cotton uses less amounts of water than conventional one due to the use of sustainable chemicals and dyes during processing. For an excellent sustainable sportswear, the organic cotton is blended with spandex and such garments possess lightweight, durable, comfortable, moisture-wicking, fast drying and biodegradability (Chouinard & Brown, 1997; Sung & Lee, 2011; Coppedè et al., 2014).

Merino wool naturally keeps the wearer warm in the cold and, cool in the heat due to its moisture-wicking properties. Merino wool is resistant to odors and static charges and easily washable. Merino wool finds applications in trekking clothes, winter sports garments, after workout outfits, yoga wear, running clothes and clothing for gym workout (Wang et al., 2014; Alderson, 2015; Chaudhari et al., 2004).

Hemp fibre is the most sustainable and a substitute for cotton fibres. Hemp is strong, naturally UV and microbial resistant fibre, moves easily with the human body, breathable and exhibit thermo—regulating properties. Additionally, hemp compared with linen fibre wrinkles less and required occasional or low temperature ironing (during the use). However, its less stretchability limits the applications as sportswear, which necessitates blending with spandex fibres (Wambua et al., 2003; Wood et al., 2011; Begum et al., 2020).

Linen is a natural sustainable fibre used in activewears. Linen fabrics are mostly preferred in hot and humid condition as it releases moisture in air. As a sustainable fibre, it is used in sportswear due to the certain inherent properties that include durable, absorbent, strong, quick drying, wicking, lightweight, antimicrobial and biodegradable (Buckley, 2005).

Fibres with diameter less than a denier, categorised as microfibres, possess valuable properties such as softness, durable and high absorbency required for a sportswear. Ultrafine fibres are found to have fibre diameter less than 0.3 denier and commonly produced by the process of bi-component fibres (Stegmaier et al., 2005).

A fibre with two polymers chemically or physically different are termed as bi-component fibres and used in sportswear such as t-shirts, shorts and sweatshirts. Bi-component fibres are produced as concentric sheath and core—sheath made of polymers having low melting point and core with polymers having high melting point, eccentric sheath and core— core is found to be out of centre, side-by-side—two polymers with equal share, pie wedges— hole is provided at the centre of the pie wedge to split the filaments and islands/sea—one type of polymer is dispersed (island) in another polymer (sea).

10 Fabric Selection for Sportswear: Sustainable Approach

Sportswear are designed to provide ease of movement along with the human body. An activewear gives protection from external elements and balance the heat produced by the wearer. When excess heat is produced due to high metabolic rate, the fabrics should have the capability of dissipating the heat and cause perspiration. Fabrics made of woven and knitted possess the desired characteristics such as tactile properties, liquid absorption, thermal insulation and evaporating water to stay dry. Coated and laminated fabrics are commercially used in sportswear for their breathable and barrier characteristics against external factors, when fabrics are manufactured using microporous, hydrophilic membranes, water vapour transmission membranes, etc. Phase change materials provide thermally adaptive technology in sportswear and activewear and finishing with such substances help in interacting with microclimate and responding to the fluctuations in temperature caused by the levels of activities. Table 6 lists some of the characteristics of sportswear required for various activities (McCann, 2015, 2016; Shishoo, 2015; Wang & Shen, 2017).

Table 6 Fabric characteristics required for sportswear

Type of sports	Fabric requirement
Aerobic/ gym wear	Stretch, opacity
Ball sports	Sweat absorption, breathability, quick drying, cooling
Athletics	Sweat absorption, breathability, quick drying, cooling, stretch
Water sports	Water and air resistance, stretch, opacity
Snow sports	Water proof, water vapour permeability, fast drying and temperature balance
Motor sports	Good tenacity, thermal retention, low air resistance
Contact sports	Lightweight, flexible, shock absorption and protection

Waterproof breathable fabrics are designed to give protection from environmental factors such as wind and rain, and heat loss from the body. Breathability is an essential characteristic expected in the case of fabrics finished with high waterproofness and breathable waterproof fabrics including closely woven fabrics, hydrophilic membranes and coatings, microporous membranes and coatings, combination of microporous and hydrophilic membranes. Closely woven fabric is made up of long staple cotton fibres. When such fabric becomes wet, the cotton fibres swell up and reduce the pore size in the fabric between the yarns. The characteristics of waterproof fabrics include air permeability and breathability are found to be improved. Another possible way of producing closely woven fabric is by using microfilament synthetic yarns.

Swimwear is clothing that is used for swimming designed for all categories of men, women and children and it combines swimsuit, cap and eyewear into a single piece of outfit. A swimwear is designed considering the basic requirements including biomechanics of swimming, measurement of drag force, physiological and biomechanical responses during swimming; such designs allow swimmers to move comfortably with increased hydrodynamic efficiency. Initially, swimsuits were made up of silk fabrics for properties such as lightness, strength, elasticity and feel. Fibres that are commonly used in swimwear include nylon, polyester and elastane for stretch and resilience. Texturised filaments with modified stretch yarn (false twist) is commercially used in swimwear compared with spun yarn. Tricot produces adequate two-way stretch and in jersey fabric elastomeric material is used for stretching and body fitting. Rib structure is also found to be more elastic than single jersey. So the commonly used rib structure for swimwear is interlock and Swiss pique using stretch nylon and stretch polyester (Moran, 2014; Bloodhart & Swim, 2020; Chau, n.d.).

Skiers and snowboarders require a sound protective gear to prevent physical damages, fitted with airbags to prevent injuries (Parkkari et al., 2001). Apparels with sensors are used to secure areas prone to abrasions to avoid inquires, while jackets equipped with sensors spontaneously adjust temperatures based on weather conditions. The water resistant and moisture-permeable materials are further categorised into (i) densely woven waterproof breathable fabrics, (ii) laminated waterproof breathable fabrics, (iii) coated waterproof breathable fabrics. Moisture vapour transmission in activewear deals with temperature and pressure gradient that exist between inner and outer faces of a garment. Moisture transmission takes place through absorption, wicking and evaporation. Sweat generation would be very during high sporting activities and hence instant wicking and evaporation is required to ensure the comfort levels of the players. Wigwam socks are made up of merino wool combined with hydrophilic and hydrophobic fibres that regulates body temperature. When the atmosphere outside is cold, the natural blends present in the fibre traps the warm air and when outside environment is found to be warm, merino wool quickly traps the sweat from skin to keep cool and dry. Moisture is wicked by the socks and released through the air mesh linings of the boot. By pairing right choice of socks and boots, an environment of cold and clammy feet can be created where moisture and heat can escape (Laskowski, 1999).

Densely woven waterproof breathable fabrics are constructed using cotton or synthetic microfilament yarns with tight fabric structure, e.g. *Ventile*. Long staple fibre-combed-yarns are used with Oxford weave for minimum porous structure, which, when swells transversely reduces the pores further there by necessitating more pressure for penetration.

In the laminated materials, thin membranes produced by polymeric materials of 10 microns thickness allows the water vapour to pass through but prevents water-drop penetration. Further, the membranes can be of two types, namely (i) microporous membranes, having pore size smaller than rain drops but larger than water vapour molecule, produced using Poly(tetra fluoro ethylene) and Poly(vinylidene difluoride), (ii) hydrophilic membranes—made up of chemically modified polyester or polyurethane that forms amorphous regions in the main polymer units, which functions as intermolecular pores to allow passage of water vapour molecules and resist liquid penetration. In the case of coated fabrics, polymers such as polyurethane is applied as a coating on the surface of the fabric as either microporous (fine interconnected channels) coat or hydrophilic coat (breathability through by adsorption—diffusion and desorption mechanism). Polyester fabric with hydrophobic inner side and hydrophilic outer side is the commercially used fabric for high active sportswear for superior moisture management along the fabric thickness.

GoreTex is a two-layered membrane made up of stretched polytetrafluoroethylene (PTFE). This membrane contains micropores whose pore size is larger than water vapour and smaller than water droplet, suitable for golfing, cycling, skiing, running, etc. *Pro* is a three-layered membrane with membrane sandwiched between outer and inner lining that ensures durability and suitable for winter climbing, sailing and snowboarding (Virk & Kocher, 2011; Slack, 2014).

Phase change materials (PCMs) provide a sustainable approach to sports textiles by reducing the need for constant washing and drying, thus conserving water and energy. PCM can absorb, store and release energy (heat) for moisture and temperature management thereby providing comfortable microclimate. High levels of sporting activities result in dissipation of heat energy from overheated skin, where heat is absorbed by phase change materials and making the skin cool down, and dries the sweat of skin while stored heat is returned. This technology proactively stops the body from sweating by regulating the skin temperature. By regulating the microclimate and absorbing and storing heat energy, PCMs prevent overheating and excessive sweating, keeping the skin cool and dry. This reduces the need for frequent changes of clothing and washing, reducing the environmental impact of textile production and usage. Additionally, PCMs can be incorporated into sports textiles using eco-friendly materials, further promoting sustainability in the sports industry (Mondal, 2008; Ye, 2014; Kwiecien et al., 2020).

11 Conclusion

Developments in the science and technology has led to additional competitive elements in all the sports and games in terms of comfort levels with which a player is performing and the efforts made by the manufacturers and endorsed by the players in promoting sustainable features associated with their actions and intents. There many ways available in promoting sustainability during manufacturing—in terms of fibres, processes and supply chain nature while thrid-party agencies try to suggest parameters, metrics and targets for sustainability labelling. Volunteering of manufacturers and the players in adopting conscious measures to promote the sustainable practices further.

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