A Novel Hybrid Decision-Making Framework for Measuring Industry 4.0 Driven Circular Economy Performance for Textile Industry

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Abstract: The sustainability strategy focuses on conscious production and consumption, with the Circular Economy (CE) as an innovative approach to maximize resource value and minimize waste. Industry 4.0 technologies like AI, robotics, and blockchain play a significant role in enhancing the competitiveness of businesses pursuing the CE. These advanced technologies help organizations achieve their sustainability goals, particularly within the CE framework. The study analyses how Industry 4.0-driven CE practices impact sustainable business performance, using the Indian textile industry as a case study. The researchers developed a three-stage hybrid decision-making framework, integrating various methods to assess sustainable performance. A novel three-stage hybrid decision making framework was developed by integrating Kendall's Agreement Test (Kendall's W), Fuzzy Delphi, Best Worst Method (BWM), Full Consistency Method (FUCOM), and Combined Compromise Solution (CoCoSo) methods. The findings highlight positive outcomes such as enhanced incentives, government support, greener logistics, and improved monitoring of emissions, waste, and pollution. However, there is room for further improvements to address market demand and increase the profitability of green products.

Keywords: Circular economy; Industry 4.0; Smart circularity practices; Smart circularity performances; Kendall's W; Hybrid method.

1. Introduction

Earth's abundant natural resources play a crucial role in satisfying humanity's diverse requirements. These interconnected resources form a delicate chain, and any disruption can jeopardize the established balance, ultimately undermining economic values and the overall stability of the economy (Panchal *et al.* 2021). Stakeholders from many fields stress the need to move towards a sustainable economic framework that protects resources (Bag *et al.* 2021b). This transition has been examined by businesses, governments, civil society, and academics, acknowledging the historical imbalance between economic growth and environmental and social concerns (Kazancoglu *et al*., 2020; Khan, Ali, & Singh, 2022).

The integration of digital technologies has been found to be instrumental in encouraging business adoption of circular economy principles (Agrawal *et al.*, 2022). These technologies enable the implementation of innovative business models and facilitate the redesign of products and value chains, all within the context of a smart circular economy paradigm (Mahtab *et al.* 2020). The integration of digital technologies throughout a product's life cycle allows for the implementation of circular strategies and practices known as “smart circularity”. This paradigm involves leveraging digital technologies to optimize resource use, enable product tracking and traceability, promote sharing and collaboration, and facilitate the attainment of efficient and sustainable operations. The Textile and Clothing (T&C) industry is intricately linked with nature throughout the entire supply chain (Kazancoglu *et al*., 2020; 2022), starting from production and extending to the final utilization of the products (Coppola *et al.* 2023). T&C industry is a sector with a volume of nearly $1.5 trillion and has a value that could have the world’s 14th economy. The T&C industry has a considerable negative environmental impact that surpasses that of many other sectors in terms of global production, consumption, and trade capabilities (Coppola *et al.* 2023). The greenhouse gas emissions of this sector represent about 10% of global emissions, more than the aviation and maritime sectors combined.

The Indian economy relies heavily on textiles and apparel for economic growth domestically and globally. Textile and apparel contribute 4% to India’s GDP and account for 15% of exports and are the country's top foreign exchange earners. T&C manufacturing in India has a competitive advantage due to natural raw materials (cotton, silk, cellulosic fiber) and skilled labor, traditional designs, colors, and embroidery (NCFAT’20, 2020). In the realm of sustainable fashion in India, several noteworthy brands have emerged, each with its own unique approaches and initiatives. Manickam and Duraisamy (2019) highlighted that historically, the Indian textile industry has had issues with sustainability, primarily because it has traditionally been a labor-intensive industry. 'Period', for instance, sets itself apart by utilizing handloom textiles exclusively and adhering to a "no synthetics policy." 'Greenthemap' takes an innovative approach to sustainability by transforming old tyres, tetrapacks, waste cloths, waste leather, and other apparel wastes into new materials. They employ tailors from disadvantaged backgrounds and strive to provide them with a supportive work environment. 'DoUSpeakGreen' garners recognition as India's pioneering fashion brand and webstore, distinguished by its utilization of organic bamboo and cotton fabric in garments produced within Fair Trade-certified factories. Notably, they allocate 10% of their sales value to environmental conservation processes, demonstrating a commitment to sustainability beyond their production practices. 'Bhusattva' has been at the forefront of sustainability in the Indian textile industry, championing the infusion of innovative materials such as bamboo, banana, and soybean fibers blended with traditional fabrics like khadi, silk, and cotton. This combination allows them to bridge the gap between sustainable fashion and mainstream appeal. ‘No Nasties’ is another noteworthy sustainable fashion brand, advocating for organic textiles and ethical craftsmanship. Originating from the purpose of addressing farmer suicides in India, their initiatives include promoting organic and fair-trade farming practices. Doodlage excels in the art of upcycling, converting waste fabrics into exquisite and eco-friendly patchwork clothing and home furnishings. Their commitment to sustainability lies in transforming discarded materials into beautiful creations.

Globally, customers are increasingly considering whether the core materials in a product are sustainably sourced (Kayikci *et al.*, 2022a, Khan, Ali, & Singh, 2022). Industry professionals believe that products that are part of a circular value chain have a distinct advantage over another (Kazancoglu *et al.*, 2022). With the increasing demand, companies focusing on sustainability are being sought out for their products. Addressing environmental risks remains the foremost motivation for the textile and clothing industry's adoption of circular economy models (Kazancoglu *et al.*, 2020; Bag *et al.*, 2021a). Still, it is equally important to consider the human aspect of such models.

A CE offers a straightforward and reliable path to overcoming sustainability challenges that put an equal focus on individuals, the planet, and profits. Recycling and reusing products are essential aspects of a CE (Bag *et al.* 2021b). Energy consumption, resource use, and waste production are under pressure already. However, scaling and profitability are also important (Kazancoglu *et al.*, 2020; 2022). The adoption of CE practices in the textile industry offers significant benefits to manufacturers. By implementing strategies that prioritize resource optimisation, manufacturers can reduce costs and improve efficiency. Embracing sustainable practices also fosters enhanced customer loyalty, as consumers increasingly value environmentally responsible products (Sahoo *et al.*, 2023).

The APAC region includes India, Bangladesh, Vietnam, China, Pakistan, Indonesia, and Sri Lanka as large textile production hotspots (Khan*,* 2021). As many as 15% of discarded textiles are reproduced through recycling, reselling, or donation. There are 45 million people across the value chain employed by this industry in India, with many women. It is essential to design circularity initiatives that contribute to social inclusion (Kotamaraju *et al.*, 2021).

Innovation and resilience are the keys to survival and growth in today's competitive world. Dynamic industry challenges of Industry 4.0 are amplifying the disruptive effects of e-commerce in fashion retail. Innovations in the manufacturing sector are not only driven by product innovation but through the application of new digital technologies (Kayikci *et al.*, 2022a). Embracing Industry 4.0 can significantly impact a labor-intensive industries like textiles and apparel (Kotamaraju *et al.*, 2021). Recycling and recovering can be more cost-effective and environmentally friendly when technologies are integrated with the CE (Kayikci *et al.*, 2022a). In addition to providing trust across stakeholder groups, reliability, visibility, and traceability, adoption of smart technology with a SCE will also cause an increase in financial burden for the organization (Jaeger & Upadhyay 2020). This study uses the Natural-Resource-Based View (NRBV) as a theoretical background to fill the above-mentioned significant research gap; NRBV can be a great enabler for smart circular economy due to its theory of competitive advantage based on the firm's relationship with the natural environment (Hart, 1995). According to the NRBV, smart circular supply chain is conveyed as key organizational primary resources and strategic capabilities with environment that can lead to significant improvements in sustainable performance (Kayikci et al., 2022a).

This study focused on the following Research Objectives (ROs):

RO1: To investigate and identify smart circularity practices within the textile industry that contribute to enhancing sustainability performances; and

RO2: To develop a decision-making framework that guides organizations in reaching their goals.

This paper aims to address research objectives by conducting a comprehensive literature review based on NRBV theory in the textile industry. It targets to identify smart circularity practices and circularity-based sustainable performance indicators through extensive literature search and expert consultation. To achieve this, a novel hybrid decision-making framework is proposed, combining methods such as Kendall's Agreement Test (Kendall's W), Fuzzy Delphi, Best Worst Method (BWM), Full Consistency Method (FUCOM), and Combined Compromise Solution (CoCoSo). This framework will help provide answers to the research objectives, contributing to a better understanding of smart circularity in the textile industry. The unique integration of methods in the novel framework yields a powerful decision-making tool. This research introduces the integrated approach for the first time, focusing on measuring the sustainable performance of smart circularity practices in the textile industry. It provides researchers with an effective means to address diverse problems in this context. This study serves as a guideline for practitioners, managers, and users facilitating the implementation of advanced technologies and aligning production strategies with smart circularity practices to promote sustainable performance in the textile industry.

The remainder of the article is organized as follows. Section 2 introduces the theoretical foundation of building initiatives of smart circularity practices for circularity-based sustainable performance. Section 3 summarizes the research framework of the solution procedure and explains the three-stage methodology in detail. Section 4 introduced the case study and obtained results and discussion are interpreted in Section 5. Section 6 gives the conclusions of the paper with suggestions for future works.

2. Smart Circularity Practices for Circularity-based Sustainable Performance

The "end-of-waste" mechanism aims to promote sustainable waste treatment and mutual recognition of results (Khan, Ali, & Singh, 2022). When waste becomes a product or secondary raw material, the Smart Circular Economy (SCE) must show that its use won't harm the environment or human health. Driven by growing public awareness of environmental degradation and stringent government regulations, supply chains are increasingly compelled to adopt environmentally friendly practices (Bressanelli *et al.* 2022). Excessive focus on environmental performance can have negative implications on economic performance (Jaeger & Upadhyay 2020). SCE promotes circularity and economic growth and considers environmental and social benefits for sustainable development. CE is gaining interest to stimulate the economy by encouraging innovation, confronting resource constraints, creating jobs, and delivering notable environmental benefits (Agrawal *et al.*, 2022). CE migration helps organizations enhance sustainability, financial performance, and cater to diverse stakeholders for business growth.

The transition to a SCE in the textile industry is a challenging process, supported by prior research Coppola *et al.* (2023). As a result, organizations are gradually embracing CE principles to overcome these obstacles (Jaeger & Upadhyay, 2020). Industries recycling components as raw materials embrace CE faster, but it should involve all stakeholders, including consumers (Kayikci *et al.*, 2022b). Developed nations like the USA, Japan, EU, Germany, and Italy have embraced CE for sustainable development goals. However, emerging economies, including India, lag behind in adopting CE practices. Many Indian SMEs are unaware of the benefits of CE, such as improved efficiency, cost reduction, and reduced environmental impact. Therefore, implementing CE-based business models is crucial for Indian SMEs to realize its potential (Agrawal *et al.*, 2021). As argued by Coppola *et al.* (2023), the textile and clothing sectors (T&C) present both significant environmental challenges and strategic opportunities within the context of the circular economy (CE). The T&C industry is a prime instance where waste products are not utilized as raw materials for creating new products (Khan *et al.* 2022).

The textile industry, one of the most polluting industries in the world, deserves more attention as it is one of the largest in CE as a result of the exponential growth of clothing that ends up in a landfill. This is a result of the fast fashion phenomenon, which creates the impression that clothes are disposable (Kazancoglu *et al*., 2020; 2022). A sustainable fashion that can provide circular material flows is required to solve this problem. This requires the cooperation of consumers in promoting long-lasting fashion, choosing quality over quantity, and viewing clothing as an investment (Kayikci *et al.*, 2022a). Therefore, there is a need for effective garment collection systems and sorting procedures. It is assumed that new textile recycling technologies in the textile industry have the potential to reorient material resource flows, impact secondary markets, and restructure the waste hierarchy (Jaeger and Upadhyay 2020). Industry 4.0 technologies enable CE business models, with digitization enhancing asset and product visibility and intelligence (Kayikci *et al.*, 2022a). In the age of digitization, companies improve their business performance through the use of digital technologies (Agrawal *et al.*, 2022). Organizations in both developed and developing economies attach great importance to the industry 4.0 revolution and related uses of technologies because of their potential benefits (Bag *et al.* 2021b). AI-powered systems analyze data to suggest more sustainable sourcing options or provide predictive maintenance for machinery, ensuring optimal usage and minimizing waste (Bag *et al.* 2021a). While there is undoubtedly growing interest in understanding and applying Industry 4.0 from both academia and industry, it is an emerging concept that many industry sectors have yet to fully explore and commit to. Therefore, academic research must progress rapidly to identify knowledge gaps related to Industry 4.0 and to address its impact on sustainability and CE (Sahoo *et al.*, 2023).

2.1 Exploring the Performance of Smart Circularity: A Theory-Based Analysis through the Resource-Based View

Coppola *et al.* (2023) uses a NRBV as a theoretical framework and employs a multiple-case study approach. The strategies of pollution prevention, product stewardship, and sustainable development, along with the associated capabilities of sensing, seizing, and reconfiguring, are examined. The fast-paced nature of the fashion industry raises resource consumption and waste generation issues significantly. The quick turnover of products, characterized by their rapid acquisition and disposal, contributes to the industry's environmental challenges. This high-speed approach to fashion not only leads to increased utilization of resources but also results in substantial waste production. Thus, addressing these concerns is crucial for the industry's sustainability and calls for the adoption of strategies that promote a more circular and responsible approach to fashion production and consumption. Drawing from grounded theory building and multiple case studies, Kouhizadeh *et al.* (2020) presented preliminary evidence that connects blockchain applications to dimensions of the circular economy, including Regeneration, Sharing, Optimization, Looping, Virtualization, and Exchange (ReSOLVE model) by using multiple cases.

2.1.1 Smart circularity practices

Smart circularity practices involve the use of digital technologies throughout a product's life cycle to implement circular strategies. Kouhizadeh *et al.* (2020) argued that with the advent of Industry 4.0, organizational activities are poised for transformation through technological innovations. This approach aims to create value by improving sustainable performance (Bressanelli *et al.* 2022). Robots can be employed for tasks like sorting and recycling waste materials, reducing human error and improving recycling efficiency. In the context of the textile industry, the following 'smart circularity practices' have been recommended based on review of literature based on NRBV theory:

Technical capability*:* Technical capability is an essential practice or enabler that facilitates the implementation of cutting-edge technologies across diverse domains. This capability comprises the requisite technical expertise to utilize state-of-the-art technologies in an efficient manner, such as blockchain, 3D printing, machine learning, cloud computing, big data analytics, human-machine interaction, robotics, infrastructure development, and the Internet of Things (IoT). By effectively utilizing these technologies, businesses can optimize their operational processes (Kotamaraju *et al.*, 2021), foster innovation, and attain long-term, sustainable expansion.

Shayganmehr *et al.* (2021) highlighted valuable insights regarding the importance of technical capability as a facilitator, emphasizing its capacity to revolutionize and influence sectors by means of the efficient application of cutting-edge technologies.

Competitive pressures: Competitive pressures are a significant catalyst or implementation in promoting innovation across industries, specifically with regard to the circular economy (CE) and Industry 4.0. By utilizing Industry 4.0 tools and remaining abreast of the actions of competitors, businesses can innovate their processes and products, thereby obtaining a market advantage. In order to foster community engagement in waste management, institutions offer rewards for the collection, sorting, and restoration of particular refuse categories—such as furniture and textiles (Coppola *et al.* 2023). This may result in the establishment of new repair and reuse businesses, which will have a positive effect on society. Bag *et al*. (2021b) emphasizes the importance of competitive pressures in driving innovation and generating societal benefits at the intersection of Industry 4.0 and Circular Economy (CE) in the textile industry.

Policy and regulation: This aims to explore how rules and policies can foster responsible actions that align with the goals of the circular economy in the textile industry (Coppola *et al.* 2023). Companies, supply systems, institutions, and people are all encouraged by the government to follow responsible practices (Kotamaraju *et al.*, 2021) that are in line with CE and Industry 4.0 (Shayganmehr *et al.* 2021). To do this, policies must be put in place to support CE and Industry 4.0, and strategies must be made and put into action that are especially designed to support CE and Industry 4.0. The development and utilization of effective performance metrics are essential for evaluating the effectiveness of integrating CE practices with Industry 4.0 (Shayganmehr *et al.* 2021).

Financial capability*:* Gedam *et al.* (2021) and Khalifa *et al*. (2022) explore how well reward and incentive policies, budget allocation strategies, and international groups helps Clean Energy (CE) and Industry 4.0 move forward. Implementing reward and incentive systems support the rapid improvement of CE technologies and Industry 4.0 practices by promoting an atmosphere that stimulates innovation. Furthermore, allocating a proper budget expressly for supporting CE and Industry 4.0 activities is critical for their successful implementation (Kotamaraju *et al.*, 2021). Association of international groups encourage knowledge sharing and collaboration by giving chances to utilize global expertise and resources needed to drive CE and Industry 4.0 progress.

Fair acceptance*:* Kotamaraju *et al.* (2021) stress the importance of fair business practices and adherence to laws and regulations while working with suppliers and consumers in the context of smart circularity. Gedam *et al.* (2021) emphasizes the role of organizations in implementing Industry 4.0 solutions and advancing CE through compliance and equity.

Security and safety: In the implementation of Industry 4.0 infrastructure within the circular economy (CE), ensuring security and safety is crucial. This involves protecting employee confidentiality and securing Industry 4.0 systems. Smart elements and the safe deployment of Industry 4.0 technologies contribute to a safer work environment and enhance competitive edge initiatives. Shayganmehr *et al.* (2021) emphasized the role of security and safety in successfully implementing Industry 4.0 technologies and achieving CE objectives.

System flexibility*:* Sensor-based technology has the capability to gather real-time data pertaining to resource consumption, waste generation, and production efficiency. Through the application of AI/ML techniques (Bag *et al.* 2021a), this data can be analyzed to extract valuable insights that can optimize production processes, identify areas for waste reduction, and enable effective reuse or recycling of materials. The utilization of flexible system such as Big Data (Sahoo *et al.* 2023) and AI/ML (Bag *et al.* 2021a) empowers organizations to seamlessly integrate circular economy practices within the framework of Industry 4.0, in line with the findings highlighted by Shayganmehr *et al.* (2021).

Support and maintenance*:* The implementation of smart factory tools is crucial for effective reverse collection in a smart circular economy. Leveraging Industry 4.0 systems such as blockchain enhances inventory tracking capabilities, facilitating seamless coordination between circular economy and Industry 4.0 activities (Kouhizadeh *et al.* 2020). By establishing a cloud technologies infrastructure, organizations ensure compliance, improve business efficiency (Kotamaraju *et al.*, 2021), and enable real-time decision-making across the supply chain through the utilization of Industry 4.0 tools and technologies.

Stakeholders' readiness: Preparing stakeholders for the adoption of CE concepts, dynamics, and operations backed by Industry 4.0 technology is an aspect of this. Torgautov *et al.* (2021) and Palafox-Alcantar *et al.* (2022) emphasize the significance of industry-wide policies and public procurement activities that promote circularity. By using IoT devices and data analytics as part of Industry 4.0 in procurement, companies can rate their suppliers' success in terms of sustainability and circularity. These technologies allow for monitoring, tracking of waste, and supply chain analysis. They make sure that sustainability standards are met while rendering it easier to choose a supplier that fits with a smart circular economy and the use of environmental labels (Panchal *et al.* 2021).

Regulatory pressures*:* It functions as a major facilitator or practice in the deployment of the CE and Industry 4.0 technologies. According to Kazancoglu *et al.* (2022), CE and Industry 4.0 are more likely to be adopted when companies follow the law. Effective communication of circular actions and practices to society is crucial, and environmental labelling and certification incentives play a significant role in encouraging sustainable behaviors and choices (Kotamaraju *et al.*, 2021), thus showcasing the circular economy's benefits and sustainable impacts.

Process and product design for energy and resource efficiency: The concept of the CE emphasizes the regenerative and restorative features of the design in order to optimize the advantages derived from energy, components, and products (Ali *et al.* 2023). Another environmental strategy that has been explored is Extended Producer Responsibility (EPR), a concept that places the onus on manufacturers to assume responsibility for the complete life cycle of their products. Producers in industries like electronics and textiles pay EPR fees, which are determined by the quantities of their products (Palafox-Alcantar *et al.* 2022), in order to incentivize and support environmentally responsible practices. Augmented Reality (AR) simulations allow users to visualize the effects of different materials or product lifecycles, enabling sustainable choices.

Education and participation: This investigates the factors that facilitate education and engagement within the framework of Industry 4.0 technologies and their impact on fostering equitable and efficient resource utilization. Key methods include providing training to employers on business principles and encouraging the active involvement of management-level personnel in the growing framework of Industry 4.0-enabled CE. By analyzing big data, businesses can identify patterns and trends in consumption, enabling smarter product design, waste reduction, and improved inventory management. Shayganmehr *et al.* (2021) highlights the significance of establishing objectives that span over an extended period and recognizing the possible consequences of integrating Industry 4.0 technologies into CE framework (Ali *et al.* 2023).

2.1.2 Circularity-based sustainable performance

By adopting circular economy thinking, the textile business hopes to do a better job of being environmentally friendly. This study looks into how using circular economic drivers driven by Industry 4.0 might help the industry do better in the long term. Cutting-edge technologies such as

AI, IoT, and big data analytics enable the achievement of circularity. Predictive analytics and AI make production processes more efficient, and smart supply lines make it easier to see how resources are being used. Digital manufacturing and additive technologies cut down on waste, and reverse supply lines make recycling easier and more effective. The integration of circular economy principles and Industry 4.0 technologies offers potential for a more sustainable future in the textile industry. However, challenges such as security issues and high costs need to be overcome (Jaeger & Upadhyay 2020). Based on a review of existing literature based on NRBV theory, the following 'circularity-based sustainable performance' indicators have been suggested in the context of the textile industry.

Increase in resource circularity: The aim of this approach is to retain resource value by ensuring their reincorporation into the product cycle post-use. By minimizing raw material consumption, waste generation, and value chain risks, companies can contribute to a more sustainable and efficient resource management system (Lopez *et al.* 2019; Weissbrodt *et al.* 2020).

Better adoption of digital technology: To bolster sustainability initiatives, it is imperative to advocate for the increased implementation of digital technology. This process entails integrating the implementation of digital technological advancements into multiple organizational departments with the aim of optimizing the advantages that arise from this integration (Khan, Ali, & Singh, 2022). Through the strategic utilization of digital technologies, organizations can enhance their sustainability performance and streamline operations. IoT applications enable better monitoring and optimization of resource usage, such as smart energy management systems that minimize energy waste and enhance efficiency.

Improve human efficiency: This involves optimizing resource utilization by aligning tasks with appropriate skills, prioritizing training and development, harnessing digital technologies to save time, enhancing manpower efficiency, and finding innovative work methodologies. Previous studies by Lopez *et al.* (2019) and Hoang-Khac *et al.* (2022) support the importance of these practices in achieving higher efficiency levels.

Improve human skills: The implementation of Industry 4.0 in clothing organizations aims to maximize the potential of individuals by enhancing the skills of experts and upskilling low-skilled workers to increase their competencies. Using advanced technological systems such as automation, robotics, and artificial intelligence, big data, the Internet of Things, blockchain, 3D printing, cloud technologies, augmented reality Industry 4.0 enables clothing organizations to provide training programs and develop personalized learning opportunities (Hoang-Khac *et al.* 2022).

Increase in profit from green products: Efficiency is improved by minimizing the use of natural resources, such as water and energy, and hazardous substances in production. Additionally, negative environmental impacts at the end of a product's life are reduced. Green products are produced to promote recycling and reusability, leading to increased profitability (Ali *et al.* 2023; Lopez *et al.* 2019, Li *et al.* 2020).

Improved usage of green logistics*:* Trying to implement a sustainable transportation policy in order to develop the concept of green logistics, such as using more environmentally friendly vehicles and fuels in the production and transportation phase, turning to the more environmentally friendly sea and railway, or commissioning integrated transportation systems rather than road transportation, which increases greenhouse gas emissions (Ying and Li-jun, 2012).

Better employees and community health: To improve sustainable development in a way that includes not only income increase but also the quality of life, and to try to increase the funds allocated to health by accepting health as a tool of economic development. Wearable sensors and real-time monitoring systems enhance worker safety and well-being in the T&C industry. Improved health and safety conditions not only reduce the risk of accidents and injuries but also promote higher productivity and overall job satisfaction among workers, leading to a more sustainable and efficient workforce (Ali *et al.* 2023).

Improved green purchasing: The goal is to encourage companies to shift towards a circular economy by opting for products and services that have lower impacts on human health and the environment compared to alternatives serving the same purpose (Ali *et al.* 2023, Khan, Ali, & Singh, 2022).

Better usage of green warehousing*:* Efforts are made to improve the operational performance of enterprises through green warehouse management practices such as increasing energy efficiency by using timed lighting systems, motion sensors and energy-efficient lighting fixtures, using natural light or solar panels in appropriate places in the warehouse, using hot water systems for heating and cold water systems for cooling the warehouse, using energy efficient tools and equipment in handling processes, reducing energy usage in warehouse operations through efficient planning by accurately predicting demand, production and stock levels, sharing real-time sales data using information and communication technologies, and updating stock levels and reorder statuses (Ali *et al.* 2023).

Better/improved market demand: To gain a positive image among customers by producing sustainable, environmentally friendly products that do not have harmful effects on human health, to promote products by communicating information about products to consumers, to keep products in accessible and convenient locations, and to try to ensure reliability and integrity among customers (Palafox-Alcantar *et al.* 2022).

Improved develop the CE based smart culture*:* To make all forms of culture diverse and technologically advanced by adopting technologies that provide new protection, storage, and archiving opportunities that will provide fair access to available resources for both current and future generations, that is, to realize the transition from culture to smart culture via the existence and functioning of various and sundry implementations in the digital ecosystem. In this context, it is aimed to create a circular economy, if information and communication systems and technologies are also applied and used in the company culture (Salvioni and Almici, 2020).

Increase in cost saving through product quality: To increase the quality of every commodity that enters the production process, to reduce the losses in production and the resulting labor time, and to increase cost savings in this way (Kouhizadeh *et al.* 2020). 3D printing allows on-demand production, reducing the waste associated with unsold inventory and transportation. It also facilitates design customization, enabling products to be easily remanufactured.

Decrease in emission, waste, and pollution monitoring: Trying to develop and produce products that leave a less carbon footprint in nature, use environmentally friendly clean technologies and techniques, prevent environmental pollution, and reduce energy consumption and carbon emissions through waste management (Palafox-Alcantar *et al.* 2022).

Improved incentives and government legislation support and incentives*:* In the direction of the transition of enterprises to circular economy model for sustainable development, work on designing important strategies to disseminate the application, preparing appropriate legislation, and developing the right government incentives (Salvioni, & Almici 2020). Incentives can support the commercial development of circular economy businesses, remove entry barriers to specific sectors or markets, favor the adoption of new technology, develop original competencies and skills, and inject new capital to contribute to capex and opex, respectively (De Giovanni and Folgiero, 2023).

Many researchers agree that using smart circular economy (SCE) methods is important for achieving sustainable development goals, especially when it comes to production and consumption by using one of Industry4.0 driven integration (Sahoo *et al.*, 2023; Panchal *et al.*, 2021; Mahtab *et al.*, 2020).

2.2 Research Gaps

The study by Coppola et al. (2023) examines the circular competitive advantages of firms in Italy's textile and clothing industry, a sector known for its environmental impact. Their objective is to identify the necessary capabilities for implementing a circular economy and achieving a restorative industrial system. Using a natural-resource-based view as a theoretical framework, the study employs a multiple-case study approach. In contrast, our research focuses on the textile industry of emerging market. We utilize extensive searches and expert input to identify best practices and measure performance using a novel framework tailored to this specific context. Despite the existing research on smart circular economy (SCE) methods for achieving sustainable development goals, there are several research gaps that need to be addressed. While studies by Kouhizadeh et al. (2020). Sahoo et al. (2023), and Bag et al. (2021a) have explored the integration of specific Industry 4.0 technologies, such as blockchain, big data, and artificial intelligence into circular economy practices, there are further investigation into the potential of incorporating Industry 4.0 concepts was done by Bag et al. (2021b), Hoang-Khac et al. (2022), and Shayganmehr et al. (2021).

Although, Kayikci et al. (2022a) have assessed the readiness and maturity levels of small and medium-sized enterprises (SMEs) in implementing smart circular supply chains, there is a research gap in understanding how one sector can effectively adopt and integrate smart circularity practices into their supply chain operations. Furthermore, while Kayikci et al. (2022b) have focused on the use of smart circular supply chains for achieving Sustainable Development Goals (SDGs) in a post-pandemic context. Therefore, our work examines the integration of diverse Industry 4.0 technologies to assess the influence of Industry 4.0-oriented CE practices on the sustainable performance. We will identify best practices and measure performance using a novel framework tailored to this specific context. By utilizing extensive searches and expert input, we aim to provide insights into effective smart circularity practices in the textile industry in emerging markets.

The next section proposes a three-stage integrated decision-making model that utilizes the MCDM approach. It aims to provide a comprehensive framework for complex decisions by integrating multiple criteria and methods. This research employs expert opinions gathered through questionnaires after rigorous meetings and discussions, enhancing the validity and comprehensiveness of the study.

3. Methodology

A three-stage integrated decision-making model utilizing the Multi-Criteria Decision-Making (MCDM) approach is proposed in this research. The model aims to provide a comprehensive and effective framework for making complex decisions by integrating multiple criteria and decision-making methods. In this research, a hybrid decision-making model using Kendall's W-Fuzzy Delphi-BWM-FUCOM-CoCoSo framework is utilized to assess circularity-based sustainable performances within the context of various smart circularity practices. Figure 1 illustrates the framework of a comprehensive analysis applied.

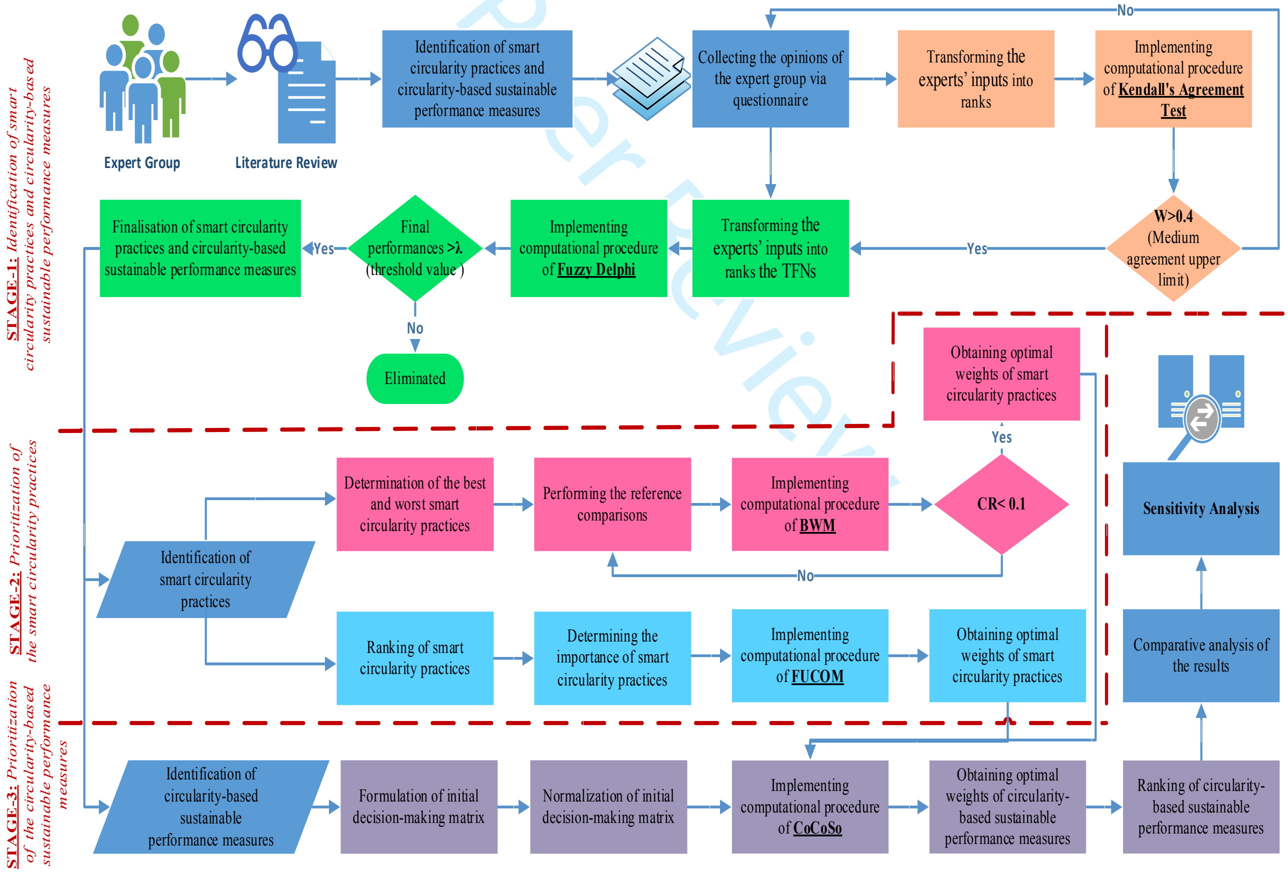

Figure 1: The hybrid decision making framework

To establish a foundation for the industry 4.0-driven circular economy (CE4.0) performance of the Indian textile industry, the initial stage of the research involved identifying smart circularity practices and circularity-based sustainable performances. This was accomplished through a questionnaire. The questionnaire was broken down into five main sections. Kendall's Agreement Test ensures reliable evaluations by assessing consensus among experts, while Fuzzy Delphi accommodates uncertainties and vagueness within expert opinions, yielding accurate and comprehensive outcomes. BWM aids in prioritizing criteria or alternatives, facilitating efficient decision-making, while FUCOM enhances coherence and consistency in pairwise comparisons to eliminate biases. CoCoSo combines multiple criteria, achieving balanced solutions that consider trade-offs. By integrating these methods, the hybrid approach provides robustness, handles uncertainties, prioritizes, fosters consistency, and achieves optimal solutions. Consequently, it stands as a valuable tool for complex decision-making scenarios.

3.1 Stage-1

The first phase focused on the identification of smart circular economy practices and sustainability performance in the T&C industries. This involved conducting a thorough literature survey to gather existing knowledge. An agreement test between two groups of experts was applied using the Kendall's test to validate their consensus for the identified practices and performance. Further, the fuzzy Delphi technique was applied to further enhance the selection and rejection of SCE practices and sustainability performance.

i) Kendall's Agreement Test: Maurice G. Kendall and Bernard Babington Smith first introduced Kendall's W, also known as Kendall's coefficient of concordance, as a non-parametric statistic in 1939. This statistical measure is employed to assess agreement among various rankings or raters, with values ranging from 0 (indicating no agreement) to 1 (representing complete agreement). Kendall's W can be computed on either an interval or ordinal scale. Higher values of the W statistic indicate a greater level of agreement among experts' groups.

The value of W determines the level of agreement among raters or respondents. W=1 means complete unanimity, with everyone assigning the same rank. W=0 indicates no agreement, and responses are essentially random. Intermediate values represent varying degrees of unanimity among the raters or respondents (Farooq *et al.*,2020; Legendre, 2005).

ii) Fuzzy Delphi Method: Multiple surveys are utilized in a Delphi process to gather and aggregate expert opinions. This method, however, requires more time and money to implement. The Fuzzy Delphi approach incorporates fuzzy set theory into the classic Delphi technique to account for the imprecision or uncertainty of experts' responses. In comparison to the Delphi method, this strategy significantly reduces the number of surveys rounds and saves time (Ali *et al.* 2023). To further enhance the reliability of the previous findings, the fuzzy Delphi method was used to finalize the CE4.0 practices and sustainable performance. This method allowed for the aggregation and evaluation of expert opinions to reach a consensus among the experts regarding the most relevant and effective measures of smart circularity practices and sustainable performance in the textile and clothing industries. Please see Appendix AA1, which has a detailed description of the Fuzzy Delphi procedure, for further information.

3.2 Stage-2

The second phase is focused on ranking the identified smart circular economy practices for achieving sustainable performance in the textile and clothing industries. Two methods were applied to accomplish this task. The BWM is based on the best-worst pairwise comparison, and then the FUCOM frameworks compare the weight coefficients of all elements in each hierarchy level. This is done to ensure the comparison is provided in a comprehensive ranking of smart circular economy practices.

i) Best Worst Method (BWM): BWM is a Multi-Criteria Decision Making (MCDM) technique (Rezaei 2015). Due to the fewer pairwise comparisons between factors and less mathematical complexity, this method is widely accepted in academia. Some current studies using this method are given in Table 1. It distinguishes itself by emphasizing the identification of the best and worst criteria and facilitating comparisons with other criteria. As a result, this approach reduces the pairwise comparison to only two vectors, streamlining the decision-making process. In contrast, while single-vector methods like SMART are efficient for large data sets, they lack the ability to guarantee consistency in pairwise comparisons. Full matrix methods like AHP enable consistency checks but can be time-consuming, particularly with large datasets. In contrast, the BWM method provides a balanced approach by allowing for consistency checks while remaining time-efficient in managing substantial amounts of data. This makes it a valuable tool for research and decision-making processes in various fields (Rezaei, 2020).

The consistency of the comparison depending on the value of ξ^L, a value close to 0 indicates higher consistency and the value is < 0.1 preferred for consistency (Rezaei, 2015). Refer to Appendix AA2 for the steps to be followed for BWM method.

ii) Full Consistency Method (FUCOM): The FUCOM, which ensures the precise assignment of weight values, mutually compares the weight coefficients of all elements in each hierarchy level and provides consistent conditions for comparison. In reality, the pairwise comparison values a_{ij} = w_i/w_j (where a_{ij} indicates the relative preference of criterion i over criterion j) are based on subjective estimates, not accurate measurements. In addition, there is a deviation of a_{ij} values from the ideal ratio w_i/w_j (where w_i and w_j represent weights of criteria i and j, respectively) (Pamučar *et al.*,2018). Table 1 includes the studies done by using the FUCOM method.

According to Pamučar *et al.* (2018), the FUCOM model, like AHP, BWM, SWARA, and DEMATEL, depends on the decision maker's subjective input to establish the weights for the criterion. The FUCOM model recommends using a straightforward algorithm, such as BWM, for implementation and evaluating the pairwise comparison's divergence from full consistency to confirm the algorithm's dependability. Notably, the FUCOM model exhibits minimal changes in weight coefficient values for criteria compared to other models under scrutiny. The steps of the FUCOM are presented in Appendix AA4.

Table 1: Recent studies on BWM, FUCOM and CoCoSo applications

Authors	**Applied method**	**Focus area**	**Experts Size**	**Objectives**
Shang *et al.*, (2022)	BWM- Fuzzy MULTIMOORA	Sustainability	17	Sustainable supplier selection.
Ali *et al.*, (2021)	BWM	Technology	8	Decision-making approach for the Drone integration in the emerging economics.
Moktadir *et al.* (2020a)	BWM, DEMATEL	Circular economy	15	Identification and evaluation of critical success factors of CE practices application.
Rezaei et al (2018)	BWM-SERVQUAL	Service quality	5	Quality assessment of airline baggage handling systems.
Khosravi *et al* (2022)	Fuzzy FUCOM-MARCOS	Structural adjustment policy	6	The most suitable organizational structure selection for hospitals.
Pamucar *et al.* (2020)	Fuzzy FUCOM-D'Bonferroni	Sustainability	5	The appropriate transportation demand management measures selection.

Pamučar *et al. (*2018)	FUCOM	Method development	1	The FUCOM model validation by comparing with respect to the subjective methods (AHP-BWM).
Ali *et al.* (2021)	Fuzzy Delphi, BWM, CoCoSo	Sustainable practice	8	Propose a framework for ranking the sustainable practices and warehousing performance.
Liu *et al.* (2021)	Pythagorean Fuzzy CoCoSo	Management of Medical waste	4	Propose a framework for selection of medical waste treatment technology.
Wen *et al.* (2019)	SWARA and CoCoSo	Cold chain logistic	4	Drug cold chain logistics selection.

3.3 Stage-3

In the third phase, the prioritization of sustainable performance measures was conducted using the CoCoSo method. Data gathered through a questionnaire and evaluated using a linguistic decision matrix helped to determine the importance of each sustainable performance. Weights found with the help of the BWM and FUCOM methods were then used in the final CoCoSo calculations.

Since its introduction by Yazdani et al. (2019), the Combined Compromise Solution (CoCoSo) method has been a popular Multi-Criteria Decision-Making (MCDM) approach. This method ranks choices based on how well they meet certain pre-dominated criteria. It does this by using both simple additive weighting and an exponentially weighted product model. In this study, sustainable performance measurements are compared to smart circular economy practices using the CoCoSo technique. The CoCoSo technique has acquired substantial interest and fame in research areas connected to supply chain management and other topics. As the method's efficacy and use have been acknowledged, it has become a useful resource for decision-making in various fields Yazdani et al. (2019). Refer to Appendix AA5 for the discussion related to steps.

Through an extensive literature review, we discovered that the integrated methods used in our study is unique and has not been previously explored. While individual methods and approaches have been widely applied in research on circular economy, green and sustainable supply chains and logistics, their integration with Industry 4.0 technology to address enablers, Critical Success Factors (CFS), practices, and performance remains unexplored. Therefore, our study fills this research gap by employing these methods in a novel context, thereby contributing to the existing body of knowledge in this field. In the next section, robust and well-designed methodology to strengthen the validity and contribution of our research based on the case is presented.

4. Case Study

The Indian firms chosen for research purpose are in the North Indian region of India. Ludhiana, Punjab has leading manufacturers of cotton, wool, and acrylic knitwear. Data is collected from the industries identified that have already implemented circularity in their integration processes. The selected textile companies had been operating for average 10 years and the minimum number of employees was 500. The selection process for circular economy experts is done in a manner that only the most qualified and experienced professionals are chosen. A comprehensive search is conducted to identify experts with relevant backgrounds in sustainability, resource management, corporate social responsibility, waste reduction and technology integration. A screening process evaluates their educational and professional qualifications, work experience, and expertise to deal with the difficult T&C projects. They were purposefully chosen to provide a broader perspective on the business landscape and other industrial aspects related to CE principle. The final selection is made based on the candidate's expertise, experience, and demonstrated ability to contribute valuable insights and recommendations on circular economy practices. They were selected based on their knowledge in implementing closed-loop production, recycling the waste, reprocessing for some raw materials activities, following "Zero waste to landfill" policy, focusing on recycling metal scraps from their manufacturing processes. The experts were from sustainable manufacturing processes, textile waste management, upcycling techniques and sustainable dyeing and finishing techniques with average work experience of 10 years. Detailed information about the experts is given in Table 2.

Table 2: Expert profile and case companies

Main features	**Turnover**	**Experts working**	**Experts experience (in years)**
Specialises in the production of sustainable and organic textiles. Also focuses on textile waste collection, sorting, and recycling processes.	USD 5-6 million annually	Three Professionals with expertise in sustainable manufacturing processes having a BTech, MBA in Supply Chain Management working as General manager	10-15
Focuses on recycling and upcycling textile waste to create new products.	USD 2-8.5 million annually	Two professionals with expertise in textile waste management having a B Tech working as Manager Operation and Production	8-12

Produces textiles using environmentally friendly processes and materials. manufactures sustainable and eco-friendly clothing using recycled materials	USD 6.2 million annually	Two professionals specialized in sustainable dyeing and finishing techniques having a BTech, MBA in Supply Chain Management working as Technical Manager	7-9
Specializes in the production of circular and regenerative fibres. manufactures sustainable and eco-friendly clothing using recycled materials.	USD 10 million annually	Two Professional experienced in sustainable fibre production having a MTech working as Director	9-11
Focuses on textile waste collection, sorting, and recycling processes.	USD 1.5 million annually	One professional experienced in textile recycling methods having a BTech, MBA in Supply Chain Management working as Senior Production manager	10

Experts remain same throughout, this continuity allowed for a thorough understanding of the study from start to finish, enabling the experts to delve into each consideration and contribute to the development of the questionnaires. By having the same experts throughout the research, we ensured that their deep familiarity with the project improved the credibility and consistency of our findings and conclusions.

To make sure there was clear communication with experts and an easy way to respond, the questionnaires for stage-based inquiries were made with separate, specific sets of questions that used scales according to analysis requirements. Through iterative rounds of email exchanges and follow-ups, the experts' feedback and insights were gathered, analyzed, and incorporated to refine and improve the questionnaire, ultimately enhancing its validity and effectiveness for data collection. In the initial stage, the experts were presented with the problem, accompanied by a brief explanation of its purpose. Subsequently, the questionnaire commenced, consisting of SCE practices questions that guided the assessments.

These questions were answered using a scale ranging from 1 to 5, where 1 corresponded to 'not considered,' 2 indicated ‘little consideration’, 3 denoted ‘an average level of consideration’, 4 represented ‘better possibilities’, and 5 indicated ‘necessary consideration’ (Ali *et al.* 2019). Any necessary changes to preserve the essence of the response value were made without compromising accuracy. Furthermore, participants were provided with an opportunity to share additional comments in cases where the answer options were insufficient or if they wished to provide further support or justification for their responses. This allowed for a more comprehensive understanding of their perspectives and ensured that all relevant aspects were adequately addressed. Kendall's

Agreement Test was employed to measure the level of agreement between two group of experts to measure their agreement and disagreement. The experts are divided in two groups depending on the year of operation as less than and more than 10 years, ensuring reliable evaluations. To gather data for acceptance and rejection of each SCE practices and circular economy related sustainable performance, the study utilized the Fuzzy Delphi technique. It is a rational process for gathering expert viewpoints and achieving consensus by using the Linguistic scale of 1(very low) to 5 (very high). This involves meeting experts, formulating questions, and iteratively refining the responses. It helps minimize biases and allows experts to revise their opinions.

In the subsequent round of stage 2, following the completion of the Fuzzy Delphi results presented in Table 3. A comprehensive list of practices and performances that have emerged through consensus from the survey is compiled. The SCE practices list is then used to gather responses using a 9-point scale, ranging from "1: equally important" to "9: extremely important," for the purposes of conducting the Best Worst Method (BWM) analysis. In the fourth round, the questionnaire is expanded to incorporate expert responses related to Smart Circular Economy (SCE) practices again for the FUCOM analysis. Experts have given their responses to the priority order of SCE practices to evaluate the importance of these practices. by using "1: strongly disagree" to "5: strongly agree." By gathering expert opinions through this approach, a comprehensive understanding of the perceived importance of SCE practices is achieved. The process included several rounds of email correspondence and diligent follow-ups to fix a meeting. The same experts took part for BWM and FUCOM questionnaire responses.

In the last, a linguistic scale is added to the questionnaire to find out how experts would rate circularity-based sustainable performance in the context of Smart Circular Economy (SCE) practices. The scale ranges from "1: very low" to "5: very high" and is included for evaluation and preferences regarding the level of circularity-based sustainable performances associated with SCE practices. Questionnaire responses were gathered from all ten experts who participated in the study from round 1 to round 5.

4.1 Finalization of Smart Circularity Practices and Circularity-based Sustainable Performance Measures

Upon reviewing the existing literature, it was apparent that the combination of methods employed in our study had not been previously utilized. These individual approaches, as well as their integration with other techniques (Ali *et al.,* 2023), have been widely employed in research pertaining to green and/or sustainable supply chain/ logistics. However, their application in conjunction with Industry 4.0 technology to address appropriate enablers, Critical Success Factors (CFS), practices, and performance has not been explored so far. Therefore, our study fills this gap by employing these methods in a novel context, contributing to the existing body of knowledge in this area. Literature search helped us to identify twelve circular practices and fourteen circularity-based sustainable performance measures. During the subsequent phase, a questionnaire was developed with the aim of determining the specific smart circular practices and circularity-based sustainable performance indicators. To gauge the level of agreement among expert assessments, Kendall's W statistic was employed prior to proceeding with the application of Fuzzy Delphi. The survey results from the experts' opinions on smart circular practices and circularity-based sustainable performances are presented in Table A4. The experts utilized a five-point scale ranging from 1 (not considered) to 5 (necessary consideration) to convey their opinions. In order to calculate Kendall's W statistic, which is used to assess stability and consensus within the Delphi method, the data in Table A4 is transformed into ranks, as shown in Table A5. This transformation is carried out using Equation (1) (Legendre, 2005), as follows:

$$\sum_{i=1}^{n} r_{ij} = 1 + 2 + \dots + n = \frac{n(n+1)}{2} \tag{1}$$

For smart circular practices and circularity-based sustainable performances, $\overline{R}$ was calculated as 65 and 75; S was calculated as 7738.5 and 11550; and W was calculated as 0.54 and 0.51 respectively, using Equations (A2-A4). Hence finally, the concordance values showed medium agreement between experts as indicated in Table A1.

Utilizing expert consensus and employing Fuzzy Delphi analysis, the smart circular practices and circularity-based sustainable performance measures were finalized. The finalized measures are presented in Table 3. Subsequently, a final questionnaire was prepared to gather responses from the experts regarding the finalized smart circular practices and circularity-based sustainable performance indicators. The acceptance threshold for all practices and performances was set at 0.7 based on the recommendations of Chang, Huang, & Lin (2000). If the de-fuzzy value of a smart circularity practice or performance is equal to or greater than 0.7, it is deemed significant; otherwise, it is considered not significant. The significant smart circularity practices and circularity-based sustainable performances, based on the threshold value, are considered for the proposed research questions and are presented in Table 3 and Figure 2.

Table 3: Finalization of the smart circularity practices and performances using Fuzzy Delphi

Smart Circularity Practices	**Lowest assessment**	**Geometric Mean**	**Highest assessment**	**Crisp value**	**Decision**
Technical capability **(SCP1)**	0.5	0.793725	0.9	0.731242	Accept
Competitive pressures	0.1	0.538937	0.9	0.512979	*Reject*
Policy and Regulation **(SCP2)**	0.5	0.774026	0.9	0.724675	Accept
Financial capability **(SCP3)**	0.5	0.813926	0.9	0.737975	Accept
Fair Acceptance	0.1	0.329723	0.7	0.376574	*Reject*
Security and Safety **(SCP4)**	0.5	0.813926	0.9	0.737975	Accept
System flexibility **(SCP5)**	0.5	0.793725	0.9	0.731242	Accept
Support and maintenance **(SCP6)**	0.5	0.754816	0.9	0.718272	Accept
Stakeholders' readiness	0.1	0.278554	0.7	0.359518	*Reject*
Regulatory Pressures	0.1	0.20345	0.7	0.334483	*Reject*
Process and product design for resource and energy efficiency **(SCP7)**	0.5	0.813926	0.9	0.737975	Accept
Education and participation **(SCP8)**	0.5	0.754816	0.9	0.718272	Accept
Circularity-Based Sustainable Performance	**Lowest assessment**	**Geometric Mean**	**Highest assessment**	**Crisp value**	**Decision**
Increase in resource circularity **(CEISP1)**	0.5	0.793725	0.9	0.731242	Accept
Better adoption of digital technology	0.1	0.278554	0.7	0.359518	*Reject*
Improve human efficiency **(CEISP2)**	0.5	0.793725	0.9	0.731242	Accept
Improve human skills	0.1	0.278554	0.7	0.359518	*Reject*
Increase in profit from green products **(CEISP3)**	0.5	0.793725	0.9	0.731242	Accept
Improved usage of green logistics **(CEISP4)**	0.5	0.793725	0.9	0.731242	Accept
Better employees and community health **(CEISP5)**	0.5	0.793725	0.9	0.731242	Accept
Improved green purchasing **(CEISP6)**	0.5	0.793725	0.9	0.731242	Accept
Better usage of green warehousing **(CEISP7)**	0.5	0.793725	0.9	0.731242	Accept
Better/improved market demand **(CEISP8)**	0.5	0.793725	0.9	0.731242	Accept
Improved develop the CE based smart culture	0.1	0.278554	0.7	0.359518	*Reject*
Increase in cost saving through product quality **(CEISP9)**	0.5	0.793725	0.9	0.731242	Accept
Decrease in emission, waste, and pollution monitoring **(CEISP10)**	0.5	0.793725	0.9	0.731242	Accept
Improved incentives and government legislation support and incentives **(CEISP11)**	0.5	0.793725	0.9	0.731242	Accept

Figure 2: Smart circularity practices and performances of T&C industry

4.2 Prioritization of Smart Circularity Practices

The experts were contacted via email to confirm their availability for a meeting to collect the response. This approach ensured a systematic and structured process for gathering professional perspectives and insights. The same group of experts who provided their perspectives to finalize the list of selected smart circular practices and sustainable performance were contacted again to gather the response. This ensured consistency and allowed for a comprehensive analysis of their opinions. By involving the same experts for the 2nd stage, their insights and expertise are utilized to enrich the study and provide a well-rounded understanding of the selected research subject. This method of data collection maintained rigorous homogeneity during various stages of the research methodology to obtain the necessary information. In the BWM implementation, the experts' input was utilized to identify both the best and worst smart circularity practices using Saaty's nine-point (1-9) scale. Other practices are ranked based on the best and worst practices that have already been chosen. The same procedure was repeated for the selection of the other smart circularity practices over the worst smart circularity practice as per their preferences. After gathering the experts' responses, we prioritized smart circularity practices using the Best Worst Method (BWM). Priority order responses were gathered and Full Consistency Method (FUCOM) was applied. These identified practices with expert responses are presented in Table A4.

BWM's optimization model according to Equation (A8) is applied to obtain the optimal weights of the smart circularity practices for ten experts and presented in Table 4.

Table 4: Best and worst smart circularity practices and performance measures along with the optimal weights from each expert

	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**E10**
Best	**SCP1**	**SCP6**	**SCP4**	**SCP2**	**SCP8**	**SCP4**	**SCP1**	**SCP1**	**SCP5**	**SCP8**
Worst	**SCP6**	**SCP3**	**SCP3**	**SCP8**	**SCP1**	**SCP6**	**SCP6**	**SCP3**	**SCP2**	**SCP2**
SCP1	0.34	0.19	0.19	0.21	0.04	0.20	0.34	0.22	0.20	0.20
SCP2	0.14	0.13	0.13	0.33	0.14	0.14	0.22	0.34	0.04	0.04
SCP3	0.11	0.03	0.03	0.07	0.15	0.03	0.04	0.03	0.06	0.06
SCP4	0.09	0.08	0.31	0.14	0.14	0.32	0.07	0.07	0.07	0.07
SCP5	0.09	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.34	0.13
SCP6	0.03	0.32	0.06	0.07	0.07	0.06	0.05	0.07	0.08	0.08
SCP7	0.06	0.05	0.06	0.07	0.07	0.07	0.09	0.07	0.08	0.08
SCP8	0.14	0.13	0.13	0.04	0.33	0.10	0.11	0.11	0.13	0.34
CR	0.10	0.05	0.07	0.08	0.08	0.09	0.09	0.10	0.06	0.06

*E refers to Expert

From Table 4, it is obvious that CR is close less than 0.10 (Rezaei 2015; 2016), so the comparisons drawn are quite consistent/reliable. Further, a single weight is found by calculating the average of each smart circularity practices and indicated in Table 5. Ranking by weight of each smart circularity practices is calculated and indicated in Table 5.

Table 5: Weight and rank of smart circularity practices by BWM

Smart circularity practices	**Weights**	**Rank**
Technical capability (SCP1)	0.2122	1
Policy and Regulation (SCP2)	0.1625	2
Financial capability (SCP3)	0.0610	8
Security and Safety (SCP4)	0.1341	4
System flexibility (SCP5)	0.1134	5
Support and maintenance (SCP6)	0.0905	6
Process and product design for resource and energy efficiency (SCP7)	0.0704	7
Education and participation (SCP8)	0.1559	3
Average Consistency Ratio (CR) = 0.07777		

To implement the FUCOM method, the first step is to establish the priority order of smart circularity practices. This is achieved by evaluating the importance levels of these practices using a Likert scale, with questionnaire input taken from a panel of same experts. The results of the FUCOM application by optimizing the final mathematical model are presented in Table 6.

Table 6: Local weights from each expert for smart circularity practices by FUCOM

	E1	E2	E 3	E 4	E5	E 6	E7	E 8	E 9	E10
SCP1	0.39	0.18	0.18	0.19	0.05	0.18	0.39	0.19	0.19	0.19
SCP2	0.13	0.12	0.12	0.37	0.12	0.12	0.20	0.39	0.05	0.05
SCP3	0.97	0.04	0.05	0.06	0.18	0.05	0.05	0.05	0.05	0.05
SCP4	0.08	0.07	0.35	0.13	0.12	0.37	0.07	0.07	0.06	0.06
SCP5	0.08	0.07	0.07	0.08	0.07	0.07	0.08	0.08	0.38	0.13
SCP6	0.05	0.35	0.06	0.06	0.06	0.05	0.05	0.07	0.08	0.08
SCP7	0.06	0.05	0.06	0.06	0.06	0.06	0.08	0.07	0.08	0.08
SCP8	0.13	0.12	0.12	0.05	0.35	0.09	0.10	0.10	0.13	0.38
DFC	0	0	0	0	0	0	0	0	0	0

From Table 6, it is evident that all deviations from full consistency (DFC) are equal to 0, for this reason, the comparisons made are highly consistent. The final weights are found by averaging the values obtained from all experts. Ranking according to the weight of each smart circularity implementation is calculated and is given in Table 7.

Table 7: Weight and rank of smart circularity practices by FUCOM

Smart circularity practices	**Weights**	**Rank**
Technical capability (SCP1)	0.2117	1
Policy and Regulation (SCP2)	0.1654	2
Financial capability (SCP3)	0.1560	3
Security and Safety (SCP4)	0.1362	5
System flexibility (SCP5)	0.1092	6
Support and maintenance (SCP6)	0.0897	7
Process and product design for resource and energy efficiency (SCP7)	0.0639	8
Education and participation (SCP8)	0.1554	4
Average Deviation from full consistency (DFC)= 0		

4.3 Prioritization of Circularity-based Sustainable Performance Measures

In the third stage, CoCoSo method is applied to get the performance priorities in relation to various smart circularity practices. The questionnaire administered includes a linguistic scale to assess the preferences of experts in evaluating circularity-based sustainable performances. A decision matrix is included in to capture each expert's response, considering evaluation of smart circularity practices. After the ten linguistic matrix decision matrices are taken, the linguistic terms are transformed into the decision matrix by replacing them with the crisp values shown in Table A3 (in Appendix AA1). Ten matrices are converted into initial decision-making matrix utilizing the average and shown in Table A6 (in Appendix).

Next, the normalized matrix is received by Equation (A15) and Equation (A16) and demonstrated in Table A7. Sj is calculated for each smart circularity-based performance by Equation (A17). Sj is shown in Table A8. Similarly, Pi is calculated using the weights obtained by BWM and FUCOM for each smart circularity performance, respectively, using Equation (A18), and presented in Tables A9 and A10.

In the last step of CoCoSo, three different aggregation methods are used to calculate the relative weights (k_{ia}, k_{ib},k_{ic}) of each smart circularity performance using the Equation (A19-A21). These relative weights are used to define the final weights (and indicated by K column) by Equation (A22, refer to Appendix AA5) is indicated in Tables 8 and 9. Depending on final weights, each smart circularity practice is prioritized, and all final ranks are calculated and indicated in Tables 8 and 9.

Table 8: Relative weights, final weights and ranking of circularity-based sustainable performance measures using BWM weights

Performance	**K_a**	**Ranking**	**K_b**	**Ranking**	**K_c**	**Ranking**	**K**	**Final Ranking**
CEISP1	0.100	5	3.262	6	0.939	5	2.107	**6**
CEISP2	0.073	9	2.586	9	0.687	9	1.622	**9**
CEISP3	0.071	10	2.133	10	0.667	10	1.423	**10**
CEISP4	0.106	2	4.029	2	0.992	2	2.459	**2**
CEISP5	0.079	8	2.978	7	0.740	8	1.823	**8**
CEISP6	0.096	6	2.935	8	0.901	6	1.944	**7**
CEISP7	0.102	4	3.573	4	0.959	4	2.249	**4**
CEISP8	0.069	11	2.000	11	0.652	11	1.356	**11**
CEISP9	0.093	7	3.453	5	0.870	7	2.125	**5**
CEISP10	0.105	3	3.842	3	0.983	3	2.377	**3**
CEISP11	0.107	1	4.041	1	1.000	1	2.471	**1**

Table 9: Relative weights, final weights and ranking of circularity-based sustainable performance measures using FUCOM weights

Performance	**K_a**	**Ranking**	**K_b**	**Ranking**	**K_c**	**Ranking**	**K**	**Final Ranking**
CEISP1	0.099	5	3.480	6	0.928	5	2.187	**5**
CEISP2	0.073	9	2.909	9	0.685	9	1.749	**9**
CEISP3	0.072	10	2.518	10	0.675	10	1.585	**10**

CEISP4	0.105	3	4.349	2	0.986	3	2.581	**2**
CEISP5	0.079	8	3.356	7	0.742	8	1.975	**8**
CEISP6	0.096	6	3.250	8	0.899	6	2.070	**7**
CEISP7	0.102	4	3.886	4	0.953	4	2.370	**4**
CEISP8	0.069	11	2.000	11	0.646	11	1.352	**11**
CEISP9	0.091	7	3.618	5	0.850	7	2.174	**6**
CEISP10	0.105	2	4.309	3	0.986	2	2.565	**3**
CEISP11	0.107	1	4.466	1	1.000	1	2.639	**1**

5. Results

Results of Stage 1: First, with the help of literature review, 12 smart circularity practices were determined to measure Industry 4.0 driven-CE performances for textile industry, and they were evaluated by 10 experts to perform Kendall's W statistic consensus analysis before the validation by Fuzzy Delphi analysis. It was observed that there was a moderate level of agreement among the experts. In the Delphi analysis application, 8 of the smart circularity practices and 11 of the circularity-based sustainable performances were accepted for further evaluation based on the acceptance criteria of 0.7.

Results of Stage 2: In order to evaluate the circularity-based sustainable performances according to the CoCoSo method, firstly, weighting processes were performed for each smart circularity practices. During the weighting process, comparative analysis was performed using the weights obtained from the FUCOM and BWM. The values found are shown in Table 10.

Table 10: BWM and FUCOM results

	BWM		**FUCOM**	
Smart circularity practices	**Weights**	**Rank**	**Weights**	**Rank**
Technical capability (SCP1)	0.2122	1	0.2117	1
Policy and Regulation (SCP2)	0.1625	2	0.1654	2
Financial capability (SCP3)	0.0610	8	0.1560	3
Security and Safety (SCP4)	0.1341	4	0.1362	5
System flexibility (SCP5)	0.1134	5	0.1092	6
Support and maintenance (SCP6)	0.0905	6	0.0897	7
Process and product design for resource and energy efficiency (SCP7)	0.0704	7	0.0639	8
Education and participation (SCP8)	0.1559	3	0.1554	4
Average consistency	**0.078**		**0**	

Determining the criteria weights in MCDM problems has important effects on the ranking of the alternatives. BWM and FUCOM methods are both methods used in criterion weighting. The processing steps of both methods are based on a simple algorithm and weights are obtained as a result of solving a mathematical model. However, when n is the number of criteria, BWM (2n-3) makes comparisons, while FUCOM (n-1) makes comparisons. These comparisons constitute the constraints of the linear programming model. In both methods, the objective function presents the consistency ratio of the comparisons made.

According to the results presented in Table 10, all circularity-based sustainable performances have weight values very close to each other except SCP3. In terms of ranking, the 1st and 2nd Ranks were the same in both methods, while the SCP3 alternative, which was in the 3rd rank in FUCOM, was in the last rank in BWM, so the next rank shifts one rank. For example, while SCP4 was in the 4th rank in BWM, it was in the 5th rank in FUCOM.

As per the calculated consistency ratios, it is interpreted that the comparisons are consistent in both methods and the results are reliable. However, since the deviation from full consistency in FUCOM is equal to 0, it can be interpreted that the received values of the criterion weight coefficients are equal to the optimum value as a result of all calculations. This is because, unlike BWM, there must be mathematical transitivity in the relationship between the criteria and the relationship between the weighting coefficients of the criteria must be equal to the comparative importance of the criteria in FUCOM. As a result, the FUCOM both reduces the processing load and can achieve reliable results by preventing the researcher from facing the problem of inconsistency while performing analysis in a short time, due to its mathematical structure and fewer pairwise comparisons.

Results of Stage-3: In the last step, the CoCoSo method was applied by using the weights obtained from both BWM and FUCOS to get the ranking of circularity-based sustainable performance. The values found are demonstrated in Table 11.

Table 11: CoCoSo results

Performance	**Ranking of K_a**		**Ranking of K_b**		**Ranking of K_c**		**Final Ranking of K**	
	BWM	**FUCOM**	**BWM**	**FUCOM**	**BWM**	**FUCOM**	**BWM**	**FUCOM**
CEISP1	5	5	6	6	5	5	6	5
CEISP2	9	9	9	9	9	9	9	9
CEISP3	10	10	10	10	10	10	10	10
CEISP4	2	3	2	2	2	3	2	2
CEISP5	8	8	7	7	8	8	8	8
CEISP6	6	6	8	8	6	6	7	7
CEISP7	4	4	4	4	4	4	4	4
CEISP8	11	11	11	11	11	11	11	11

CEISP9	7	7	5	5	7	7	5	6
CEISP10	3	2	3	3	3	2	3	3
CEISP11	1	1	1	1	1	1	1	1
r_s	**0.99**		**1.00**		**0.99**		**0.99**	

These weight changes in different methods (BWM and FUCOS) revealed minor changes in the ranking of the circularity-based sustainable performances. From Table 11, most of the circularity-based sustained performances are perceived to remain the same or slightly change across all aggregation approaches. Sperman's rank correlation coefficient (rs) is used to determine the correlation between the obtained circularity-based sustainable performances rankings and takes a value between 0 and 1. When the obtained value is greater than 0.8, a very strong similarity is mentioned. According to Table 11, all correlation coefficients are greater than 0.8 and there is a strong similarity between the results. Thus, we could deduce that the proposed method is adequately consistent, reliable, stable, and robust to acquire the result.

5.1 Robustness of Model

Multi-Criteria Decision Making (MCDM) strategies have been developed to aid decision makers in comprehending complex problems and considering diverse factors that may impact their decisions. These strategies aim to facilitate the identification of "Good" enough solutions through a systematic evaluation process (Ali, *et al.* 2021, 2023). The presence of variations in a selected set of variables or even in endogenous variables serves as an indication of robustness and provides insights into the stability and reliability of the results. In this section, the weights of the criteria are varied and the changes that may occur in the result are tried to be determined. Sensitivity analysis is performed by gradually changing the weight of the criterion with the highest importance (weight). The highest weighted criterion for smart circular applications is SCP1- “Technical capability”, so nine tests were created by changing the weight of this criterion from 0.1 to 0.9 in increments of 10%. According to the change in SCP1 weight, other criteria weights were changed in proportion to their own weight ratio, and the total weight percentage was ensured to be 100%. Steps followed are represented in Appendix AA6. w_i^0 and w_j^0 are the weight values of criteria i and j before the sensitivity analysis, respectively. In this context, 9 different experimental sets created by changing the weights of the criteria obtained by both BWM and FUCOM are given in Tables 12 and 13.

Table 12: The first experiment set of smart circularity practices weights for sensitivity analysis

SCPs	**Original by BWM**	**Test-1**	**Test-2**	**Test-3**	**Test-4**	**Test-5**	**Test-6**	**Test-7**	**Test-8**	**Test-9**
SCP1	**0.2122**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
SCP2	0.1625	0.1856	0.1650	0.1444	0.1238	0.1031	0.0825	0.0619	0.0413	0.0206
SCP3	0.0610	0.0697	0.0619	0.0542	0.0465	0.0387	0.0310	0.0232	0.0155	0.0077
SCP4	0.1341	0.1532	0.1362	0.1192	0.1021	0.0851	0.0681	0.0511	0.0340	0.0170
SCP5	0.1134	0.1296	0.1152	0.1008	0.0864	0.0720	0.0576	0.0432	0.0288	0.0144
SCP6	0.0905	0.1034	0.0919	0.0804	0.0689	0.0574	0.0460	0.0345	0.0230	0.0115
SCP7	0.0704	0.0804	0.0715	0.0626	0.0536	0.0447	0.0357	0.0268	0.0179	0.0089
SCP8	0.1559	0.1781	0.1583	0.1385	0.1187	0.0989	0.0792	0.0594	0.0396	0.0198

Table 13: The second experiment set of smart circularity practices weights for sensitivity analysis

SCPs	**Original by FUCOM**	**Test-1**	**Test-2**	**Test-3**	**Test-4**	**Test-5**	**Test-6**	**Test-7**	**Test-8**	**Test-9**
SCP1	**0.2117**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
SCP2	0.1654	0.1888	0.1679	0.1469	0.1259	0.1049	0.0839	0.0629	0.0420	0.0210
SCP3	0.1560	0.1781	0.1583	0.1406	0.1187	0.0989	0.0792	0.0594	0.0396	0.0198
SCP4	0.1362	0.1555	0.1382	0.1227	0.1037	0.0864	0.0691	0.0518	0.0346	0.0173
SCP5	0.1092	0.1247	0.1108	0.0984	0.0831	0.0693	0.0554	0.0416	0.0277	0.0139
SCP6	0.0897	0.1024	0.0910	0.0808	0.0683	0.0569	0.0455	0.0341	0.0228	0.0114
SCP7	0.0639	0.0730	0.0648	0.0576	0.0486	0.0405	0.0324	0.0243	0.0162	0.0081
SCP8	0.1554	0.1774	0.1577	0.1400	0.1183	0.0986	0.0789	0.0591	0.0394	0.0197

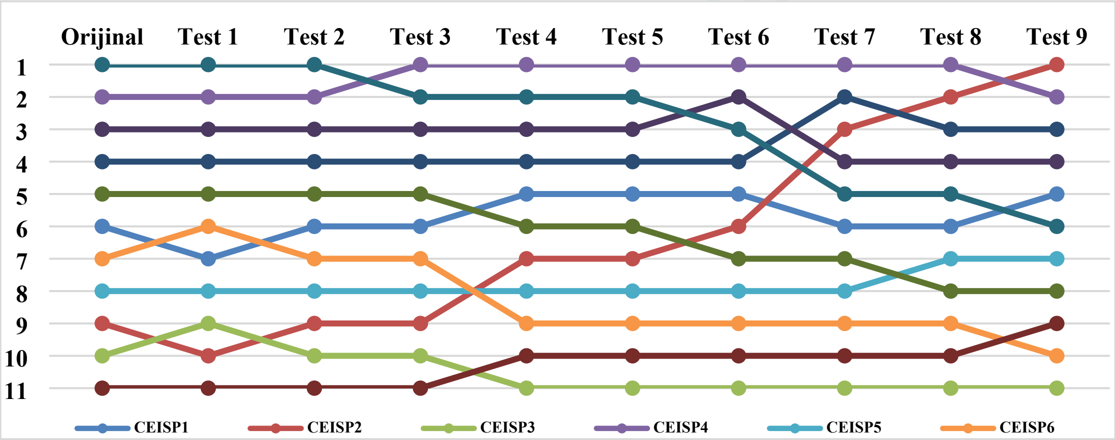

Figure 3: The graphical view of circularity-based sustainable performance ranking in the first experiment set

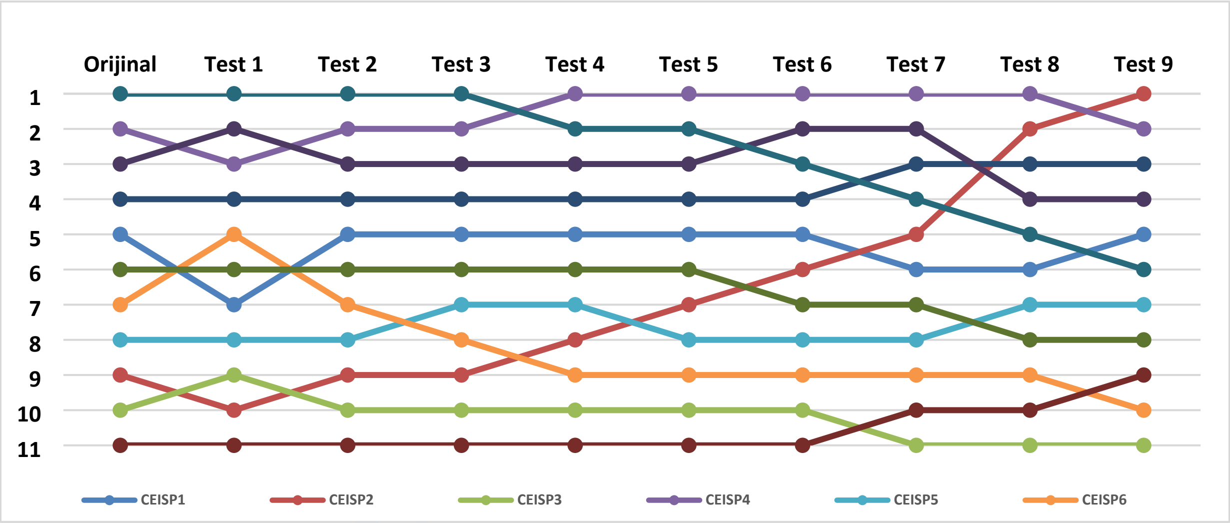

Figure 4: The graphical view of circularity-based sustainable performance ranking in the second experiment set

The ranking of circularity-based sustainable performance obtained by the CoCoSo method using a total of 18 different test data created by changing the existing weights obtained as a result of each criteria weighting method (BWM and FUCOM) is presented in Tables A11 and A12 respectively. In Figures 3 and 4, the changes in the Circularity-based sustainable performance rankings can be seen more clearly.

According to this, other Circularity-based sustainable performances other than CEISP2 and followed by CEISP11 either remained the same or changed slightly in all tests. On the other hand, CEISP2, which was 9th in both original rankings (BWM and FUCOM), increased overall and ranked 1st in the final tests. Again, CEISP11, which was in the 1st in both original rankings (BWM and FUCOM), decreased 1 step in the first 5 tests to the 2nd, and in the following tests, it decreased continuously and regressed to the 6th rank in the last tests. From this point of view, it can be concluded that the best criterion, SCP1- "Technical capability", sensitizes the ranking results because it has an effect on these two performances (CEISP2 and CEISP11), and since the changes in other sustainable performance rankings are very small, the ranking results are robust and stable.

6. Discussion of Findings

Sustainability and the adoption of circular economy practices are indeed becoming increasingly important for organizations. This is justified as the transition from traditional production models to more sustainable practices require evaluating sustainability performance and finding ways to balance economic growth with environmental protection and aligned with the findings of Bag *et al.* (2021b). Organizations are facing increasing pressure to change the production models from traditional to sustainable and rather Industry4.0 driven, which strengthens the requirement to evaluate their performance at sustainability points, as highlighted by Kayikci *et al.* (2022 a) in their discussions. Industry 4.0 has accelerated the process of overcoming the barriers to circularity, and digitalization has become progressively facilitating for the implementation and adoption of the CE and aligned with Kouhizadeh *et al.* (2020). Scholars and academics have paid close attention to how government support changes in the plans and actions of systems in a CE4.0.

The case companies were selected from the Indian region involved in the highest T&C production. These organizations from the Punjab region in Ludhiana demonstrated their commitment to circular economy principles related to the study's focus, such as green practices, sustainability, technology adoption, and innovation by implementing sustainable practices, utilizing recycled materials, and embracing innovative techniques to contribute to a more sustainable textile industry in India.

Since the research goal of the study is to determine the effect of smart circularity practices on achieving sustainability performances, qualitative concepts such as ideas and thoughts on this subject was evaluated with the help of experts after reviewing the literature, a similar pattern of findings was followed in research of Ali *et al*. (2023) and Khan *et al.*, (2022). An experts' group specialized in the textile industry was formed to explore and document opinions regarding smart circular economy practices. The group comprised ranges from various sectors, including textile manufacturing, sustainability, fashion design, waste management, and technology. Through insightful discussions and collaborative sessions, these experts shared their extensive knowledge and experiences in implementing circular economy strategies within the textile industry. Their opinions were meticulously recorded, capturing innovative ideas, best practices, and potential challenges specific to the textile sector. This valuable repository of expertise serves as a guide for industry stakeholders, policymakers, and researchers seeking to foster sustainable practices, minimize waste, and promote circularity in the textile value chain. After a detailed literature review and consultation with the experts, 10 smart circularity practices and in the context of achieving sustainability in the textile industry, 12 circularity-based sustainable performance indicators were determined. The selection process ensures a high level of expertise and diversity within the expert group, enhancing the quality and impact of their work. Therefore, our research study incorporated various decision-making frameworks to answer research questions depending on the type of data we need. The pretesting of a questionnaire involved an experts' group, utilizing Kendall's Agreement Test and Fuzzy Delphi methodology. The experts were provided with the questionnaire and were asked to assess its clarity, relevance, and comprehensiveness. The Fuzzy Delphi technique helped capture their opinions, accounting for uncertainties and vagueness. These applications were finalized using the concordance agreement test and the Fuzzy Delphi method in line with the responses from ten relevant experts. Once the sustainable performance metrics and smart circular practices were finalized, a questionnaire was further developed. These frameworks involve qualitative methods, such as BWM, and FUCOM. By combining these methods, a comprehensive evaluation of circular economy performance was achieved through CoCoSo. A robustness analysis was further done to validate the results of the analysis

Discussion based on BWM & FUCOM. The emergence of Industry 4.0 and the digitalization of processes have played a significant role in facilitating the adoption of circular economy practices. This aligns with the concept of Industry 4.0-driven circular economy, where technological advancements enable greater efficiency and optimization in resource usage as highlighted by Kouhizadeh *et al.* (2020), Sahoo *et al.* (2023), and Bag *et al.* (2021a). This study focused on sustainable performance criteria in circular economy (CE) organizations. Technical proficiency and the capacity to adopt ground-breaking technology for resource and energy efficiency are key factors in sustainable performance in our work and matches with the findings of Sahoo *et al.* (2023). Organizations that promoted innovative technologies and technical competence were more sustainable. Policy and regulation, which encourages circular practices and sets resource efficiency requirements, was the second most important component is aligned with Ali *et al.* (2023). Education and participation placed third, emphasizing stakeholder awareness and engagement. Education about CE principles and encouraging sustainable practices improves sustainable performance. However, education and participation are ranked last in FUCOM. Security, safety, waste, and hazardous materials management scored fourth for sustainable performance. System flexibility—adaptability to market needs and environmental changes—ranked fifth and contradicts with the Lopez, *et al.* (2019). Support and maintenance were crucial to optimizing circular practices and reducing waste, hence supports Salvioni, & Almici (2020) work, while resource and energy-efficient processes and product design affected sustainability. Financial capability—sufficient funds and investments—ranked last in BWM. However, financial capacity helps organizations adopt circular programs and support sustainable technologies, and it is ranked 3rd in FUCOM.

Discussion based on CoCoSo. The study revealed that improved incentives by the government and legislation were ranked as the top performers for promoting sustainability. These measures play a crucial role in encouraging organizations to adopt sustainable practices by providing financial benefits and creating a favorable regulatory environment and similar to the contributions of researchers like Jaeger & Upadhyay (2020); Moktadir *et al.* (2020a) and Ali and Kaur (2022). The second-ranked performance was the improved usage of green logistics is similar results aligned with Manickam, & Duraisamy, (2019). This includes initiatives such as optimizing transportation routes, adopting eco-friendly packaging, and utilizing sustainable transportation methods to reduce carbon emissions and minimize environmental impact. Third on the list was monitoring and reducing emissions, waste, and pollution is similar to Sahoo, *et al.* (2023). Organizations that actively monitor and manage their carbon emissions, waste generation, and pollution levels were found to be more sustainable. The next-ranked performance was better usage of green warehousing (Ali *et al.* 2023). This involves implementing sustainable and energy-efficient practices in warehousing operations, such as utilizing renewable energy sources and minimizing waste generation and supports work of Kazancoglu *et al*. (2020). The fifth-ranked factor was the increase in resource circularity, which refers to maximizing the reuse, recycling, and recovery of materials to minimize resource depletion and environmental impact.

Further down, the study identified other performances such as cost savings through product quality, improved green purchasing, better employee and community health, improved human efficiency, increased profit from green products, and better or improved market demand, all of which contribute to sustainable circular economy performance. These were aligned with the findings of Ali *et al.* (2023)

6.1 Theoretical Contributions

This study has several theoretical contributions to the literature by addressing measurement of Industry 4.0 driven circular economy performance in textile industry. Firstly, this research provides a detailed literature review in smart circularity practices and circularity-based sustainable performance indicators, determines them in in textile industry based on expert opinions. Secondly, a novel hybrid decision-making framework containing Kendall's W-Fuzzy Delphi-BWM-FUCOM-CoCoSo is proposed. This hybrid approach is not only useful for powerful decision-making, but also allows practitioners, managers, and users to address and solve problems effectively. As a theoretical base, NRBV was adopted in this study. Smart circularity practices and circularity-based sustainable performance indicators were separately examined in the current literature based on NRBV and gathered under a three-stage integrated decision-making tool. Because this approach provides key organizational primary resources and strategic capabilities for smart circularity practices to improve circularity-based sustainable performance and achieve competitive advantages.

6.2 Managerial Implications

This study introduces a novel hybrid approach for evaluating the Circular Economy performance of the textile industry in the context of Industry 4.0. This approach can assist industry leaders, and other stakeholders in the textile industry to monitor progress and make informed decisions related to circular economy initiatives. The application of smart circularity refers to the utilization of digital technologies throughout a product's life cycle to implement circular strategies and practices (Sahoo *et al.* 2023). This includes leveraging digital tools for optimizing resource use, enabling product tracking and traceability, facilitating sharing and collaboration, and achieving efficient and sustainable operations (Salvioni, & Almici 2020). The results verify the role of improved incentives and government legislation support and incentives for positive results. Government support and incentives are crucial in promoting and encouraging the implementation of circular economy practices in industries. The Punjab region of India, for example, serves as a case study in understanding the importance of such support and legislation in driving positive outcomes.

The findings of this study have several managerial implications. Organizations should focus on adopting innovative technologies and building technical competence to improve their sustainable performance in the circular economy (Sahoo *et al.* 2023). This may involve investing in advanced machinery and systems that enable resource and energy efficiency. Policy and regulation play a crucial role in promoting circular practices and setting resource efficiency requirements. It is crucial for government bodies and lawmakers to introduce improved incentives and legislation that support sustainable practices. Therefore, managers should actively engage in policy discussions and ensure compliance with relevant regulations. Educating stakeholders about circular economy principles and encouraging their participation in sustainable practices can significantly improve sustainable performance. This highlights the importance of awareness campaigns and training programs within organizations. Managing security, safety, waste, and hazardous materials is vital for sustainable performance (Salvioni, & Almici 2020). Organizations should prioritize the effective management of these aspects to reduce environmental risks and improve sustainability. Additionally, system flexibility and the ability to adapt to market needs and environmental changes are critical for sustainable performance. Managers should strive to create agile and adaptable systems that can respond effectively to changing circumstances. Organizations should focus on optimizing their logistics operations to reduce carbon emissions and minimize environmental impact. Initiatives such as optimizing transportation routes, adopting eco-friendly packaging, and using sustainable transportation methods are effective in achieving this goal.

Actively monitoring and managing carbon emissions, waste generation, and pollution levels is essential for organizations to enhance their sustainability performance. Next, implementing sustainable and energy-efficient practices in warehousing operations can contribute to sustainability goals. This includes replacing them with renewable energy sources and minimizing waste generation (Kazancoglu *et al*., 2020). Additionally, increasing resource circularity by maximizing reuse, recycling, and recovery of materials helps to minimize resource depletion and environmental impact. Financial capability ranks lower in the BWM analysis, but it should not be neglected as organizations can achieve sustainability objectives by aiming to achieve cost savings through product quality, improved green purchasing, better employee and community health, improved human efficiency, increased profit from green products, and responding to market demand. By providing financial benefits and creating a favorable regulatory environment, organizations are more likely to adopt sustainability initiatives. Managers should allocate appropriate resources to ensure the successful implementation of circular economy initiatives (Kazancoglu *et al*., 2022).

7. Conclusion, Limitation and Future Research

The Circular Economy is a pivotal component of the United Nations 2030 Agenda for Sustainable Development. The transition to CE can be facilitated by the technologies of Industry 4.0, which represent a significant driver of digital transformation (Nobre & Tavares, 2023). The implementation of CE can facilitate the achievement of sustainable development in businesses. However, the precise relationship between CE and sustainable development is not clearly defined in the existing literature. Furthermore, additional research is required to investigate the potential of Industry 4.0 technologies to facilitate reverse flow activities and reduce impurities in recycled materials, thereby enabling the closure of the loop (Panchal *et al*., 2021). The scientific community has already established models, theoretical frameworks, and case studies that demonstrate the connection between CE and Industry 4.0 (Nobre & Tavares, 2023). The subject of CE is studied in different fields, including automotive (Montemayor & Chanda, 2023), electronics (Pinheiro *et al*., 2022), pulp and paper (Amândio *et al*., 2022), metals and mining (Golev & Corder, 2016), energy (Jansson & Holmberg, 2022), construction (Hossain *et al*., 2020), and others. A variety of techniques have been employed to assess the CE performance (Panchal *et al*., 2021). Nevertheless, the research agenda must address the lack of understanding of how practitioners use these technologies to drive circularity (Nobre & Tavares, 2023). This article aims to understand how Industry 4.0 technologies support the transition to CE for the textile industry and how Industry 4.0-focused CE practices affect sustainable business performance by developing a three-stage hybrid decision-making framework that integrates various methods outside the areas studied in the literature. As highlighted by (Coppola *et al.* 2023), SCE practices in the textile industry help mitigate environmental impact by conserving natural resources, reducing greenhouse gas emissions, and minimizing landfill waste. These practices foster sustainability within the industry and facilitate the shift towards a circular and environmentally conscious textile ecosystem. It has become increasingly evident that the conversation is shifting from Corporate Social Responsibility (CSR) to finance decision-makers (Ali & Kaur 2021).

Academic research in the textile industry must progress rapidly in order to resolve the implications of Industry 4.0 on sustainability and the Circular Economy (CE) and to identify knowledge gaps associated with it. For future research, the solution framework discussed for the textile industry can be tested for other industries. It could be to examine the extent to which the findings of this study can be applied to other sectors through the conduct of an additional case study of a company operating within a different area. Finally, different combinations could be tried by changing the MCDM methods used in the study with other existing methods. The solution framework can be expanded by combining them with different techniques by using the concepts of transitioning to sustainable practices, the role of Industry 4.0 in circular economy adoption, and the significance of government support. Future research needs to focus on conducting theory-based empirical investigations to test the effectiveness of the decision-making model, specifically using reflective and formative constructs. There is a need to investigate the practical challenges and barriers that decision-makers may face when implementing the model in other emerging markets related to textile industries. Taking into account factors such as organizational culture, information availability, stakeholder involvement, and resource requirements can help in the development of strategies and guidelines for dealing with them. It is critical to investigate the scalability, flexibility, and customization of smart circular economy practices and CE-based sustainable performance to fit other sectors and other industries. Integration of the model with emerging technologies such as artificial intelligence, machine learning, digital twin, and big data analytics can also be investigated in order to capitalize on their potential for improving the model's capabilities and addressing evolving sustainability practices and emerging circularity concepts. Through these technologies, comparisons can be made by simulating an existing linear economy business with a circular economy. The FUCOM scale utilized in our research is an integer; however, this might be investigated with a decimal or fuzzy scale.

A limitation of this article is that the current and planned operations of selected textile companies are not publicly available. As a result, some details about the companies' activities may have been left out. In addition, the determination, evaluation, and performance indicators finalization of the smart circularity practices and its circularity-based sustainable performance were made according to today's conditions within the limitations of the study, and it should not be overlooked that they may vary depending on the rapidly changing and developing economic and technological conditions, and also that applying with different experts or choosing different solution methods may produce different results.

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Appendix A

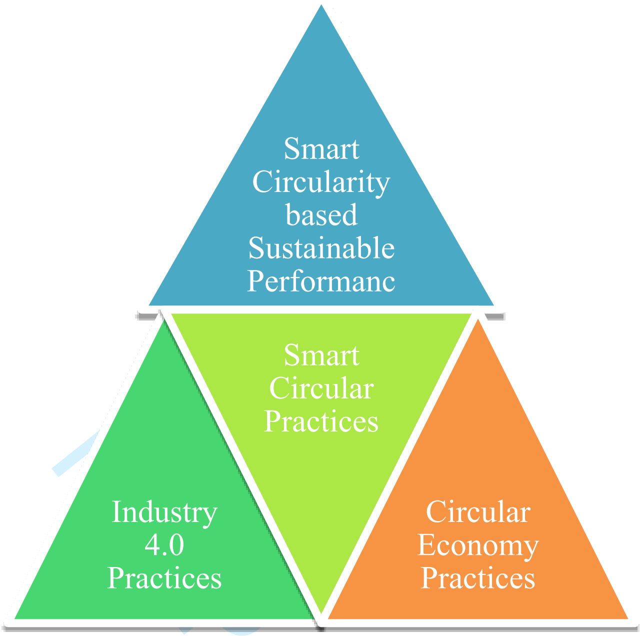

Figure A1. Conceptual Framework

AA1: Steps of Kendall's Agreement Test

Table A1: The Kendall's W agreement degree

Correlation Coefficient	Interpretation
1	Perfect agreement
0.9–1	Very high agreement
0.7–0.9	High agreement
0.4–0.7	Medium agreement
0.2–0.4	Low agreement
0–0.2	Very low agreement
0	No agreement

Assume that item i is given the rank r_{ij} by rater number j, where there are m raters and n items in total. The calculation process begins with the sum of the ranking of item i via Equation (A1) (Farooq et al.,2020):

$$R_i = \sum_{j=1}^{m} r_{ij}, \tag{A1}$$

and the mean value of total ranks is:

$$\overline{R} = \frac{1}{n}\sum_{j=1}^{n} R_i, \tag{A2}$$

The sum of squared deviations (S) is defined as

$$S = \sum_{i=1}^{n} (R_i - \overline{R})^2, \qquad \text{(A3)}$$

and Kendall's W is measured from the Equation (A4):

$$W = \frac{12S}{m^2(n^3 - n)} \qquad \text{(A4)}$$

After applying Equation (A4), the result will give the concordance among the different raters.

AA2: Steps of Fuzzy Delphi

Step 1. Identify the criteria/ factors

In this step, the sensible criteria/factors (for our study; smart circularity practices & circularity-based sustainable performance measures) related to the identified problem are determined through experts' interviews and a literature survey.

Step 2. Collecting the experts' opinions

The experts' opinions are collected for the importance of the smart circularity practices and circularity-based sustainable performance by a questionnaire survey. As Table A2 shows, we construct the questionnaire using a five-point Linguistic scale to get expert opinions.

Table A2: Linguistic scale and their related TFNs

Scale	Level of significance	Triangular fuzzy number
1	Very low	(0.1,0.1,0.3)
2	Low	(0.1,0.3,0.5)
3	Medium	(0.3,0.5,0.7)
4	High	(0.5,0.7,0.9)
5	Very high	(0.7,0.9,0.9)

Step 3. Setting up of the triangular fuzzy numbers

According to Table 3, the inputs of the experts are converted into TFNs. The maximum and minimum values of the experts' input are calculated using TFNs. Our study applied the geometric mean (M_A) to demonstrate the consensus of the expert group. The computation procedure is given as follows:

Assume the evaluation value of the importance of the jth element given by ith expert among the n experts is $\tilde{w}_{ij} = (l_{ij}, m_{ij}, u_{ij})$, $i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, m$. Then fuzzy weighting $\tilde{w}_j$ of jth element is:

$$\tilde{w}_j = (l_j, m_j, u_j)$$

$$l_j = min_i(l_{ij})$$

$$m_j = \sqrt[n]{\prod_i^n m_{ij}} \tag{A5}$$

$$u_j = max_i(u_{ij})$$

Where w_{ij} denotes that ith expert's evaluation for smart circularity practices and circularity-based sustainable performance measures j, l_j characterize the lowest appraisal values of smart circularity practices and circularity-based sustainable performance measures j, m_j demonstrate the M_A of all the expert assessment values for element j, and u_j demonstrates the highest expert assessment values for criterion j.

Step 4. Defuzzification of the TFNs

TFNs are transformed into crisp number (S_i) of each smart circularity practices and circularity-based sustainability performance measures operating the center of gravity method as per Equation (A6)

$$S_j = \left(\frac{l_j + m_j + u_j}{3}\right) \tag{A6}$$

Step 5. Finalisation of the smart circularity practices circularity-based sustainable performance

The last step of the Fuzzy Delphi is the finalization of the smart circularity practices and circularity-based sustainable performance. To obtain the significant smart circularity practices and their corresponding circularity-based sustainable performance, the weights obtained for each factor are compared with a threshold value (λ). The logic behind the significant smart circularity practices and their corresponding circularity-based sustainability performance selection process is as follows:

If $S_i \geq \lambda$, then the practice/performance i is selected.

If $S_i < \lambda$, then the practice/performance i is rejected.

AA3: Steps of BWM

Step 1. Identification of smart circularity practices

The significant smart circularity practices ("n" number of smart circularity practices: SCP1, SCP2, SCP3,…,SCPn) are identified as a result of Fuzzy Delphi.

Step 2. Determine the best and worst smart circularity practices.

The experts specify the best and the worst smart circularity practices among the finalized smart circularity practices. The best and worst smart circularity practices is indicated as cB, and cW respectively.

Step 3. Implement the reference comparisons with smart circularity practices.

The preference of the best smart circularity practices is determined over all the other smart circularity practices utilizing 9-point scale (1-9) by expert input and characterized by the AB vector as:

AB = (aB1, aB2, ..., aBn)

Where AB the Best-to-Others (BO) vectors, aBj refers the preference of the best smart circularity practices B over smart circularity practices j and aBB=1

Step 4. Implement the reference comparisons with worst smart circularity practices

The preference of all the other smart circularity practices is determined over the worst smart circularity practices utilizing 9-point scale (1-9) by expert input and characterized by AW vector as:

AW = $(a_{1W}, a_{2W}, \ldots, a_{nW})$T

Where AB the Others-to-Worst (OW) vector, a_{jW} denotes the preference of the smart circularity practices j over the worst smart circularity practices W and $a_{WW} = 1$

Step 5. Determine the optimal weights

The optimum weight for each smart circularity practice is the one where, for each pair wB/wj and wj/wW, it must have wB/wj = aBj and wj/wW = ajW. For satisfying these conditions for all j, maximum absolute differences minimized of the set {|wB −aBjwj|, |wj − ajWwW|}. The problem could be represented as follow:

min max {|wB −aBjwj|, |wj − ajWwW|}.

Subject to:

$$\sum_j w_j = 1 \qquad \text{(A7)}$$

$w_j \geq 0$; ⍰j

Model (A7) can be transformed into following linear problem.

min ξ^L

s.t.

$\left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi^L$ for all j

$\left|\frac{w_j}{w_W} - a_{jW}\right| \leq \xi^L$ for all j

$\sum_j w_j = 1$

$w_j \geq 0$ for all j (A8)

The optimum weights of each smart circularity practices (w_1^*,w_2^*, w_3^*..... w_n^*) and optimal value of ξ^Lobtained by solving the linear problem Equation (A8). Also, the consistency ratio (CR) of the comparisons is checked.

AA4: Steps of FUCOM

Step 1. Ranking of criteria

The criteria from the predefined criteria set $C = \{C_1, C_2, ..., C_n\}$ are ranked. Ranking is done according to the importance of the criteria; beginning from the criterion that is predicted to have the highest weighting coefficient to the criterion of the least importance. Therefore, the criteria ordered according to the expected weight values are obtained.

$$C_{j(1)} > C_{j(2)} > ... > C_{j(k)} \quad \text{(A9)}$$

where k presents the order of the mentioned criterion. If there are more than one criterion with the same importance, the " = " sign is positioned between these criteria instead of the " > " sign in Expression (A9)

Step 2. Determining the importance of the criteria

A comparison of the ranked criteria is performed and the comparative importance $\varphi_{k/(k+1)}$ of the criteria is determined. $\varphi_{k/(k+1)}$ presents the importance (priority) of $C_{j(k)}$ rank compared to $C_{j(k+1)}$ rank. The vectors of the comparative importance (priorities) of the evaluation criteria are got as;

$$\phi = (\varphi_{1/2}, \varphi_{1/2}, \ldots, \varphi_{k/(k+1)}) \quad \text{(A10)}$$

The FUCOM method permits pairwise comparison of criteria utilizing integer values, decimal values, or values of a predefined scale.

Step 3. Finding the final values of the weight coefficients

The final weight coefficients values of the evaluation criteria $(w_1, w_2, ..., w_n)^T$are calculated. They must meet the following two conditions:

The weight coefficients ratios should equal to the comparative priority among the criteria, i.e., the following condition is met:

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} \quad \text{(A11)}$$

The final weight coefficients values must meet the mathematical transitivity condition, i.e., $\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$. Since $\varphi_{k/(k+1)} = \frac{w_k}{w_{k+1}}$ and $\varphi_{(k+1)/(k+2)} = \frac{w_{k+1}}{w_{k+2}}$, that $\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$ is obtained. Thus, another condition is obtained,

$$\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \tag{A12}$$

Full consistency i.e., minimum deviation from full consistency (χ) is satisfied only if transitivity is completely respected, i.e., when both conditions given above are met. In this way, the requirement for maximum consistency is fulfilled, i.e., $\chi = 0$ for the obtained the weight coefficient values. In order for the conditions to be met, the weight coefficient values $(w_1, w_2, \ldots, w_n)^T$ must meet the condition $\left|\frac{w_k}{w_{k+1}} - \varphi_{k/(k+1)}\right| \leq \chi$ and $\left|\frac{w_k}{w_{k+2}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \leq \chi$ with the minimization of the value χ. In this way, the maximum consistency requirement is satisfied. In this way, the requirement for maximum consistency is fulfilled. Based on the settings defined, the final model can be defined as follows to determine the final the weight coefficients values of the criteria.

Min χ

s.t.

$\left|\frac{w_k}{w_{k+1}} - \varphi_{k/(k+1)}\right| \leq \chi$, for all *j*

$\left|\frac{w_k}{w_{k+2}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \leq \chi$, for all *j*

$\sum_{j=1}^{n} w_j = 1$, for all *j*

$w_j \geq 0$ for all *j* (A13)

By solving the model (A13), the final values of $(w_1, w_2, \ldots, w_n)^T$ and the degree of χ are obtained (Pamučar *et al.*,2018).

AA5: Steps of CoCoSo

Step 1. The initial decision matrix is formulated with linguistic terms according to the evaluation criteria/applications as indicated in Table A3. This matrix is as follows:

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}; i = 1,2,\ldots.n, j = 1,2,\ldots.m \tag{A14}$$

The matrix $[X]_{m\times n}$ represents the initial decision-making matrix that contains the m: number of alternatives (performances) and n: evaluation criteria(practices). In this context, "x_{ij}" contains that the ith "circularity-based sustainable performances" are realized by adopting the jth smart circularity practices.

Table A3: Linguistic scale with associated crisp value

Linguistic Scale	**Crisp Value**
Very Low (VL)	1
Low (L)	2
Medium (M)	3
High (H)	4
Very High (VH)	5

Step 2. The normalization of the initial decision-making matrix is executed by the Equations (A15 -A16) (Zeleny, 1973):

For benefit criteria

$$r_{ij} = \frac{x_{ij} - \min\limits_{i} x_{ij}}{\underset{i}{max}\, x_{ij} - \min\limits_{i} x_{ij}}\,; \qquad \text{(A15)}$$

For non-benefit/cost criteria

$$r_{ij} = \frac{\max\limits_{i} x_{ij} - x_{ij}}{\underset{i}{max}\, x_{ij} - \min\limits_{i} x_{ij}}; \qquad \text{(A16)}$$

Step 3. The weighted comparability sequence (S_i) and its' power weight (P_i) for each alternative are calculated by the Equations (A17-A18) respectively.

$$S_i = \sum_{j=1}^{n} (w_j r_{ij}) \qquad \text{(A17)}$$

$$P_i = \sum_{j=1}^{n} (r_{ij})^{w_j} \qquad \text{(A18)}$$

Step 4. Relative weights of each alternative are calculated by three aggregation approaches that are provided as Equations (A19–A21):

$$k_{ia} = \frac{S_i + P_i}{\sum_{i=1}^{m} (P_i + S_i)}; \qquad \text{(A19)}$$

The Equation (A19) indicates the arithmetic mean of sums of scores, weighted sum measure (S_i) and weight power measure (P_i)

$$k_{ib} = \frac{S_i}{\min\limits_{i} S_i} + \frac{P_i}{\min\limits_{i} P_i} \qquad \text{(A20)}$$

The Equation (20) delivers a sum of S_i and P_i compared to the best.

$$k_{ic} = \frac{\lambda(S_i)+(1-\lambda)(P_i)}{(\lambda \max\limits_i S_i + (1-\lambda) \max\limits_i P_i)} \tag{A21}$$

The Equation (A21) signifies the balanced compromise of S_i and P_i scores. The value of λ is usually 0.5 or it may be chosen by experts according to need.

Step 5. The weight of the alternatives is based on the value of k_i, it is calculated by Equation (22).

$$k_i = (k_{ia}k_{ib}k_{ic})^{\frac{1}{3}} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic}) \tag{A22}$$

The final ranking is achieved according to the descending order of $k_i$values i.e., the alternative (performance) with the larger value of k_i is more important.

AA6: Steps of Sensitivity Analysis

The following equation was used for the sensitivity analysis to be applied to the relevant criteria (Triantaphyllou and Sanchez, 1997; Triantaphyllou, 2000):

$$\mathrm{w}_j = (1 - w_i) * \left(\frac{w_j^0}{(1-w_i^0)}\right) \tag{A23}$$

w_j shows the new weight value to be used in the sensitivity analysis of criterion j.

w_i is the new weight value of criterion i, subjected to weight increase or decrease in the sensitivity analysis.

Table A4: Questionnaire results

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
Smart circularity practices										
PR1	4	5	5	4	5	4	5	4	5	4
PR2	2	2	3	2	4	4	5	4	4	4
PR3	4	5	4	4	5	4	5	4	5	4
PR4	4	5	5	4	5	4	5	4	5	5
PR5	1	3	2	3	2	3	2	3	2	2
PR6	4	5	5	4	5	4	5	4	5	5
PR7	4	5	5	4	5	4	5	4	5	4
PR8	4	5	4	4	4	4	5	4	5	4
PR9	1	3	1	3	1	3	2	3	2	3
PR10	1	3	1	2	1	2	2	1	2	2
PR11	4	5	5	4	5	4	5	4	5	5
PR12	4	5	5	4	4	4	5	4	4	4
Circularity-based sustainable performance										
PE1	4	5	5	4	5	4	5	4	5	4
PE2	1	3	1	3	1	3	2	3	2	3
PE3	4	5	5	4	5	4	5	4	5	4

PE4	1	3	1	3	1	3	2	3	2	3
PE5	4	5	5	4	5	4	5	4	5	4
PE6	4	5	5	4	5	4	5	4	5	4
PE7	4	5	5	4	5	4	5	4	5	4
PE8	4	5	5	4	5	4	5	4	5	4
PE9	4	5	5	4	5	4	5	4	5	4
PE10	4	5	5	4	5	4	5	4	5	4
PE11	1	3	1	3	1	3	2	3	2	3
PE12	4	5	5	4	5	4	5	4	5	4
PE13	4	5	5	4	5	4	5	4	5	4
PE14	4	5	5	4	5	4	5	4	5	4

Table A5: The same data in the questionnaire results matrix transformed into ranks

	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**E10**	
Smart circularity practices											R_i
PR1	4.5	4.5	3.5	4.5	3.5	5	5	5	4	6.5	46
PR2	9	12	9	11.5	8	5	5	5	8.5	6.5	79.5
PR3	4.5	4.5	7.5	4.5	3.5	5	5	5	4	6.5	50
PR4	4.5	4.5	3.5	4.5	3.5	5	5	5	4	2	41.5
PR5	11	10	10	9.5	10	10.5	11	10.5	11	11.5	105
PR6	4.5	4.5	3.5	4.5	3.5	5	5	5	4	2	41.5
PR7	4.5	4.5	3.5	4.5	3.5	5	5	5	4	6.5	46
PR8	4.5	4.5	7.5	4.5	8	5	5	5	4	6.5	54.5
PR9	11	10	3.5	9.5	11.5	10.5	11	10.5	11	10	98.5
PR10	11	10	11.5	11.5	11.5	12	11	12	11	11.5	113
PR11	4.5	4.5	11.5	4.5	3.5	5	5	5	4	2	49.5
PR12	4.5	4.5	3.5	4.5	8	5	5	5	8.5	6.5	55
Circularity-based sustainable performance											R_i
PE1	6	6	6	6	6	6	6	6	6	6	60
PE2	13	13	13	13	13	13	13	13	13	13	130
PE3	6	6	6	6	6	6	6	6	6	6	60
PE4	13	13	13	13	13	13	13	13	13	13	130
PE5	6	6	6	6	6	6	6	6	6	6	60
PE6	6	6	6	6	6	6	6	6	6	6	60
PE7	6	6	6	6	6	6	6	6	6	6	60
PE8	6	6	6	6	6	6	6	6	6	6	60
PE9	6	6	6	6	6	6	6	6	6	6	60
PE10	6	6	6	6	6	6	6	6	6	6	60
PE11	13	13	13	13	13	13	13	13	13	13	130
PE12	6	6	6	6	6	6	6	6	6	6	60
PE13	6	6	6	6	6	6	6	6	6	6	60
PE14	6	6	6	6	6	6	6	6	6	6	60

Table A6: Initial decision Matrix

Performance Measures	**SC P1**	**SC P2**	**SC P3**	**SC P4**	**SC P5**	**SC P6**	**SC P7**	**SC P8**
Increase in resource circularity **(CEISP1)**	3.3	3.4	3.2	2.4	3.4	2.8	2.5	2.5
Improve human efficiency **(CEISP2)**	3.9	3.3	3.5	2.3	2.4	2.1	1.8	2.3
Increase in profit from green products **(CSP3)**	1.9	4.6	3.8	2.3	2.1	2.2	2.5	1.7
Improved usage of green logistics **(CEISP4)**	3.6	3.2	3.3	2.4	3.9	3.4	3.4	3.9
Better employees and community health **(CEISP5)**	3.3	4.7	3.8	2.3	2	2.8	2.6	1.7
Improved green purchasing **(CEISP6)**	2.1	3.1	3.4	2.8	3.2	3.6	2.8	2.5
Better usage of green warehousing **(CEISP7)**	3.4	3.2	3.4	2.7	2.6	4	3.6	2.4
Better/improved market demand **(CEISP8)**	2.3	3.3	2.5	2.1	2.7	3.2	3.1	2.1
Increase in cost saving through product quality **(CEISP9)**	3.1	2.8	2.8	2.3	4	3.6	3.2	4.2
Decrease in emission, waste, and pollution monitoring **(CEISP10)**	3.3	3.4	3.9	2.4	3.4	3.6	4	2.9
Improved incentives and government legislation support and incentives **(CEISP11)**	3.2	3.5	3.7	3.2	3.5	3.3	3.3	2.7

Table A7: Normalized decision Matrix

Performance Measures	**SCP1**	**SCP2**	**SCP3**	**SCP4**	**SCP5**	**SCP6**	**SCP7**	**SCP8**
CEISP1	0.70	0.32	0.50	0.27	0.70	0.37	0.32	0.32
CEISP2	1.00	0.26	0.71	0.18	0.20	0.00	0.00	0.24
CEISP3	0.00	0.95	0.93	0.18	0.05	0.05	0.32	0.00
CEISP4	0.85	0.21	0.57	0.27	0.95	0.68	0.73	0.88
CEISP5	0.70	1.00	0.93	0.18	0.00	0.37	0.36	0.00
CEISP6	0.10	0.16	0.64	0.64	0.60	0.79	0.45	0.32
CEISP7	0.75	0.21	0.64	0.55	0.30	1.00	0.82	0.28
CEISP8	0.20	0.26	0.00	0.00	0.35	0.58	0.59	0.16
CEISP9	0.60	0.00	0.21	0.18	1.00	0.79	0.64	1.00
CEISP10	0.70	0.32	1.00	0.27	0.70	0.79	1.00	0.48
CEISP11	0.65	0.37	0.86	1.00	0.75	0.63	0.68	0.40

Table A8: Weighted comparability sequence matrix

Performance Measures	**SCP1**	**SCP2**	**SCP3**	**SCP4**	**SCP5**	**SCP6**	**SCP7**	**SCP8**
CEISP1	0.15	0.06	0.03	0.04	0.09	0.03	0.02	0.04
CEISP2	0.22	0.05	0.04	0.02	0.02	0.00	0.00	0.03
CEISP3	0.00	0.17	0.05	0.02	0.01	0.00	0.02	0.00
CEISP4	0.19	0.04	0.03	0.04	0.12	0.06	0.05	0.11
CEISP5	0.15	0.18	0.05	0.02	0.00	0.03	0.02	0.00
CEISP6	0.02	0.03	0.04	0.08	0.07	0.07	0.03	0.04
CEISP7	0.17	0.04	0.04	0.07	0.04	0.09	0.05	0.04
CEISP8	0.04	0.05	0.00	0.00	0.04	0.05	0.04	0.02
CEISP9	0.13	0.00	0.01	0.02	0.12	0.07	0.04	0.13

CEISP10	0.15	0.06	0.06	0.04	0.09	0.07	0.07	0.06
CEISP11	0.14	0.07	0.05	0.13	0.09	0.06	0.05	0.05

Table A9: Exponentially comparability sequence matrix using BWM weights

Performance Measures	**SCP1**	**SCP2**	**SCP3**	**SCP4**	**SCP5**	**SCP6**	**SCP7**	**SCP8**
CEISP1	0.924	0.813	0.962	0.845	0.957	0.911	0.926	0.863
CEISP2	1.000	0.787	0.981	0.801	0.819	0.000	0.000	0.832
CEISP3	0.000	0.990	0.996	0.801	0.689	0.760	0.926	0.000
CEISP4	0.965	0.756	0.969	0.845	0.994	0.965	0.979	0.984
CEISP5	0.924	1.000	0.996	0.801	0.000	0.911	0.935	0.000
CEISP6	0.601	0.718	0.976	0.943	0.939	0.978	0.949	0.863
CEISP7	0.938	0.756	0.976	0.924	0.861	1.000	0.987	0.848
CEISP8	0.700	0.787	0.000	0.000	0.878	0.950	0.965	0.789
CEISP9	0.893	0.000	0.918	0.801	1.000	0.978	0.970	1.000
CEISP10	0.924	0.813	1.000	0.845	0.957	0.978	1.000	0.909
CEISP11	0.909	0.836	0.991	1.000	0.965	0.958	0.975	0.888

Table A10: Exponentially comparability sequence matrix using FUCOM weights

Performance Measures	**SCP1**	**SCP2**	**SCP3**	**SCP4**	**SCP5**	**SCP6**	**SCP7**	**SCP8**
CEISP1	0.927	0.826	0.898	0.838	0.962	0.914	0.929	0.838
CEISP2	1.000	0.802	0.949	0.793	0.839	0.000	0.000	0.801
CEISP3	0.000	0.991	0.989	0.793	0.721	0.768	0.929	0.000
CEISP4	0.966	0.773	0.916	0.838	0.994	0.967	0.980	0.980
CEISP5	0.927	1.000	0.989	0.793	0.000	0.914	0.937	0.000
CEISP6	0.614	0.737	0.933	0.940	0.946	0.979	0.951	0.838
CEISP7	0.941	0.773	0.933	0.921	0.877	1.000	0.987	0.821
CEISP8	0.711	0.802	0.000	0.000	0.892	0.952	0.967	0.752
CEISP9	0.898	0.000	0.786	0.793	1.000	0.979	0.972	1.000
CEISP10	0.927	0.826	1.000	0.838	0.962	0.979	1.000	0.892
CEISP11	0.913	0.848	0.976	1.000	0.969	0.960	0.976	0.867

Table A11: Circularity-based sustainable performance rank in the first experiment set

CSPs	**Original Rank by BWM**	**Test-1**	**Test-2**	**Test-3**	**Test-4**	**Test-5**	**Test-6**	**Test-7**	**Test-8**	**Test-9**
CEISP1	6	7	6	6	5	5	5	6	6	5
CEISP2	9	10	9	9	7	7	6	3	2	1
CEISP3	10	9	10	10	11	11	11	11	11	11
CEISP4	2	2	2	1	1	1	1	1	1	2
CEISP5	8	8	8	8	8	8	8	8	7	7
CEISP6	7	6	7	7	9	9	9	9	9	10

CEISP7	4	4	4	4	4	4	4	2	3	3
CEISP8	11	11	11	11	10	10	10	10	10	9
CEISP9	5	5	5	5	6	6	7	7	8	8
CEISP10	3	3	3	3	3	3	2	4	4	4
CEISP11	1	1	1	2	2	2	3	5	5	6

Table A12: Circularity-based sustainable performance rank in the second experiment set

CSPs	**Original Rank by FUCOM**	**Test-1**	**Test-2**	**Test-3**	**Test-4**	**Test-5**	**Test-6**	**Test-7**	**Test-8**	**Test-9**
CEISP1	5	7	5	5	5	5	5	6	6	5
CEISP2	9	10	9	9	8	7	6	5	2	1
CEISP3	10	9	10	10	10	10	10	11	11	11
CEISP4	2	3	2	2	1	1	1	1	1	2
CEISP5	8	8	8	7	7	8	8	8	7	7
CEISP6	7	5	7	8	9	9	9	9	9	10
CEISP7	4	4	4	4	4	4	4	3	3	3
CEISP8	11	11	11	11	11	11	11	10	10	9
CEISP9	6	6	6	6	6	6	7	7	8	8
CEISP10	3	2	3	3	3	3	2	2	4	4
CEISP11	1	1	1	1	2	2	3	4	5	6

A Novel Hybrid Decision-Making Framework for Measuring Industry 4.0 Driven Circular Economy Performance for Textile Industry

Abstract: The sustainability strategy focuses on conscious production and consumption, with the Circular Economy (CE) as an innovative approach to maximize resource value and minimize waste. Industry 4.0 technologies like AI, robotics, and blockchain play a significant role in enhancing the competitiveness of businesses pursuing the CE. These advanced technologies help organizations achieve their sustainability goals, particularly within the CE framework. The study analyses how Industry 4.0-driven CE practices impact sustainable business performance, using the Indian textile industry as a case study. The researchers developed a three-stage hybrid decision-making framework, integrating various methods to assess sustainable performance. A novel three-stage hybrid decision making framework was developed by integrating Kendall's Agreement Test (Kendall's W), Fuzzy Delphi, Best Worst Method (BWM), Full Consistency Method (FUCOM), and Combined Compromise Solution (CoCoSo) methods. The findings highlight positive outcomes such as enhanced incentives, government support, greener logistics, and improved monitoring of emissions, waste, and pollution. However, there is room for further improvements to address market demand and increase the profitability of green products.

Keywords: Circular economy; Industry 4.0; Smart circularity practices; Smart circularity performances; Kendall's W; Hybrid method.

1. Introduction

Earth's abundant natural resources play a crucial role in satisfying humanity's diverse requirements. These interconnected resources form a delicate chain, and any disruption can jeopardize the established balance, ultimately undermining economic values and the overall stability of the economy (Panchal *et al.* 2021). Stakeholders from many fields stress the need to move towards a sustainable economic framework that protects resources (Bag *et al.* 2021b). This transition has been examined by businesses, governments, civil society, and academics, acknowledging the historical imbalance between economic growth and environmental and social concerns (Kazancoglu *et al*., 2020; Khan, Ali, & Singh, 2022).

The integration of digital technologies has been found to be instrumental in encouraging business adoption of circular economy principles (Agrawal *et al.*, 2022). These technologies enable the implementation of innovative business models and facilitate the redesign of products and value chains, all within the context of a smart circular economy paradigm (Mahtab *et al.* 2020). The integration of digital technologies throughout a product's life cycle allows for the implementation of circular strategies and practices known as “smart circularity”. This paradigm involves leveraging digital technologies to optimize resource use, enable product tracking and traceability, promote sharing and collaboration, and facilitate the attainment of efficient and sustainable operations. The Textile and Clothing (T&C) industry is intricately linked with nature throughout the entire supply chain (Kazancoglu *et al*., 2020; 2022), starting from production and extending to the final utilization of the products (Coppola *et al.* 2023). T&C industry is a sector with a volume of nearly $1.5 trillion and has a value that could have the world’s 14th economy. The T&C industry has a considerable negative environmental impact that surpasses that of many other sectors in terms of global production, consumption, and trade capabilities (Coppola *et al.* 2023). The greenhouse gas emissions of this sector represent about 10% of global emissions, more than the aviation and maritime sectors combined.

The Indian economy relies heavily on textiles and apparel for economic growth domestically and globally. Textile and apparel contribute 4% to India’s GDP and account for 15% of exports and are the country's top foreign exchange earners. T&C manufacturing in India has a competitive advantage due to natural raw materials (cotton, silk, cellulosic fiber) and skilled labor, traditional designs, colors, and embroidery (NCFAT’20, 2020). In the realm of sustainable fashion in India, several noteworthy brands have emerged, each with its own unique approaches and initiatives. Manickam and Duraisamy (2019) highlighted that historically, the Indian textile industry has had issues with sustainability, primarily because it has traditionally been a labor-intensive industry. 'Period', for instance, sets itself apart by utilizing handloom textiles exclusively and adhering to a "no synthetics policy." 'Greenthemap' takes an innovative approach to sustainability by transforming old tyres, tetrapacks, waste cloths, waste leather, and other apparel wastes into new materials. They employ tailors from disadvantaged backgrounds and strive to provide them with a supportive work environment. 'DoUSpeakGreen' garners recognition as India's pioneering fashion brand and webstore, distinguished by its utilization of organic bamboo and cotton fabric in garments produced within Fair Trade-certified factories. Notably, they allocate 10% of their sales value to environmental conservation processes, demonstrating a commitment to sustainability beyond their production practices. 'Bhusattva' has been at the forefront of sustainability in the Indian textile industry, championing the infusion of innovative materials such as bamboo, banana, and soybean fibers blended with traditional fabrics like khadi, silk, and cotton. This combination allows them to bridge the gap between sustainable fashion and mainstream appeal. ‘No Nasties’ is another noteworthy sustainable fashion brand, advocating for organic textiles and ethical craftsmanship. Originating from the purpose of addressing farmer suicides in India, their initiatives include promoting organic and fair-trade farming practices. Doodlage excels in the art of upcycling, converting waste fabrics into exquisite and eco-friendly patchwork clothing and home furnishings. Their commitment to sustainability lies in transforming discarded materials into beautiful creations.

Globally, customers are increasingly considering whether the core materials in a product are sustainably sourced (Kayikci *et al.*, 2022a, Khan, Ali, & Singh, 2022). Industry professionals believe that products that are part of a circular value chain have a distinct advantage over another (Kazancoglu *et al.*, 2022). With the increasing demand, companies focusing on sustainability are being sought out for their products. Addressing environmental risks remains the foremost motivation for the textile and clothing industry's adoption of circular economy models (Kazancoglu *et al.*, 2020; Bag *et al.*, 2021a). Still, it is equally important to consider the human aspect of such models.

A CE offers a straightforward and reliable path to overcoming sustainability challenges that put an equal focus on individuals, the planet, and profits. Recycling and reusing products are essential aspects of a CE (Bag *et al.* 2021b). Energy consumption, resource use, and waste production are under pressure already. However, scaling and profitability are also important (Kazancoglu *et al.*, 2020; 2022). The adoption of CE practices in the textile industry offers significant benefits to manufacturers. By implementing strategies that prioritize resource optimisation, manufacturers can reduce costs and improve efficiency. Embracing sustainable practices also fosters enhanced customer loyalty, as consumers increasingly value environmentally responsible products (Sahoo *et al.*, 2023).

The APAC region includes India, Bangladesh, Vietnam, China, Pakistan, Indonesia, and Sri Lanka as large textile production hotspots (Khan, 2021). As many as 15% of discarded textiles are reproduced through recycling, reselling, or donation. There are 45 million people across the value chain employed by this industry in India, with many women. It is essential to design circularity initiatives that contribute to social inclusion (Kotamaraju *et al.*, 2021). Innovation and resilience are the keys to survival and growth in today's competitive world. Dynamic industry challenges of Industry 4.0 are amplifying the disruptive effects of e-commerce in fashion retail. Innovations in the manufacturing sector are not only driven by product innovation but through the application of new digital technologies (Kayikci *et al.*, 2022a). Embracing Industry 4.0 can significantly impact a labor-intensive industries like textiles and apparel (Kotamaraju *et al.*, 2021). Recycling and recovering can be more cost-effective and environmentally friendly when technologies are integrated with the CE (Kayikci *et al.*, 2022a). In addition to providing trust across stakeholder groups, reliability, visibility, and traceability, adoption of smart technology with a SCE will also cause an increase in financial burden for the organization (Jaeger & Upadhyay 2020). This study uses the Natural-Resource-Based View (NRBV) as a theoretical background to fill the above-mentioned significant research gap; NRBV can be a great enabler for smart circular economy due to its theory of competitive advantage based on the firm's relationship with the natural environment (Hart, 1995). According to the NRBV, smart circular supply chain is conveyed as key organizational primary resources and strategic capabilities with environment that can lead to significant improvements in sustainable performance (Kayikci et al., 2022a).

This study focused on the following Research Objectives (ROs):

RO1: To investigate and identify smart circularity practices within the textile industry that contribute to enhancing sustainability performances; and

RO2: To develop a decision-making framework that guides organizations in reaching their goals.

This paper aims to address research objectives by conducting a comprehensive literature review based on NRBV theory in the textile industry. It targets to identify smart circularity practices and circularity-based sustainable performance indicators through extensive literature search and expert consultation. To achieve this, a novel hybrid decision-making framework is proposed, combining methods such as Kendall's Agreement Test (Kendall's W), Fuzzy Delphi, Best Worst Method (BWM), Full Consistency Method (FUCOM), and Combined Compromise Solution (CoCoSo). This framework will help provide answers to the research objectives, contributing to a better understanding of smart circularity in the textile industry. The unique integration of methods in the novel framework yields a powerful decision-making tool. This research introduces the integrated approach for the first time, focusing on measuring the sustainable performance of smart circularity practices in the textile industry. It provides researchers with an effective means to address diverse problems in this context. This study serves as a guideline for practitioners, managers, and users facilitating the implementation of advanced technologies and aligning production strategies with smart circularity practices to promote sustainable performance in the textile industry.

The remainder of the article is organized as follows. Section 2 introduces the theoretical foundation of building initiatives of smart circularity practices for circularity-based sustainable performance. Section 3 summarizes the research framework of the solution procedure and explains the three-stage methodology in detail. Section 4 introduced the case study and obtained results and discussion are interpreted in Section 5. Section 6 gives the conclusions of the paper with suggestions for future works.

2. Smart Circularity Practices for Circularity-based Sustainable Performance

The "end-of-waste" mechanism aims to promote sustainable waste treatment and mutual recognition of results (Khan, Ali, & Singh, 2022). When waste becomes a product or secondary raw material, the Smart Circular Economy (SCE) must show that its use won't harm the environment or human health. Driven by growing public awareness of environmental degradation and stringent government regulations, supply chains are increasingly compelled to adopt environmentally friendly practices (Bressanelli *et al.* 2022). Excessive focus on environmental performance can have negative implications on economic performance (Jaeger & Upadhyay 2020). SCE promotes circularity and economic growth and considers environmental and social benefits for sustainable development. CE is gaining interest to stimulate the economy by encouraging innovation, confronting resource constraints, creating jobs, and delivering notable environmental benefits (Agrawal *et al.*, 2022). CE migration helps organizations enhance sustainability, financial performance, and cater to diverse stakeholders for business growth.

The transition to a SCE in the textile industry is a challenging process, supported by prior research Coppola *et al.* (2023). As a result, organizations are gradually embracing CE principles to overcome these obstacles (Jaeger & Upadhyay, 2020). Industries recycling components as raw materials embrace CE faster, but it should involve all stakeholders, including consumers (Kayikci *et al.*, 2022b). Developed nations like the USA, Japan, EU, Germany, and Italy have embraced CE for sustainable development goals. However, emerging economies, including India, lag behind in adopting CE practices. Many Indian SMEs are unaware of the benefits of CE, such as improved efficiency, cost reduction, and reduced environmental impact. Therefore, implementing CE-based business models is crucial for Indian SMEs to realize its potential (Agrawal *et al.*, 2021). As argued by Coppola *et al.* (2023), the textile and clothing sectors (T&C) present both significant environmental challenges and strategic opportunities within the context of the circular economy (CE). The T&C industry is a prime instance where waste products are not utilized as raw materials for creating new products (Khan *et al.* 2022).

The textile industry, one of the most polluting industries in the world, deserves more attention as it is one of the largest in CE as a result of the exponential growth of clothing that ends up in a landfill. This is a result of the fast fashion phenomenon, which creates the impression that clothes are disposable (Kazancoglu *et al*., 2020; 2022). A sustainable fashion that can provide circular material flows is required to solve this problem. This requires the cooperation of consumers in promoting long-lasting fashion, choosing quality over quantity, and viewing clothing as an investment (Kayikci *et al.*, 2022a). Therefore, there is a need for effective garment collection systems and sorting procedures. It is assumed that new textile recycling technologies in the textile industry have the potential to reorient material resource flows, impact secondary markets, and restructure the waste hierarchy (Jaeger and Upadhyay 2020). Industry 4.0 technologies enable CE business models, with digitization enhancing asset and product visibility and intelligence (Kayikci *et al.*, 2022a). In the age of digitization, companies improve their business performance through the use of digital technologies (Agrawal *et al.*, 2022). Organizations in both developed and developing economies attach great importance to the industry 4.0 revolution and related uses of technologies because of their potential benefits (Bag *et al.* 2021b). AI-powered systems analyze data to suggest more sustainable sourcing options or provide predictive maintenance for machinery, ensuring optimal usage and minimizing waste (Bag *et al.* 2021a). While there is undoubtedly growing interest in understanding and applying Industry 4.0 from both academia and industry, it is an emerging concept that many industry sectors have yet to fully explore and commit to. Therefore, academic research must progress rapidly to identify knowledge gaps related to Industry 4.0 and to address its impact on sustainability and CE (Sahoo *et al.*, 2023).

2.1 Exploring the Performance of Smart Circularity: A Theory-Based Analysis through the Resource-Based View

Coppola *et al.* (2023) uses a NRBV as a theoretical framework and employs a multiple-case study approach. The strategies of pollution prevention, product stewardship, and sustainable development, along with the associated capabilities of sensing, seizing, and reconfiguring, are examined. The fast-paced nature of the fashion industry raises resource consumption and waste generation issues significantly. The quick turnover of products, characterized by their rapid acquisition and disposal, contributes to the industry's environmental challenges. This high-speed approach to fashion not only leads to increased utilization of resources but also results in substantial waste production. Thus, addressing these concerns is crucial for the industry's sustainability and calls for the adoption of strategies that promote a more circular and responsible approach to fashion production and consumption. Drawing from grounded theory building and multiple case studies, Kouhizadeh *et al.* (2020) presented preliminary evidence that connects blockchain applications to dimensions of the circular economy, including Regeneration, Sharing, Optimization, Looping, Virtualization, and Exchange (ReSOLVE model) by using multiple cases.

2.1.1 Smart circularity practices

Smart circularity practices involve the use of digital technologies throughout a product's life cycle to implement circular strategies. Kouhizadeh *et al.* (2020) argued that with the advent of Industry 4.0, organizational activities are poised for transformation through technological innovations. This approach aims to create value by improving sustainable performance (Bressanelli *et al.* 2022). Robots can be employed for tasks like sorting and recycling waste materials, reducing human error and improving recycling efficiency. In the context of the textile industry, the following ‘smart circularity practices’ have been recommended based on review of literature based on NRBV theory:

***Technical capability**:* Technical capability is an essential practice or enabler that facilitates the implementation of cutting-edge technologies across diverse domains. This capability comprises the requisite technical expertise to utilize state-of-the-art technologies in an efficient manner, such as blockchain, 3D printing, machine learning, cloud computing, big data analytics, human-machine interaction, robotics, infrastructure development, and the Internet of Things (IoT). By effectively utilizing these technologies, businesses can optimize their operational processes (Kotamaraju *et al.*, 2021), foster innovation, and attain long-term, sustainable expansion.

Shayganmehr *et al.* (2021) highlighted valuable insights regarding the importance of technical capability as a facilitator, emphasizing its capacity to revolutionize and influence sectors by means of the efficient application of cutting-edge technologies.

Competitive pressures: Competitive pressures are a significant catalyst or implementation in promoting innovation across industries, specifically with regard to the circular economy (CE) and Industry 4.0. By utilizing Industry 4.0 tools and remaining abreast of the actions of competitors, businesses can innovate their processes and products, thereby obtaining a market advantage. In order to foster community engagement in waste management, institutions offer rewards for the collection, sorting, and restoration of particular refuse categories—such as furniture and textiles (Coppola *et al.* 2023). This may result in the establishment of new repair and reuse businesses, which will have a positive effect on society. Bag *et al.* (2021b) emphasizes the importance of competitive pressures in driving innovation and generating societal benefits at the intersection of Industry 4.0 and Circular Economy (CE) in the textile industry.

Policy and regulation: This aims to explore how rules and policies can foster responsible actions that align with the goals of the circular economy in the textile industry (Coppola *et al.* 2023). Companies, supply systems, institutions, and people are all encouraged by the government to follow responsible practices (Kotamaraju *et al.*, 2021) that are in line with CE and Industry 4.0 (Shayganmehr *et al.* 2021). To do this, policies must be put in place to support CE and Industry 4.0, and strategies must be made and put into action that are especially designed to support CE and Industry 4.0. The development and utilization of effective performance metrics are essential for evaluating the effectiveness of integrating CE practices with Industry 4.0 (Shayganmehr *et al.* 2021).

Financial capability: Gedam *et al.* (2021) and Khalifa *et al.* (2022) explore how well reward and incentive policies, budget allocation strategies, and international groups helps Clean Energy (CE) and Industry 4.0 move forward. Implementing reward and incentive systems support the rapid improvement of CE technologies and Industry 4.0 practices by promoting an atmosphere that stimulates innovation. Furthermore, allocating a proper budget expressly for supporting CE and Industry 4.0 activities is critical for their successful implementation (Kotamaraju *et al.*, 2021). Association of international groups encourage knowledge sharing and collaboration by giving chances to utilize global expertise and resources needed to drive CE and Industry 4.0 progress.

Fair acceptance: Kotamaraju *et al.* (2021) stress the importance of fair business practices and adherence to laws and regulations while working with suppliers and consumers in the context of smart circularity. Gedam *et al.* (2021) emphasizes the role of organizations in implementing Industry 4.0 solutions and advancing CE through compliance and equity.

Security and safety: In the implementation of Industry 4.0 infrastructure within the circular economy (CE), ensuring security and safety is crucial. This involves protecting employee confidentiality and securing Industry 4.0 systems. Smart elements and the safe deployment of Industry 4.0 technologies contribute to a safer work environment and enhance competitive edge initiatives. Shayganmehr *et al.* (2021) emphasized the role of security and safety in successfully implementing Industry 4.0 technologies and achieving CE objectives.

System flexibility*:* Sensor-based technology has the capability to gather real-time data pertaining to resource consumption, waste generation, and production efficiency. Through the application of AI/ML techniques (Bag *et al.* 2021a), this data can be analyzed to extract valuable insights that can optimize production processes, identify areas for waste reduction, and enable effective reuse or recycling of materials. The utilization of flexible system such as Big Data (Sahoo *et al.* 2023) and AI/ML (Bag *et al.* 2021a) empowers organizations to seamlessly integrate circular economy practices within the framework of Industry 4.0, in line with the findings highlighted by Shayganmehr *et al.* (2021).

Support and maintenance*:* The implementation of smart factory tools is crucial for effective reverse collection in a smart circular economy. Leveraging Industry 4.0 systems such as blockchain enhances inventory tracking capabilities, facilitating seamless coordination between circular economy and Industry 4.0 activities (Kouhizadeh *et al.* 2020). By establishing a cloud technologies infrastructure, organizations ensure compliance, improve business efficiency (Kotamaraju *et al.*, 2021), and enable real-time decision-making across the supply chain through the utilization of Industry 4.0 tools and technologies.

Stakeholders' readiness: Preparing stakeholders for the adoption of CE concepts, dynamics, and operations backed by Industry 4.0 technology is an aspect of this. Torgautov *et al.* (2021) and Palafox-Alcantar *et al.* (2022) emphasize the significance of industry-wide policies and public procurement activities that promote circularity. By using IoT devices and data analytics as part of Industry 4.0 in procurement, companies can rate their suppliers' success in terms of sustainability and circularity. These technologies allow for monitoring, tracking of waste, and supply chain analysis. They make sure that sustainability standards are met while rendering it easier to choose a supplier that fits with a smart circular economy and the use of environmental labels (Panchal *et al.* 2021).

***Regulatory pressures**:* It functions as a major facilitator or practice in the deployment of the CE and Industry 4.0 technologies. According to Kazancoglu *et al.* (2022), CE and Industry 4.0 are more likely to be adopted when companies follow the law. Effective communication of circular actions and practices to society is crucial, and environmental labelling and certification incentives play a significant role in encouraging sustainable behaviors and choices (Kotamaraju *et al.*, 2021), thus showcasing the circular economy's benefits and sustainable impacts.

Process and product design for energy and resource efficiency: The concept of the CE emphasizes the regenerative and restorative features of the design in order to optimize the advantages derived from energy, components, and products (Ali *et al.* 2023). Another environmental strategy that has been explored is Extended Producer Responsibility (EPR), a concept that places the onus on manufacturers to assume responsibility for the complete life cycle of their products. Producers in industries like electronics and textiles pay EPR fees, which are determined by the quantities of their products (Palafox-Alcantar *et al.* 2022), in order to incentivize and support environmentally responsible practices. Augmented Reality (AR) simulations allow users to visualize the effects of different materials or product lifecycles, enabling sustainable choices.

Education and participation: This investigates the factors that facilitate education and engagement within the framework of Industry 4.0 technologies and their impact on fostering equitable and efficient resource utilization. Key methods include providing training to employers on business principles and encouraging the active involvement of management-level personnel in the growing framework of Industry 4.0-enabled CE. By analyzing big data, businesses can identify patterns and trends in consumption, enabling smarter product design, waste reduction, and improved inventory management. Shayganmehr *et al.* (2021) highlights the significance of establishing objectives that span over an extended period and recognizing the possible consequences of integrating Industry 4.0 technologies into CE framework (Ali *et al.* 2023).

2.1.2 Circularity-based sustainable performance

By adopting circular economy thinking, the textile business hopes to do a better job of being environmentally friendly. This study looks into how using circular economic drivers driven by Industry 4.0 might help the industry do better in the long term. Cutting-edge technologies such as

AI, IoT, and big data analytics enable the achievement of circularity. Predictive analytics and AI make production processes more efficient, and smart supply lines make it easier to see how resources are being used. Digital manufacturing and additive technologies cut down on waste, and reverse supply lines make recycling easier and more effective. The integration of circular economy principles and Industry 4.0 technologies offers potential for a more sustainable future in the textile industry. However, challenges such as security issues and high costs need to be overcome (Jaeger & Upadhyay 2020). Based on a review of existing literature based on NRBV theory, the following 'circularity-based sustainable performance' indicators have been suggested in the context of the textile industry.

***Increase in resource circularity**:* The aim of this approach is to retain resource value by ensuring their reincorporation into the product cycle post-use. By minimizing raw material consumption, waste generation, and value chain risks, companies can contribute to a more sustainable and efficient resource management system (Lopez *et al.* 2019; Weissbrodt *et al.* 2020).

***Better adoption of digital technology**:* To bolster sustainability initiatives, it is imperative to advocate for the increased implementation of digital technology. This process entails integrating the implementation of digital technological advancements into multiple organizational departments with the aim of optimizing the advantages that arise from this integration (Khan, Ali, & Singh, 2022). Through the strategic utilization of digital technologies, organizations can enhance their sustainability performance and streamline operations. IoT applications enable better monitoring and optimization of resource usage, such as smart energy management systems that minimize energy waste and enhance efficiency.

Improve human efficiency: This involves optimizing resource utilization by aligning tasks with appropriate skills, prioritizing training and development, harnessing digital technologies to save time, enhancing manpower efficiency, and finding innovative work methodologies. Previous studies by Lopez *et al.* (2019) and Hoang-Khac *et al.* (2022) support the importance of these practices in achieving higher efficiency levels.

Improve human skills: The implementation of Industry 4.0 in clothing organizations aims to maximize the potential of individuals by enhancing the skills of experts and upskilling low-skilled workers to increase their competencies. Using advanced technological systems such as automation, robotics, and artificial intelligence, big data, the Internet of Things, blockchain, 3D printing, cloud technologies, augmented reality Industry 4.0 enables clothing organizations to provide training programs and develop personalized learning opportunities (Hoang-Khac *et al.* 2022).

Increase in profit from green products: Efficiency is improved by minimizing the use of natural resources, such as water and energy, and hazardous substances in production. Additionally, negative environmental impacts at the end of a product's life are reduced. Green products are produced to promote recycling and reusability, leading to increased profitability (Ali *et al.* 2023; Lopez *et al.* 2019, Li *et al.* 2020).

Improved usage of green logistics*:* Trying to implement a sustainable transportation policy in order to develop the concept of green logistics, such as using more environmentally friendly vehicles and fuels in the production and transportation phase, turning to the more environmentally friendly sea and railway, or commissioning integrated transportation systems rather than road transportation, which increases greenhouse gas emissions (Ying and Li-jun, 2012).

Better employees and community health: To improve sustainable development in a way that includes not only income increase but also the quality of life, and to try to increase the funds allocated to health by accepting health as a tool of economic development. Wearable sensors and real-time monitoring systems enhance worker safety and well-being in the T&C industry. Improved health and safety conditions not only reduce the risk of accidents and injuries but also promote higher productivity and overall job satisfaction among workers, leading to a more sustainable and efficient workforce (Ali *et al.* 2023).

Improved green purchasing: The goal is to encourage companies to shift towards a circular economy by opting for products and services that have lower impacts on human health and the environment compared to alternatives serving the same purpose (Ali *et al.* 2023, Khan, Ali, & Singh, 2022).

Better usage of green warehousing*:* Efforts are made to improve the operational performance of enterprises through green warehouse management practices such as increasing energy efficiency by using timed lighting systems, motion sensors and energy-efficient lighting fixtures, using natural light or solar panels in appropriate places in the warehouse, using hot water systems for heating and cold water systems for cooling the warehouse, using energy efficient tools and equipment in handling processes, reducing energy usage in warehouse operations through efficient planning by accurately predicting demand, production and stock levels, sharing real-time sales data using information and communication technologies, and updating stock levels and reorder statuses (Ali *et al.* 2023).

Better/improved market demand: To gain a positive image among customers by producing sustainable, environmentally friendly products that do not have harmful effects on human health, to promote products by communicating information about products to consumers, to keep products in accessible and convenient locations, and to try to ensure reliability and integrity among customers (Palafox-Alcantar *et al.* 2022).

Improved develop the CE based smart culture*:* To make all forms of culture diverse and technologically advanced by adopting technologies that provide new protection, storage, and archiving opportunities that will provide fair access to available resources for both current and future generations, that is, to realize the transition from culture to smart culture via the existence and functioning of various and sundry implementations in the digital ecosystem. In this context, it is aimed to create a circular economy, if information and communication systems and technologies are also applied and used in the company culture (Salvioni and Almici, 2020).

Increase in cost saving through product quality: To increase the quality of every commodity that enters the production process, to reduce the losses in production and the resulting labor time, and to increase cost savings in this way (Kouhizadeh *et al.* 2020). 3D printing allows on-demand production, reducing the waste associated with unsold inventory and transportation. It also facilitates design customization, enabling products to be easily remanufactured.

Decrease in emission, waste, and pollution monitoring: Trying to develop and produce products that leave a less carbon footprint in nature, use environmentally friendly clean technologies and techniques, prevent environmental pollution, and reduce energy consumption and carbon emissions through waste management (Palafox-Alcantar *et al.* 2022).

Improved incentives and government legislation support and incentives*:* In the direction of the transition of enterprises to circular economy model for sustainable development, work on designing important strategies to disseminate the application, preparing appropriate legislation, and developing the right government incentives (Salvioni, & Almici 2020). Incentives can support the commercial development of circular economy businesses, remove entry barriers to specific sectors or markets, favor the adoption of new technology, develop original competencies and skills, and inject new capital to contribute to capex and opex, respectively (De Giovanni and Folgiero, 2023).

Many researchers agree that using smart circular economy (SCE) methods is important for achieving sustainable development goals, especially when it comes to production and consumption by using one of Industry4.0 driven integration (Sahoo *et al.*, 2023; Panchal *et al.*, 2021; Mahtab *et al.*, 2020).

2.2 Research Gaps

The study by Coppola et al. (2023) examines the circular competitive advantages of firms in Italy's textile and clothing industry, a sector known for its environmental impact. Their objective is to identify the necessary capabilities for implementing a circular economy and achieving a restorative industrial system. Using a natural-resource-based view as a theoretical framework, the study employs a multiple-case study approach. In contrast, our research focuses on the textile industry of emerging market. We utilize extensive searches and expert input to identify best practices and measure performance using a novel framework tailored to this specific context. Despite the existing research on smart circular economy (SCE) methods for achieving sustainable development goals, there are several research gaps that need to be addressed. While studies by Kouhizadeh et al. (2020). Sahoo et al. (2023), and Bag et al. (2021a) have explored the integration of specific Industry 4.0 technologies, such as blockchain, big data, and artificial intelligence into circular economy practices, there are further investigation into the potential of incorporating Industry 4.0 concepts was done by Bag et al. (2021b), Hoang-Khac et al. (2022), and Shayganmehr et al. (2021).

Although, Kayikci et al. (2022a) have assessed the readiness and maturity levels of small and medium-sized enterprises (SMEs) in implementing smart circular supply chains, there is a research gap in understanding how one sector can effectively adopt and integrate smart circularity practices into their supply chain operations. Furthermore, while Kayikci et al. (2022b) have focused on the use of smart circular supply chains for achieving Sustainable Development Goals (SDGs) in a post-pandemic context. Therefore, our work examines the integration of diverse Industry 4.0 technologies to assess the influence of Industry 4.0-oriented CE practices on the sustainable performance. We will identify best practices and measure performance using a novel framework tailored to this specific context. By utilizing extensive searches and expert input, we aim to provide insights into effective smart circularity practices in the textile industry in emerging markets.

The next section proposes a three-stage integrated decision-making model that utilizes the MCDM approach. It aims to provide a comprehensive framework for complex decisions by integrating multiple criteria and methods. This research employs expert opinions gathered through questionnaires after rigorous meetings and discussions, enhancing the validity and comprehensiveness of the study.

3. Methodology

A three-stage integrated decision-making model utilizing the Multi-Criteria Decision-Making (MCDM) approach is proposed in this research. The model aims to provide a comprehensive and effective framework for making complex decisions by integrating multiple criteria and decision-making methods. In this research, a hybrid decision-making model using Kendall's W-Fuzzy Delphi-BWM-FUCOM-CoCoSo framework is utilized to assess circularity-based sustainable performances within the context of various smart circularity practices. Figure 1 illustrates the framework of a comprehensive analysis applied.

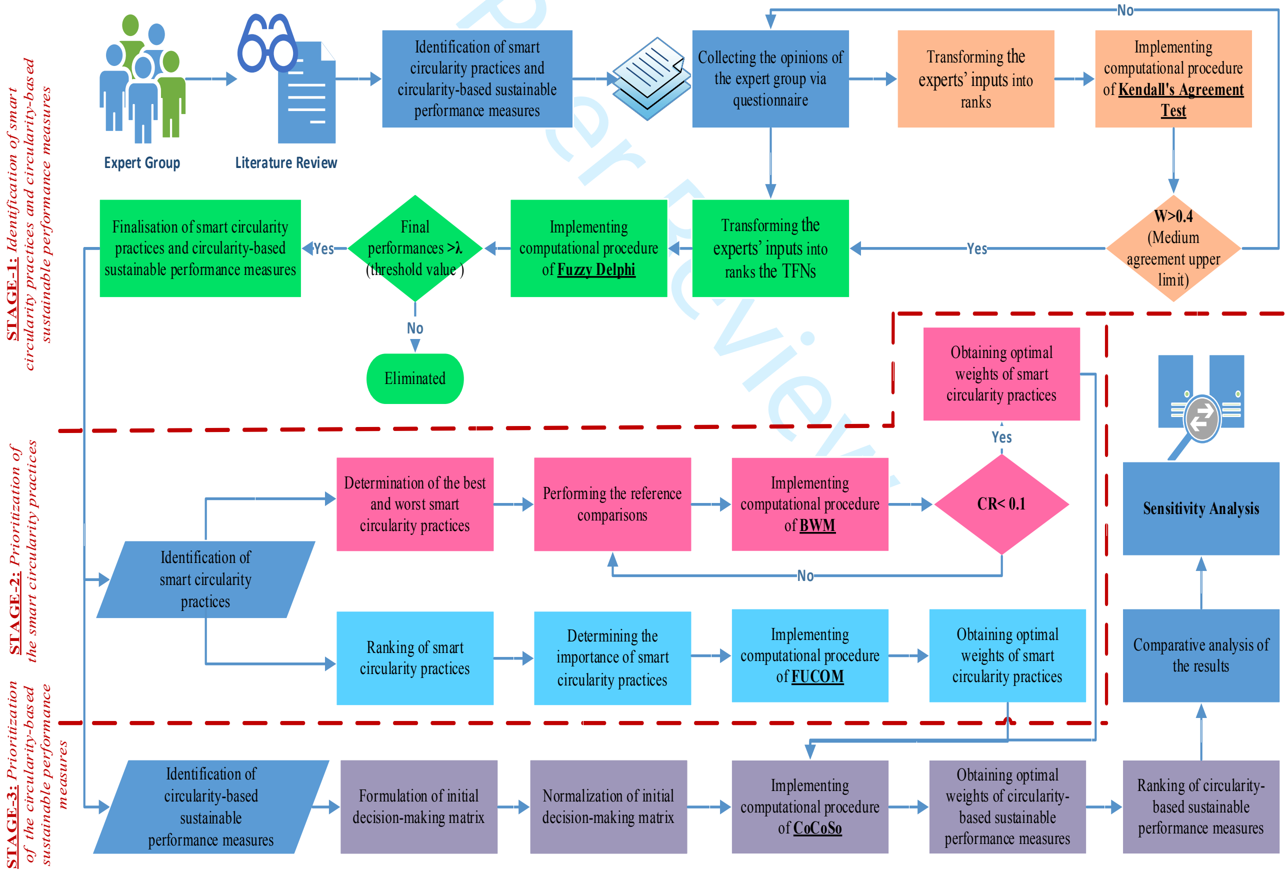

Figure 1: The hybrid decision making framework

To establish a foundation for the industry 4.0-driven circular economy (CE4.0) performance of the Indian textile industry, the initial stage of the research involved identifying smart circularity practices and circularity-based sustainable performances. This was accomplished through a questionnaire. The questionnaire was broken down into five main sections. Kendall's Agreement Test ensures reliable evaluations by assessing consensus among experts, while Fuzzy Delphi accommodates uncertainties and vagueness within expert opinions, yielding accurate and comprehensive outcomes. BWM aids in prioritizing criteria or alternatives, facilitating efficient decision-making, while FUCOM enhances coherence and consistency in pairwise comparisons to eliminate biases. CoCoSo combines multiple criteria, achieving balanced solutions that consider trade-offs. By integrating these methods, the hybrid approach provides robustness, handles uncertainties, prioritizes, fosters consistency, and achieves optimal solutions. Consequently, it stands as a valuable tool for complex decision-making scenarios.

3.1 Stage-1

The first phase focused on the identification of smart circular economy practices and sustainability performance in the T&C industries. This involved conducting a thorough literature survey to gather existing knowledge. An agreement test between two groups of experts was applied using the Kendall’s test to validate their consensus for the identified practices and performance. Further, the fuzzy Delphi technique was applied to further enhance the selection and rejection of SCE practices and sustainability performance.

i) Kendall’s Agreement Test: Maurice G. Kendall and Bernard Babington Smith first introduced Kendall's W, also known as Kendall's coefficient of concordance, as a non-parametric statistic in 1939. This statistical measure is employed to assess agreement among various rankings or raters, with values ranging from 0 (indicating no agreement) to 1 (representing complete agreement). Kendall's W can be computed on either an interval or ordinal scale. Higher values of the W statistic indicate a greater level of agreement among experts' groups.

The value of W determines the level of agreement among raters or respondents. W=1 means complete unanimity, with everyone assigning the same rank. W=0 indicates no agreement, and responses are essentially random. Intermediate values represent varying degrees of unanimity among the raters or respondents (Farooq *et al.*,2020; Legendre, 2005).

ii) Fuzzy Delphi Method: Multiple surveys are utilized in a Delphi process to gather and aggregate expert opinions. This method, however, requires more time and money to implement. The Fuzzy Delphi approach incorporates fuzzy set theory into the classic Delphi technique to account for the imprecision or uncertainty of experts' responses. In comparison to the Delphi method, this strategy significantly reduces the number of surveys rounds and saves time (Ali *et al.* 2023). To further enhance the reliability of the previous findings, the fuzzy Delphi method was used to finalize the CE4.0 practices and sustainable performance. This method allowed for the aggregation and evaluation of expert opinions to reach a consensus among the experts regarding the most relevant and effective measures of smart circularity practices and sustainable performance in the textile and clothing industries. Please see Appendix AA1, which has a detailed description of the Fuzzy Delphi procedure, for further information.

3.2 Stage-2

The second phase is focused on ranking the identified smart circular economy practices for achieving sustainable performance in the textile and clothing industries. Two methods were applied to accomplish this task. The BWM is based on the best-worst pairwise comparison, and then the FUCOM frameworks compare the weight coefficients of all elements in each hierarchy level. This is done to ensure the comparison is provided in a comprehensive ranking of smart circular economy practices.

i) Best Worst Method (BWM): BWM is a Multi-Criteria Decision Making (MCDM) technique (Rezaei 2015). Due to the fewer pairwise comparisons between factors and less mathematical complexity, this method is widely accepted in academia. Some current studies using this method are given in Table 1. It distinguishes itself by emphasizing the identification of the best and worst criteria and facilitating comparisons with other criteria. As a result, this approach reduces the pairwise comparison to only two vectors, streamlining the decision-making process. In contrast, while single-vector methods like SMART are efficient for large data sets, they lack the ability to guarantee consistency in pairwise comparisons. Full matrix methods like AHP enable consistency checks but can be time-consuming, particularly with large datasets. In contrast, the BWM method provides a balanced approach by allowing for consistency checks while remaining time-efficient in managing substantial amounts of data. This makes it a valuable tool for research and decision-making processes in various fields (Rezaei, 2020).

The consistency of the comparison depending on the value of ξ^L, a value close to 0 indicates higher consistency and the value is < 0.1 preferred for consistency (Rezaei, 2015). Refer to Appendix AA2 for the steps to be followed for BWM method.

ii) Full Consistency Method (FUCOM): The FUCOM, which ensures the precise assignment of weight values, mutually compares the weight coefficients of all elements in each hierarchy level and provides consistent conditions for comparison. In reality, the pairwise comparison values a_{ij} = w_i/w_j (where a_{ij} indicates the relative preference of criterion i over criterion j) are based on subjective estimates, not accurate measurements. In addition, there is a deviation of a_{ij} values from the ideal ratio w_i/w_j (where w_i and w_j represent weights of criteria i and j, respectively) (Pamučar *et al.*,2018). Table 1 includes the studies done by using the FUCOM method.

According to Pamučar *et al.* (2018), the FUCOM model, like AHP, BWM, SWARA, and DEMATEL, depends on the decision maker's subjective input to establish the weights for the criterion. The FUCOM model recommends using a straightforward algorithm, such as BWM, for implementation and evaluating the pairwise comparison's divergence from full consistency to confirm the algorithm's dependability. Notably, the FUCOM model exhibits minimal changes in weight coefficient values for criteria compared to other models under scrutiny. The steps of the FUCOM are presented in Appendix AA4.

Table 1: Recent studies on BWM, FUCOM and CoCoSo applications

Authors	**Applied method**	**Focus area**	**Experts Size**	**Objectives**
Shang *et al.*, (2022)	BWM-Fuzzy MULTIMOORA	Sustainability	17	Sustainable supplier selection.
Ali *et al.*, (2021)	BWM	Technology	8	Decision-making approach for the Drone integration in the emerging economics.
Moktadir *et al.* (2020a)	BWM, DEMATEL	Circular economy	15	Identification and evaluation of critical success factors of CE practices application.
Rezaei et al (2018)	BWM-SERVQUAL	Service quality	5	Quality assessment of airline baggage handling systems.
Khosravi *et al* (2022)	Fuzzy FUCOM-MARCOS	Structural adjustment policy	6	The most suitable organizational structure selection for hospitals.
Pamucar *et al.* (2020)	Fuzzy FUCOM-D'Bonferroni	Sustainability	5	The appropriate transportation demand management measures selection.

Pamučar *et al. (*2018)	FUCOM	Method development	1	The FUCOM model validation by comparing with respect to the subjective methods (AHP-BWM).
Ali *et al.* (2021)	Fuzzy Delphi, BWM, CoCoSo	Sustainable practice	8	Propose a framework for ranking the sustainable practices and warehousing performance.
Liu *et al.* (2021)	Pythagorean Fuzzy CoCoSo	Management of Medical waste	4	Propose a framework for selection of medical waste treatment technology.
Wen *et al.* (2019)	SWARA and CoCoSo	Cold chain logistic	4	Drug cold chain logistics selection.

3.3 Stage-3

In the third phase, the prioritization of sustainable performance measures was conducted using the CoCoSo method. Data gathered through a questionnaire and evaluated using a linguistic decision matrix helped to determine the importance of each sustainable performance. Weights found with the help of the BWM and FUCOM methods were then used in the final CoCoSo calculations. Since its introduction by Yazdani et al. (2019), the Combined Compromise Solution (CoCoSo) method has been a popular Multi-Criteria Decision-Making (MCDM) approach. This method ranks choices based on how well they meet certain pre-dominated criteria. It does this by using both simple additive weighting and an exponentially weighted product model. In this study, sustainable performance measurements are compared to smart circular economy practices using the CoCoSo technique. The CoCoSo technique has acquired substantial interest and fame in research areas connected to supply chain management and other topics. As the method's efficacy and use have been acknowledged, it has become a useful resource for decision-making in various fields Yazdani et al. (2019). Refer to Appendix AA5 for the discussion related to steps.

Through an extensive literature review, we discovered that the integrated methods used in our study is unique and has not been previously explored. While individual methods and approaches have been widely applied in research on circular economy, green and sustainable supply chains and logistics, their integration with Industry 4.0 technology to address enablers, Critical Success Factors (CFS), practices, and performance remains unexplored. Therefore, our study fills this research gap by employing these methods in a novel context, thereby contributing to the existing body of knowledge in this field. In the next section, robust and well-designed methodology to strengthen the validity and contribution of our research based on the case is presented.

4. Case Study

The Indian firms chosen for research purpose are in the North Indian region of India. Ludhiana, Punjab has leading manufacturers of cotton, wool, and acrylic knitwear. Data is collected from the industries identified that have already implemented circularity in their integration processes. The selected textile companies had been operating for average 10 years and the minimum number of employees was 500. The selection process for circular economy experts is done in a manner that only the most qualified and experienced professionals are chosen. A comprehensive search is conducted to identify experts with relevant backgrounds in sustainability, resource management, corporate social responsibility, waste reduction and technology integration. A screening process evaluates their educational and professional qualifications, work experience, and expertise to deal with the difficult T&C projects. They were purposefully chosen to provide a broader perspective on the business landscape and other industrial aspects related to CE principle. The final selection is made based on the candidate's expertise, experience, and demonstrated ability to contribute valuable insights and recommendations on circular economy practices. They were selected based on their knowledge in implementing closed-loop production, recycling the waste, reprocessing for some raw materials activities, following "Zero waste to landfill" policy, focusing on recycling metal scraps from their manufacturing processes. The experts were from sustainable manufacturing processes, textile waste management, upcycling techniques and sustainable dyeing and finishing techniques with average work experience of 10 years. Detailed information about the experts is given in Table 2.

Table 2: Expert profile and case companies

Main features	**Turnover**	**Experts working**	**Experts experience (in years)**
Specialises in the production of sustainable and organic textiles. Also focuses on textile waste collection, sorting, and recycling processes.	USD 5-6 million annually	Three Professionals with expertise in sustainable manufacturing processes having a BTech, MBA in Supply Chain Management working as General manager	10-15
Focuses on recycling and upcycling textile waste to create new products.	USD 2-8.5 million annually	Two professionals with expertise in textile waste management having a B Tech working as Manager Operation and Production	8-12

Produces textiles using environmentally friendly processes and materials. manufactures sustainable and eco-friendly clothing using recycled materials	USD 6.2 million annually	Two professionals specialized in sustainable dyeing and finishing techniques having a BTech, MBA in Supply Chain Management working as Technical Manager	7-9
Specializes in the production of circular and regenerative fibres. manufactures sustainable and eco-friendly clothing using recycled materials.	USD 10 million annually	Two Professional experienced in sustainable fibre production having a MTech working as Director	9-11
Focuses on textile waste collection, sorting, and recycling processes.	USD 1.5 million annually	One professional experienced in textile recycling methods having a BTech, MBA in Supply Chain Management working as Senior Production manager	10

Experts remain same throughout, this continuity allowed for a thorough understanding of the study from start to finish, enabling the experts to delve into each consideration and contribute to the development of the questionnaires. By having the same experts throughout the research, we ensured that their deep familiarity with the project improved the credibility and consistency of our findings and conclusions.

To make sure there was clear communication with experts and an easy way to respond, the questionnaires for stage-based inquiries were made with separate, specific sets of questions that used scales according to analysis requirements. Through iterative rounds of email exchanges and follow-ups, the experts' feedback and insights were gathered, analyzed, and incorporated to refine and improve the questionnaire, ultimately enhancing its validity and effectiveness for data collection. In the initial stage, the experts were presented with the problem, accompanied by a brief explanation of its purpose. Subsequently, the questionnaire commenced, consisting of SCE practices questions that guided the assessments.

These questions were answered using a scale ranging from 1 to 5, where 1 corresponded to 'not considered,' 2 indicated ‘little consideration’, 3 denoted ‘an average level of consideration’, 4 represented ‘better possibilities’, and 5 indicated ‘necessary consideration’ (Ali *et al.* 2019). Any necessary changes to preserve the essence of the response value were made without compromising accuracy. Furthermore, participants were provided with an opportunity to share additional comments in cases where the answer options were insufficient or if they wished to provide further support or justification for their responses. This allowed for a more comprehensive understanding of their perspectives and ensured that all relevant aspects were adequately addressed. Kendall's

Agreement Test was employed to measure the level of agreement between two group of experts to measure their agreement and disagreement. The experts are divided in two groups depending on the year of operation as less than and more than 10 years, ensuring reliable evaluations. To gather data for acceptance and rejection of each SCE practices and circular economy related sustainable performance, the study utilized the Fuzzy Delphi technique. It is a rational process for gathering expert viewpoints and achieving consensus by using the Linguistic scale of 1(very low) to 5 (very high). This involves meeting experts, formulating questions, and iteratively refining the responses. It helps minimize biases and allows experts to revise their opinions.

In the subsequent round of stage 2, following the completion of the Fuzzy Delphi results presented in Table 3. A comprehensive list of practices and performances that have emerged through consensus from the survey is compiled. The SCE practices list is then used to gather responses using a 9-point scale, ranging from "1: equally important" to "9: extremely important," for the purposes of conducting the Best Worst Method (BWM) analysis. In the fourth round, the questionnaire is expanded to incorporate expert responses related to Smart Circular Economy (SCE) practices again for the FUCOM analysis. Experts have given their responses to the priority order of SCE practices to evaluate the importance of these practices. by using "1: strongly disagree" to "5: strongly agree." By gathering expert opinions through this approach, a comprehensive understanding of the perceived importance of SCE practices is achieved. The process included several rounds of email correspondence and diligent follow-ups to fix a meeting. The same experts took part for BWM and FUCOM questionnaire responses.

In the last, a linguistic scale is added to the questionnaire to find out how experts would rate circularity-based sustainable performance in the context of Smart Circular Economy (SCE) practices. The scale ranges from "1: very low" to "5: very high" and is included for evaluation and preferences regarding the level of circularity-based sustainable performances associated with SCE practices. Questionnaire responses were gathered from all ten experts who participated in the study from round 1 to round 5.

4.1 Finalization of Smart Circularity Practices and Circularity-based Sustainable Performance Measures

Upon reviewing the existing literature, it was apparent that the combination of methods employed in our study had not been previously utilized. These individual approaches, as well as their integration with other techniques (Ali *et al.,* 2023), have been widely employed in research pertaining to green and/or sustainable supply chain/ logistics. However, their application in conjunction with Industry 4.0 technology to address appropriate enablers, Critical Success Factors (CFS), practices, and performance has not been explored so far. Therefore, our study fills this gap by employing these methods in a novel context, contributing to the existing body of knowledge in this area. Literature search helped us to identify twelve circular practices and fourteen circularity-based sustainable performance measures. During the subsequent phase, a questionnaire was developed with the aim of determining the specific smart circular practices and circularity-based sustainable performance indicators. To gauge the level of agreement among expert assessments, Kendall's W statistic was employed prior to proceeding with the application of Fuzzy Delphi. The survey results from the experts' opinions on smart circular practices and circularity-based sustainable performances are presented in Table A4. The experts utilized a five-point scale ranging from 1 (not considered) to 5 (necessary consideration) to convey their opinions. In order to calculate Kendall's W statistic, which is used to assess stability and consensus within the Delphi method, the data in Table A4 is transformed into ranks, as shown in Table A5. This transformation is carried out using Equation (1) (Legendre, 2005), as follows:

$$\sum_{i=1}^{n} r_{ij} = 1 + 2 + \ldots + n = \frac{n(n+1)}{2} \tag{1}$$

For smart circular practices and circularity-based sustainable performances, $\bar{R}$ was calculated as 65 and 75; S was calculated as 7738.5 and 11550; and W was calculated as 0.54 and 0.51 respectively, using Equations (A2-A4). Hence finally, the concordance values showed medium agreement between experts as indicated in Table A1.

Utilizing expert consensus and employing Fuzzy Delphi analysis, the smart circular practices and circularity-based sustainable performance measures were finalized. The finalized measures are presented in Table 3. Subsequently, a final questionnaire was prepared to gather responses from the experts regarding the finalized smart circular practices and circularity-based sustainable performance indicators. The acceptance threshold for all practices and performances was set at 0.7 based on the recommendations of Chang, Huang, & Lin (2000). If the de-fuzzy value of a smart circularity practice or performance is equal to or greater than 0.7, it is deemed significant; otherwise, it is considered not significant. The significant smart circularity practices and circularity-based sustainable performances, based on the threshold value, are considered for the proposed research questions and are presented in Table 3 and Figure 2.

Table 3: Finalization of the smart circularity practices and performances using Fuzzy Delphi

Smart Circularity Practices	**Lowest assessment**	**Geometric Mean**	**Highest assessment**	**Crisp value**	**Decision**
Technical capability **(SCP1)**	0.5	0.793725	0.9	0.731242	Accept
Competitive pressures	0.1	0.538937	0.9	0.512979	*Reject*
Policy and Regulation **(SCP2)**	0.5	0.774026	0.9	0.724675	Accept
Financial capability **(SCP3)**	0.5	0.813926	0.9	0.737975	Accept
Fair Acceptance	0.1	0.329723	0.7	0.376574	*Reject*
Security and Safety **(SCP4)**	0.5	0.813926	0.9	0.737975	Accept
System flexibility **(SCP5)**	0.5	0.793725	0.9	0.731242	Accept
Support and maintenance **(SCP6)**	0.5	0.754816	0.9	0.718272	Accept
Stakeholders' readiness	0.1	0.278554	0.7	0.359518	*Reject*
Regulatory Pressures	0.1	0.20345	0.7	0.334483	*Reject*
Process and product design for resource and energy efficiency **(SCP7)**	0.5	0.813926	0.9	0.737975	Accept
Education and participation **(SCP8)**	0.5	0.754816	0.9	0.718272	Accept
Circularity-Based Sustainable Performance	**Lowest assessment**	**Geometric Mean**	**Highest assessment**	**Crisp value**	**Decision**
Increase in resource circularity **(CEISP1)**	0.5	0.793725	0.9	0.731242	Accept
Better adoption of digital technology	0.1	0.278554	0.7	0.359518	*Reject*
Improve human efficiency **(CEISP2)**	0.5	0.793725	0.9	0.731242	Accept
Improve human skills	0.1	0.278554	0.7	0.359518	*Reject*
Increase in profit from green products **(CEISP3)**	0.5	0.793725	0.9	0.731242	Accept
Improved usage of green logistics **(CEISP4)**	0.5	0.793725	0.9	0.731242	Accept
Better employees and community health **(CEISP5)**	0.5	0.793725	0.9	0.731242	Accept
Improved green purchasing **(CEISP6)**	0.5	0.793725	0.9	0.731242	Accept
Better usage of green warehousing **(CEISP7)**	0.5	0.793725	0.9	0.731242	Accept
Better/improved market demand **(CEISP8)**	0.5	0.793725	0.9	0.731242	Accept
Improved develop the CE based smart culture	0.1	0.278554	0.7	0.359518	*Reject*
Increase in cost saving through product quality **(CEISP9)**	0.5	0.793725	0.9	0.731242	Accept
Decrease in emission, waste, and pollution monitoring **(CEISP10)**	0.5	0.793725	0.9	0.731242	Accept
Improved incentives and government legislation support and incentives **(CEISP11)**	0.5	0.793725	0.9	0.731242	Accept

Figure 2: Smart circularity practices and performances of T&C industry

4.2 Prioritization of Smart Circularity Practices

The experts were contacted via email to confirm their availability for a meeting to collect the response. This approach ensured a systematic and structured process for gathering professional perspectives and insights. The same group of experts who provided their perspectives to finalize the list of selected smart circular practices and sustainable performance were contacted again to gather the response. This ensured consistency and allowed for a comprehensive analysis of their opinions. By involving the same experts for the 2nd stage, their insights and expertise are utilized to enrich the study and provide a well-rounded understanding of the selected research subject. This method of data collection maintained rigorous homogeneity during various stages of the research methodology to obtain the necessary information. In the BWM implementation, the experts' input was utilized to identify both the best and worst smart circularity practices using Saaty's nine-point (1-9) scale. Other practices are ranked based on the best and worst practices that have already been chosen. The same procedure was repeated for the selection of the other smart circularity practices over the worst smart circularity practice as per their preferences. After gathering the experts' responses, we prioritized smart circularity practices using the Best Worst Method (BWM). Priority order responses were gathered and Full Consistency Method (FUCOM) was applied. These identified practices with expert responses are presented in Table A4.

BWM's optimization model according to Equation (A8) is applied to obtain the optimal weights of the smart circularity practices for ten experts and presented in Table 4.

Table 4: Best and worst smart circularity practices and performance measures along with the optimal weights from each expert

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
Best	**SCP1**	**SCP6**	**SCP4**	**SCP2**	**SCP8**	**SCP4**	**SCP1**	**SCP1**	**SCP5**	**SCP8**
Worst	**SCP6**	**SCP3**	**SCP3**	**SCP8**	**SCP1**	**SCP6**	**SCP6**	**SCP3**	**SCP2**	**SCP2**
SCP1	0.34	0.19	0.19	0.21	0.04	0.20	0.34	0.22	0.20	0.20
SCP2	0.14	0.13	0.13	0.33	0.14	0.14	0.22	0.34	0.04	0.04
SCP3	0.11	0.03	0.03	0.07	0.15	0.03	0.04	0.03	0.06	0.06
SCP4	0.09	0.08	0.31	0.14	0.14	0.32	0.07	0.07	0.07	0.07
SCP5	0.09	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.34	0.13
SCP6	0.03	0.32	0.06	0.07	0.07	0.06	0.05	0.07	0.08	0.08
SCP7	0.06	0.05	0.06	0.07	0.07	0.07	0.09	0.07	0.08	0.08
SCP8	0.14	0.13	0.13	0.04	0.33	0.10	0.11	0.11	0.13	0.34
CR	0.10	0.05	0.07	0.08	0.08	0.09	0.09	0.10	0.06	0.06

*E refers to Expert

From Table 4, it is obvious that CR is close less than 0.10 (Rezaei 2015; 2016), so the comparisons drawn are quite consistent/reliable. Further, a single weight is found by calculating the average of each smart circularity practices and indicated in Table 5. Ranking by weight of each smart circularity practices is calculated and indicated in Table 5.

Table 5: Weight and rank of smart circularity practices by BWM

Smart circularity practices	**Weights**	**Rank**
Technical capability (SCP1)	0.2122	1
Policy and Regulation (SCP2)	0.1625	2
Financial capability (SCP3)	0.0610	8
Security and Safety (SCP4)	0.1341	4
System flexibility (SCP5)	0.1134	5
Support and maintenance (SCP6)	0.0905	6
Process and product design for resource and energy efficiency (SCP7)	0.0704	7
Education and participation (SCP8)	0.1559	3
Average Consistency Ratio (CR) = 0.07777		

To implement the FUCOM method, the first step is to establish the priority order of smart circularity practices. This is achieved by evaluating the importance levels of these practices using a Likert scale, with questionnaire input taken from a panel of same experts. The results of the FUCOM application by optimizing the final mathematical model are presented in Table 6.

Table 6: Local weights from each expert for smart circularity practices by FUCOM

	E1	**E2**	**E 3**	**E 4**	**E5**	**E 6**	**E7**	**E 8**	**E 9**	**E10**
SCP1	0.39	0.18	0.18	0.19	0.05	0.18	0.39	0.19	0.19	0.19
SCP2	0.13	0.12	0.12	0.37	0.12	0.12	0.20	0.39	0.05	0.05
SCP3	0.97	0.04	0.05	0.06	0.18	0.05	0.05	0.05	0.05	0.05
SCP4	0.08	0.07	0.35	0.13	0.12	0.37	0.07	0.07	0.06	0.06
SCP5	0.08	0.07	0.07	0.08	0.07	0.07	0.08	0.08	0.38	0.13
SCP6	0.05	0.35	0.06	0.06	0.06	0.05	0.05	0.07	0.08	0.08
SCP7	0.06	0.05	0.06	0.06	0.06	0.06	0.08	0.07	0.08	0.08
SCP8	0.13	0.12	0.12	0.05	0.35	0.09	0.10	0.10	0.13	0.38
DFC	0	0	0	0	0	0	0	0	0	0

From Table 6, it is evident that all deviations from full consistency (DFC) are equal to 0, for this reason, the comparisons made are highly consistent. The final weights are found by averaging the values obtained from all experts. Ranking according to the weight of each smart circularity implementation is calculated and is given in Table 7.

Table 7: Weight and rank of smart circularity practices by FUCOM

Smart circularity practices	**Weights**	**Rank**
Technical capability (SCP1)	0.2117	1
Policy and Regulation (SCP2)	0.1654	2
Financial capability (SCP3)	0.1560	3
Security and Safety (SCP4)	0.1362	5
System flexibility (SCP5)	0.1092	6
Support and maintenance (SCP6)	0.0897	7
Process and product design for resource and energy efficiency (SCP7)	0.0639	8
Education and participation (SCP8)	0.1554	4
Average Deviation from full consistency (DFC)= 0		

4.3 Prioritization of Circularity-based Sustainable Performance Measures

In the third stage, CoCoSo method is applied to get the performance priorities in relation to various smart circularity practices. The questionnaire administered includes a linguistic scale to assess the preferences of experts in evaluating circularity-based sustainable performances. A decision matrix is included in to capture each expert's response, considering evaluation of smart circularity practices. After the ten linguistic matrix decision matrices are taken, the linguistic terms are transformed into the decision matrix by replacing them with the crisp values shown in Table A3 (in Appendix AA1). Ten matrices are converted into initial decision-making matrix utilizing the average and shown in Table A6 (in Appendix).

Next, the normalized matrix is received by Equation (A15) and Equation (A16) and demonstrated in Table A7. Sj is calculated for each smart circularity-based performance by Equation (A17). Sj is shown in Table A8. Similarly, Pi is calculated using the weights obtained by BWM and FUCOM for each smart circularity performance, respectively, using Equation (A18), and presented in Tables A9 and A10.

In the last step of CoCoSo, three different aggregation methods are used to calculate the relative weights (k_{ia}, k_{ib},k_{ic}) of each smart circularity performance using the Equation (A19-A21). These relative weights are used to define the final weights (and indicated by K column) by Equation (A22, refer to Appendix AA5) is indicated in Tables 8 and 9. Depending on final weights, each smart circularity practice is prioritized, and all final ranks are calculated and indicated in Tables 8 and 9.

Table 8: Relative weights, final weights and ranking of circularity-based sustainable performance measures using BWM weights

Performance	**K_a**	**Ranking**	**K_b**	**Ranking**	**K_c**	**Ranking**	**K**	**Final Ranking**
CEISP1	0.100	5	3.262	6	0.939	5	2.107	**6**
CEISP2	0.073	9	2.586	9	0.687	9	1.622	**9**
CEISP3	0.071	10	2.133	10	0.667	10	1.423	**10**
CEISP4	0.106	2	4.029	2	0.992	2	2.459	**2**
CEISP5	0.079	8	2.978	7	0.740	8	1.823	**8**
CEISP6	0.096	6	2.935	8	0.901	6	1.944	**7**
CEISP7	0.102	4	3.573	4	0.959	4	2.249	**4**
CEISP8	0.069	11	2.000	11	0.652	11	1.356	**11**
CEISP9	0.093	7	3.453	5	0.870	7	2.125	**5**
CEISP10	0.105	3	3.842	3	0.983	3	2.377	**3**
CEISP11	0.107	1	4.041	1	1.000	1	2.471	**1**

Table 9: Relative weights, final weights and ranking of circularity-based sustainable performance measures using FUCOM weights

Performance	**K_a**	**Ranking**	**K_b**	**Ranking**	**K_c**	**Ranking**	**K**	**Final Ranking**
CEISP1	0.099	5	3.480	6	0.928	5	2.187	**5**
CEISP2	0.073	9	2.909	9	0.685	9	1.749	**9**
CEISP3	0.072	10	2.518	10	0.675	10	1.585	**10**

CEISP4	0.105	3	4.349	2	0.986	3	2.581	**2**
CEISP5	0.079	8	3.356	7	0.742	8	1.975	**8**
CEISP6	0.096	6	3.250	8	0.899	6	2.070	**7**
CEISP7	0.102	4	3.886	4	0.953	4	2.370	**4**
CEISP8	0.069	11	2.000	11	0.646	11	1.352	**11**
CEISP9	0.091	7	3.618	5	0.850	7	2.174	**6**
CEISP10	0.105	2	4.309	3	0.986	2	2.565	**3**
CEISP11	0.107	1	4.466	1	1.000	1	2.639	**1**

5. Results

Results of Stage 1: First, with the help of literature review, 12 smart circularity practices were determined to measure Industry 4.0 driven-CE performances for textile industry, and they were evaluated by 10 experts to perform Kendall's W statistic consensus analysis before the validation by Fuzzy Delphi analysis. It was observed that there was a moderate level of agreement among the experts. In the Delphi analysis application, 8 of the smart circularity practices and 11 of the circularity-based sustainable performances were accepted for further evaluation based on the acceptance criteria of 0.7.

Results of Stage 2: In order to evaluate the circularity-based sustainable performances according to the CoCoSo method, firstly, weighting processes were performed for each smart circularity practices. During the weighting process, comparative analysis was performed using the weights obtained from the FUCOM and BWM. The values found are shown in Table 10.

Table 10: BWM and FUCOM results

	BWM		**FUCOM**	
Smart circularity practices	**Weights**	**Rank**	**Weights**	**Rank**
Technical capability (SCP1)	0.2122	1	0.2117	1
Policy and Regulation (SCP2)	0.1625	2	0.1654	2
Financial capability (SCP3)	0.0610	8	0.1560	3
Security and Safety (SCP4)	0.1341	4	0.1362	5
System flexibility (SCP5)	0.1134	5	0.1092	6
Support and maintenance (SCP6)	0.0905	6	0.0897	7
Process and product design for resource and energy efficiency (SCP7)	0.0704	7	0.0639	8
Education and participation (SCP8)	0.1559	3	0.1554	4
Average consistency	**0.078**		**0**	

Determining the criteria weights in MCDM problems has important effects on the ranking of the alternatives. BWM and FUCOM methods are both methods used in criterion weighting. The processing steps of both methods are based on a simple algorithm and weights are obtained as a result of solving a mathematical model. However, when n is the number of criteria, BWM (2n-3) makes comparisons, while FUCOM (n-1) makes comparisons. These comparisons constitute the constraints of the linear programming model. In both methods, the objective function presents the consistency ratio of the comparisons made.

According to the results presented in Table 10, all circularity-based sustainable performances have weight values very close to each other except SCP3. In terms of ranking, the 1st and 2nd Ranks were the same in both methods, while the SCP3 alternative, which was in the 3rd rank in FUCOM, was in the last rank in BWM, so the next rank shifts one rank. For example, while SCP4 was in the 4th rank in BWM, it was in the 5th rank in FUCOM.

As per the calculated consistency ratios, it is interpreted that the comparisons are consistent in both methods and the results are reliable. However, since the deviation from full consistency in FUCOM is equal to 0, it can be interpreted that the received values of the criterion weight coefficients are equal to the optimum value as a result of all calculations. This is because, unlike BWM, there must be mathematical transitivity in the relationship between the criteria and the relationship between the weighting coefficients of the criteria must be equal to the comparative importance of the criteria in FUCOM. As a result, the FUCOM both reduces the processing load and can achieve reliable results by preventing the researcher from facing the problem of inconsistency while performing analysis in a short time, due to its mathematical structure and fewer pairwise comparisons.

Results of Stage-3: In the last step, the CoCoSo method was applied by using the weights obtained from both BWM and FUCOS to get the ranking of circularity-based sustainable performance. The values found are demonstrated in Table 11.

Table 11: CoCoSo results

Performance	**Ranking of K_a**		**Ranking of K_b**		**Ranking of K_c**		**Final Ranking of K**	
	BWM	**FUCOM**	**BWM**	**FUCOM**	**BWM**	**FUCOM**	**BWM**	**FUCOM**
CEISP1	5	5	6	6	5	5	6	5
CEISP2	9	9	9	9	9	9	9	9
CEISP3	10	10	10	10	10	10	10	10
CEISP4	2	3	2	2	2	3	2	2
CEISP5	8	8	7	7	8	8	8	8
CEISP6	6	6	8	8	6	6	7	7
CEISP7	4	4	4	4	4	4	4	4
CEISP8	11	11	11	11	11	11	11	11

CEISP9	7	7	5	5	7	7	5	6
CEISP10	3	2	3	3	3	2	3	3
CEISP11	1	1	1	1	1	1	1	1
r_s	**0.99**		**1.00**		**0.99**		**0.99**	

These weight changes in different methods (BWM and FUCOS) revealed minor changes in the ranking of the circularity-based sustainable performances. From Table 11, most of the circularity-based sustained performances are perceived to remain the same or slightly change across all aggregation approaches. Sperman's rank correlation coefficient (rs) is used to determine the correlation between the obtained circularity-based sustainable performances rankings and takes a value between 0 and 1. When the obtained value is greater than 0.8, a very strong similarity is mentioned. According to Table 11, all correlation coefficients are greater than 0.8 and there is a strong similarity between the results. Thus, we could deduce that the proposed method is adequately consistent, reliable, stable, and robust to acquire the result.

5.1 Robustness of Model

Multi-Criteria Decision Making (MCDM) strategies have been developed to aid decision makers in comprehending complex problems and considering diverse factors that may impact their decisions. These strategies aim to facilitate the identification of "Good" enough solutions through a systematic evaluation process (Ali, *et al*. 2021, 2023). The presence of variations in a selected set of variables or even in endogenous variables serves as an indication of robustness and provides insights into the stability and reliability of the results. In this section, the weights of the criteria are varied and the changes that may occur in the result are tried to be determined. Sensitivity analysis is performed by gradually changing the weight of the criterion with the highest importance (weight). The highest weighted criterion for smart circular applications is SCP1- “Technical capability”, so nine tests were created by changing the weight of this criterion from 0.1 to 0.9 in increments of 10%. According to the change in SCP1 weight, other criteria weights were changed in proportion to their own weight ratio, and the total weight percentage was ensured to be 100%. Steps followed are represented in Appendix AA6. w_i^0 and w_j^0 are the weight values of criteria i and j before the sensitivity analysis, respectively. In this context, 9 different experimental sets created by changing the weights of the criteria obtained by both BWM and FUCOM are given in Tables 12 and 13.

Table 12: The first experiment set of smart circularity practices weights for sensitivity analysis

SCPs	**Original by BWM**	**Test-1**	**Test-2**	**Test-3**	**Test-4**	**Test-5**	**Test-6**	**Test-7**	**Test-8**	**Test-9**
SCP1	**0.2122**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
SCP2	0.1625	0.1856	0.1650	0.1444	0.1238	0.1031	0.0825	0.0619	0.0413	0.0206
SCP3	0.0610	0.0697	0.0619	0.0542	0.0465	0.0387	0.0310	0.0232	0.0155	0.0077
SCP4	0.1341	0.1532	0.1362	0.1192	0.1021	0.0851	0.0681	0.0511	0.0340	0.0170
SCP5	0.1134	0.1296	0.1152	0.1008	0.0864	0.0720	0.0576	0.0432	0.0288	0.0144
SCP6	0.0905	0.1034	0.0919	0.0804	0.0689	0.0574	0.0460	0.0345	0.0230	0.0115
SCP7	0.0704	0.0804	0.0715	0.0626	0.0536	0.0447	0.0357	0.0268	0.0179	0.0089
SCP8	0.1559	0.1781	0.1583	0.1385	0.1187	0.0989	0.0792	0.0594	0.0396	0.0198

Table 13: The second experiment set of smart circularity practices weights for sensitivity analysis

SCPs	**Original by FUCOM**	**Test-1**	**Test-2**	**Test-3**	**Test-4**	**Test-5**	**Test-6**	**Test-7**	**Test-8**	**Test-9**
SCP1	**0.2117**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
SCP2	0.1654	0.1888	0.1679	0.1469	0.1259	0.1049	0.0839	0.0629	0.0420	0.0210
SCP3	0.1560	0.1781	0.1583	0.1406	0.1187	0.0989	0.0792	0.0594	0.0396	0.0198
SCP4	0.1362	0.1555	0.1382	0.1227	0.1037	0.0864	0.0691	0.0518	0.0346	0.0173
SCP5	0.1092	0.1247	0.1108	0.0984	0.0831	0.0693	0.0554	0.0416	0.0277	0.0139
SCP6	0.0897	0.1024	0.0910	0.0808	0.0683	0.0569	0.0455	0.0341	0.0228	0.0114
SCP7	0.0639	0.0730	0.0648	0.0576	0.0486	0.0405	0.0324	0.0243	0.0162	0.0081
SCP8	0.1554	0.1774	0.1577	0.1400	0.1183	0.0986	0.0789	0.0591	0.0394	0.0197

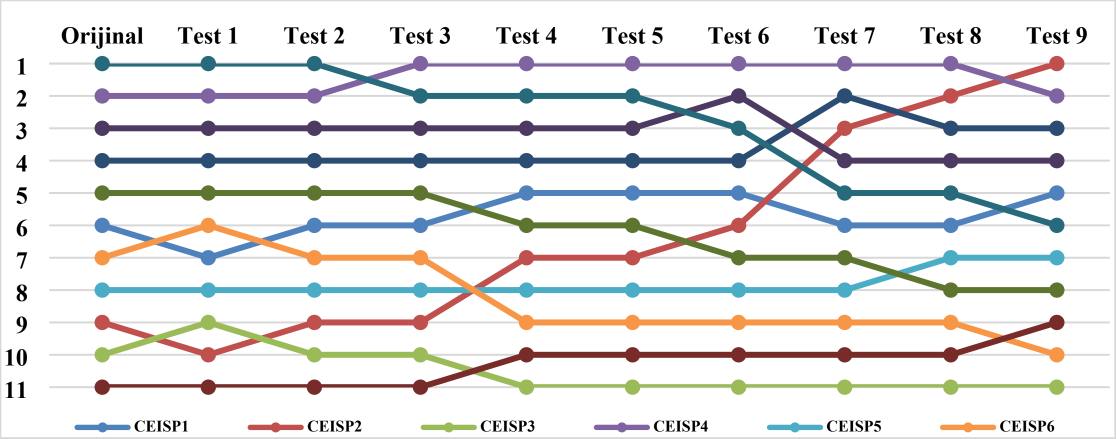

Figure 3: The graphical view of circularity-based sustainable performance ranking in the first experiment set

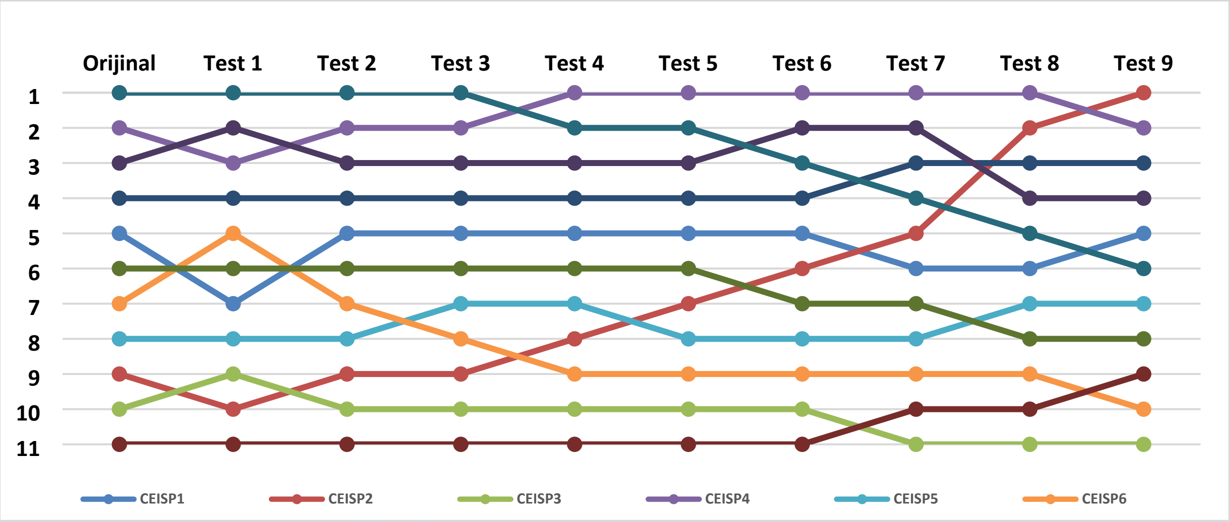

Figure 4: The graphical view of circularity-based sustainable performance ranking in the second experiment set

The ranking of circularity-based sustainable performance obtained by the CoCoSo method using a total of 18 different test data created by changing the existing weights obtained as a result of each criteria weighting method (BWM and FUCOM) is presented in Tables A11 and A12 respectively. In Figures 3 and 4, the changes in the Circularity-based sustainable performance rankings can be seen more clearly.

According to this, other Circularity-based sustainable performances other than CEISP2 and followed by CEISP11 either remained the same or changed slightly in all tests. On the other hand, CEISP2, which was 9th in both original rankings (BWM and FUCOM), increased overall and ranked 1st in the final tests. Again, CEISP11, which was in the 1st in both original rankings (BWM and FUCOM), decreased 1 step in the first 5 tests to the 2nd, and in the following tests, it decreased continuously and regressed to the 6th rank in the last tests. From this point of view, it can be concluded that the best criterion, SCP1- "Technical capability", sensitizes the ranking results because it has an effect on these two performances (CEISP2 and CEISP11), and since the changes in other sustainable performance rankings are very small, the ranking results are robust and stable.

6. Discussion of Findings

Sustainability and the adoption of circular economy practices are indeed becoming increasingly important for organizations. This is justified as the transition from traditional production models to more sustainable practices require evaluating sustainability performance and finding ways to balance economic growth with environmental protection and aligned with the findings of Bag *et al.* (2021b). Organizations are facing increasing pressure to change the production models from traditional to sustainable and rather Industry4.0 driven, which strengthens the requirement to evaluate their performance at sustainability points, as highlighted by Kayikci *et al.* (2022 a) in their discussions. Industry 4.0 has accelerated the process of overcoming the barriers to circularity, and digitalization has become progressively facilitating for the implementation and adoption of the CE and aligned with Kouhizadeh *et al.* (2020). Scholars and academics have paid close attention to how government support changes in the plans and actions of systems in a CE4.0.

The case companies were selected from the Indian region involved in the highest T&C production. These organizations from the Punjab region in Ludhiana demonstrated their commitment to circular economy principles related to the study's focus, such as green practices, sustainability, technology adoption, and innovation by implementing sustainable practices, utilizing recycled materials, and embracing innovative techniques to contribute to a more sustainable textile industry in India.

Since the research goal of the study is to determine the effect of smart circularity practices on achieving sustainability performances, qualitative concepts such as ideas and thoughts on this subject was evaluated with the help of experts after reviewing the literature, a similar pattern of findings was followed in research of Ali *et al.* (2023) and Khan *et al.*, (2022). An experts' group specialized in the textile industry was formed to explore and document opinions regarding smart circular economy practices. The group comprised ranges from various sectors, including textile manufacturing, sustainability, fashion design, waste management, and technology. Through insightful discussions and collaborative sessions, these experts shared their extensive knowledge and experiences in implementing circular economy strategies within the textile industry. Their opinions were meticulously recorded, capturing innovative ideas, best practices, and potential challenges specific to the textile sector. This valuable repository of expertise serves as a guide for industry stakeholders, policymakers, and researchers seeking to foster sustainable practices, minimize waste, and promote circularity in the textile value chain. After a detailed literature review and consultation with the experts, 10 smart circularity practices and in the context of achieving sustainability in the textile industry, 12 circularity-based sustainable performance indicators were determined. The selection process ensures a high level of expertise and diversity within the expert group, enhancing the quality and impact of their work. Therefore, our research study incorporated various decision-making frameworks to answer research questions depending on the type of data we need. The pretesting of a questionnaire involved an experts' group, utilizing Kendall's Agreement Test and Fuzzy Delphi methodology. The experts were provided with the questionnaire and were asked to assess its clarity, relevance, and comprehensiveness. The Fuzzy Delphi technique helped capture their opinions, accounting for uncertainties and vagueness. These applications were finalized using the concordance agreement test and the Fuzzy Delphi method in line with the responses from ten relevant experts. Once the sustainable performance metrics and smart circular practices were finalized, a questionnaire was further developed. These frameworks involve qualitative methods, such as BWM, and FUCOM. By combining these methods, a comprehensive evaluation of circular economy performance was achieved through CoCoSo. A robustness analysis was further done to validate the results of the analysis

Discussion based on BWM & FUCOM. The emergence of Industry 4.0 and the digitalization of processes have played a significant role in facilitating the adoption of circular economy practices. This aligns with the concept of Industry 4.0-driven circular economy, where technological advancements enable greater efficiency and optimization in resource usage as highlighted by Kouhizadeh *et al.* (2020), Sahoo *et al.* (2023), and Bag *et al.* (2021a). This study focused on sustainable performance criteria in circular economy (CE) organizations. Technical proficiency and the capacity to adopt ground-breaking technology for resource and energy efficiency are key factors in sustainable performance in our work and matches with the findings of Sahoo *et al.* (2023). Organizations that promoted innovative technologies and technical competence were more sustainable. Policy and regulation, which encourages circular practices and sets resource efficiency requirements, was the second most important component is aligned with Ali *et al.* (2023). Education and participation placed third, emphasizing stakeholder awareness and engagement. Education about CE principles and encouraging sustainable practices improves sustainable performance. However, education and participation are ranked last in FUCOM. Security, safety, waste, and hazardous materials management scored fourth for sustainable performance. System flexibility—adaptability to market needs and environmental changes—ranked fifth and contradicts with the Lopez, *et al.* (2019). Support and maintenance were crucial to optimizing circular practices and reducing waste, hence supports Salvioni, & Almici (2020) work, while resource and energy-efficient processes and product design affected sustainability. Financial capability—sufficient funds and investments—ranked last in BWM. However, financial capacity helps organizations adopt circular programs and support sustainable technologies, and it is ranked 3rd in FUCOM.

Discussion based on CoCoSo. The study revealed that improved incentives by the government and legislation were ranked as the top performers for promoting sustainability. These measures play a crucial role in encouraging organizations to adopt sustainable practices by providing financial benefits and creating a favorable regulatory environment and similar to the contributions of researchers like Jaeger & Upadhyay (2020); Moktadir *et al.* (2020a) and Ali and Kaur (2022). The second-ranked performance was the improved usage of green logistics is similar results aligned with Manickam, & Duraisamy, (2019). This includes initiatives such as optimizing transportation routes, adopting eco-friendly packaging, and utilizing sustainable transportation methods to reduce carbon emissions and minimize environmental impact. Third on the list was monitoring and reducing emissions, waste, and pollution is similar to Sahoo, *et al.* (2023). Organizations that actively monitor and manage their carbon emissions, waste generation, and pollution levels were found to be more sustainable. The next-ranked performance was better usage of green warehousing (Ali *et al.* 2023). This involves implementing sustainable and energy-efficient practices in warehousing operations, such as utilizing renewable energy sources and minimizing waste generation and supports work of Kazancoglu *et al.* (2020). The fifth-ranked factor was the increase in resource circularity, which refers to maximizing the reuse, recycling, and recovery of materials to minimize resource depletion and environmental impact.

Further down, the study identified other performances such as cost savings through product quality, improved green purchasing, better employee and community health, improved human efficiency, increased profit from green products, and better or improved market demand, all of which contribute to sustainable circular economy performance. These were aligned with the findings of Ali *et al.* (2023)

6.1 Theoretical Contributions

This study has several theoretical contributions to the literature by addressing measurement of Industry 4.0 driven circular economy performance in textile industry. Firstly, this research provides a detailed literature review in smart circularity practices and circularity-based sustainable performance indicators, determines them in in textile industry based on expert opinions. Secondly, a novel hybrid decision-making framework containing Kendall's W-Fuzzy Delphi-BWM-FUCOM-CoCoSo is proposed. This hybrid approach is not only useful for powerful decision-making, but also allows practitioners, managers, and users to address and solve problems effectively. As a theoretical base, NRBV was adopted in this study. Smart circularity practices and circularity-based sustainable performance indicators were separately examined in the current literature based on NRBV and gathered under a three-stage integrated decision-making tool. Because this approach provides key organizational primary resources and strategic capabilities for smart circularity practices to improve circularity-based sustainable performance and achieve competitive advantages.

6.2 Managerial Implications

This study introduces a novel hybrid approach for evaluating the Circular Economy performance of the textile industry in the context of Industry 4.0. This approach can assist industry leaders, and other stakeholders in the textile industry to monitor progress and make informed decisions related to circular economy initiatives. The application of smart circularity refers to the utilization of digital technologies throughout a product's life cycle to implement circular strategies and practices (Sahoo *et al.* 2023). This includes leveraging digital tools for optimizing resource use, enabling product tracking and traceability, facilitating sharing and collaboration, and achieving efficient and sustainable operations (Salvioni, & Almici 2020). The results verify the role of improved incentives and government legislation support and incentives for positive results. Government support and incentives are crucial in promoting and encouraging the implementation of circular economy practices in industries. The Punjab region of India, for example, serves as a case study in understanding the importance of such support and legislation in driving positive outcomes.

The findings of this study have several managerial implications. Organizations should focus on adopting innovative technologies and building technical competence to improve their sustainable performance in the circular economy (Sahoo *et al.* 2023). This may involve investing in advanced machinery and systems that enable resource and energy efficiency. Policy and regulation play a crucial role in promoting circular practices and setting resource efficiency requirements. It is crucial for government bodies and lawmakers to introduce improved incentives and legislation that support sustainable practices. Therefore, managers should actively engage in policy discussions and ensure compliance with relevant regulations. Educating stakeholders about circular economy principles and encouraging their participation in sustainable practices can significantly improve sustainable performance. This highlights the importance of awareness campaigns and training programs within organizations. Managing security, safety, waste, and hazardous materials is vital for sustainable performance (Salvioni, & Almici 2020). Organizations should prioritize the effective management of these aspects to reduce environmental risks and improve sustainability. Additionally, system flexibility and the ability to adapt to market needs and environmental changes are critical for sustainable performance. Managers should strive to create agile and adaptable systems that can respond effectively to changing circumstances. Organizations should focus on optimizing their logistics operations to reduce carbon emissions and minimize environmental impact. Initiatives such as optimizing transportation routes, adopting eco-friendly packaging, and using sustainable transportation methods are effective in achieving this goal.

Actively monitoring and managing carbon emissions, waste generation, and pollution levels is essential for organizations to enhance their sustainability performance. Next, implementing sustainable and energy-efficient practices in warehousing operations can contribute to sustainability goals. This includes replacing them with renewable energy sources and minimizing waste generation (Kazancoglu *et al*., 2020). Additionally, increasing resource circularity by maximizing reuse, recycling, and recovery of materials helps to minimize resource depletion and environmental impact. Financial capability ranks lower in the BWM analysis, but it should not be neglected as organizations can achieve sustainability objectives by aiming to achieve cost savings through product quality, improved green purchasing, better employee and community health, improved human efficiency, increased profit from green products, and responding to market demand. By providing financial benefits and creating a favorable regulatory environment, organizations are more likely to adopt sustainability initiatives. Managers should allocate appropriate resources to ensure the successful implementation of circular economy initiatives (Kazancoglu *et al*., 2022).

7. Conclusion, Limitation and Future Research

The Circular Economy is a pivotal component of the United Nations 2030 Agenda for Sustainable Development. The transition to CE can be facilitated by the technologies of Industry 4.0, which represent a significant driver of digital transformation (Nobre & Tavares, 2023). The implementation of CE can facilitate the achievement of sustainable development in businesses. However, the precise relationship between CE and sustainable development is not clearly defined in the existing literature. Furthermore, additional research is required to investigate the potential of Industry 4.0 technologies to facilitate reverse flow activities and reduce impurities in recycled materials, thereby enabling the closure of the loop (Panchal *et al.*, 2021). The scientific community has already established models, theoretical frameworks, and case studies that demonstrate the connection between CE and Industry 4.0 (Nobre & Tavares, 2023). The subject of CE is studied in different fields, including automotive (Montemayor & Chanda, 2023), electronics (Pinheiro *et al.*, 2022), pulp and paper (Amândio *et al.*, 2022), metals and mining (Golev & Corder, 2016), energy (Jansson & Holmberg, 2022), construction (Hossain *et al.*, 2020), and others. A variety of techniques have been employed to assess the CE performance (Panchal *et al.*, 2021). Nevertheless, the research agenda must address the lack of understanding of how practitioners use these technologies to drive circularity (Nobre & Tavares, 2023). This article aims to understand how Industry 4.0 technologies support the transition to CE for the textile industry and how Industry 4.0-focused CE practices affect sustainable business performance by developing a three-stage hybrid decision-making framework that integrates various methods outside the areas studied in the literature. As highlighted by (Coppola *et al.* 2023), SCE practices in the textile industry help mitigate environmental impact by conserving natural resources, reducing greenhouse gas emissions, and minimizing landfill waste. These practices foster sustainability within the industry and facilitate the shift towards a circular and environmentally conscious textile ecosystem. It has become increasingly evident that the conversation is shifting from Corporate Social Responsibility (CSR) to finance decision-makers (Ali & Kaur 2021).

Academic research in the textile industry must progress rapidly in order to resolve the implications of Industry 4.0 on sustainability and the Circular Economy (CE) and to identify knowledge gaps associated with it. For future research, the solution framework discussed for the textile industry can be tested for other industries. It could be to examine the extent to which the findings of this study can be applied to other sectors through the conduct of an additional case study of a company operating within a different area. Finally, different combinations could be tried by changing the MCDM methods used in the study with other existing methods. The solution framework can be expanded by combining them with different techniques by using the concepts of transitioning to sustainable practices, the role of Industry 4.0 in circular economy adoption, and the significance of government support. Future research needs to focus on conducting theory-based empirical investigations to test the effectiveness of the decision-making model, specifically using reflective and formative constructs. There is a need to investigate the practical challenges and barriers that decision-makers may face when implementing the model in other emerging markets related to textile industries. Taking into account factors such as organizational culture, information availability, stakeholder involvement, and resource requirements can help in the development of strategies and guidelines for dealing with them. It is critical to investigate the scalability, flexibility, and customization of smart circular economy practices and CE-based sustainable performance to fit other sectors and other industries. Integration of the model with emerging technologies such as artificial intelligence, machine learning, digital twin, and big data analytics can also be investigated in order to capitalize on their potential for improving the model's capabilities and addressing evolving sustainability practices and emerging circularity concepts. Through these technologies, comparisons can be made by simulating an existing linear economy business with a circular economy. The FUCOM scale utilized in our research is an integer; however, this might be investigated with a decimal or fuzzy scale.

A limitation of this article is that the current and planned operations of selected textile companies are not publicly available. As a result, some details about the companies' activities may have been left out. In addition, the determination, evaluation, and performance indicators finalization of the smart circularity practices and its circularity-based sustainable performance were made according to today's conditions within the limitations of the study, and it should not be overlooked that they may vary depending on the rapidly changing and developing economic and technological conditions, and also that applying with different experts or choosing different solution methods may produce different results.

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Appendix A

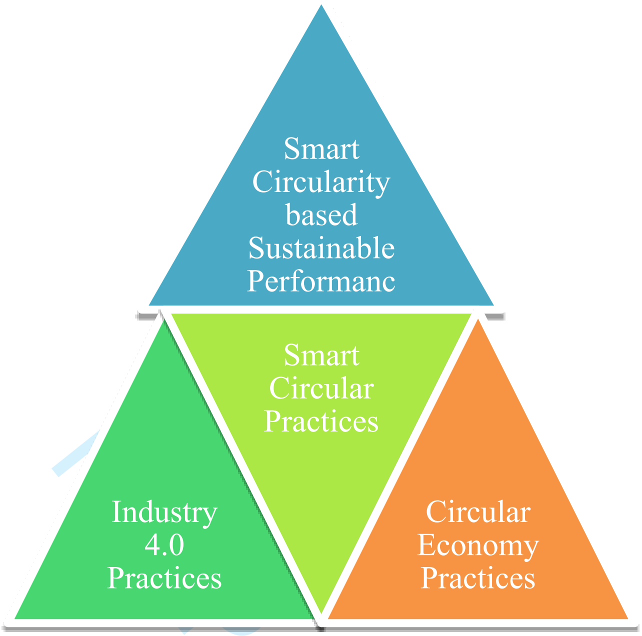

Figure A1. Conceptual Framework

AA1: Steps of Kendall's Agreement Test

Table A1: The Kendall's W agreement degree

Correlation Coefficient	Interpretation
1	Perfect agreement
0.9–1	Very high agreement
0.7–0.9	High agreement
0.4–0.7	Medium agreement
0.2–0.4	Low agreement
0–0.2	Very low agreement
0	No agreement

Assume that item i is given the rank r_{ij} by rater number j, where there are m raters and n items in total. The calculation process begins with the sum of the ranking of item i via Equation (A1) (Farooq et al.,2020):

$$R_i = \sum_{j=1}^{m} r_{ij}, \qquad \text{(A1)}$$

and the mean value of total ranks is:

$$\overline{R} = \frac{1}{n}\sum_{j=1}^{n} R_i, \qquad \text{(A2)}$$

The sum of squared deviations (S) is defined as

$$S = \sum_{i=1}^{n} (R_i - \bar{R})^2, \quad \text{(A3)}$$

and Kendall's W is measured from the Equation (A4):

$$W = \frac{12S}{m^2(n^3-n)} \quad \text{(A4)}$$

After applying Equation (A4), the result will give the concordance among the different raters.

AA2: Steps of Fuzzy Delphi

Step 1. Identify the criteria/ factors

In this step, the sensible criteria/factors (for our study; smart circularity practices & circularity-based sustainable performance measures) related to the identified problem are determined through experts' interviews and a literature survey.

Step 2. Collecting the experts' opinions

The experts' opinions are collected for the importance of the smart circularity practices and circularity-based sustainable performance by a questionnaire survey. As Table A2 shows, we construct the questionnaire using a five-point Linguistic scale to get expert opinions.

Table A2: Linguistic scale and their related TFNs

Scale	Level of significance	Triangular fuzzy number
1	Very low	(0.1,0.1,0.3)
2	Low	(0.1,0.3,0.5)
3	Medium	(0.3,0.5,0.7)
4	High	(0.5,0.7,0.9)
5	Very high	(0.7,0.9,0.9)

Step 3. Setting up of the triangular fuzzy numbers

According to Table 3, the inputs of the experts are converted into TFNs. The maximum and minimum values of the experts' input are calculated using TFNs. Our study applied the geometric mean (M_A) to demonstrate the consensus of the expert group. The computation procedure is given as follows:

Assume the evaluation value of the importance of the jth element given by ith expert among the n experts is $\tilde{w}_{ij} = (l_{ij}, m_{ij}, u_{ij})$, $i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, m$. Then fuzzy weighting $\tilde{w}_j$ of jth element is:

$$\tilde{w}_j = (l_j, m_j, u_j)$$

$$l_j = min_i(l_{ij})$$

$$m_j = \sqrt[n]{\prod_i^n m_{ij}} \tag{A5}$$

$$u_j = max_i(u_{ij})$$

Where w_{ij} denotes that ith expert's evaluation for smart circularity practices and circularity-based sustainable performance measures j, l_j characterize the lowest appraisal values of smart circularity practices and circularity-based sustainable performance measures j, m_j demonstrate the $\mathrm{M_A}$ of all the expert assessment values for element j, and u_j demonstrates the highest expert assessment values for criterion j.

Step 4. Defuzzification of the TFNs

TFNs are transformed into crisp number (S_i) of each smart circularity practices and circularity-based sustainability performance measures operating the center of gravity method as per Equation (A6)

$$S_\text{j} = \left(\frac{l_j + m_j + u_j}{3}\right) \tag{A6}$$

Step 5. Finalisation of the smart circularity practices circularity-based sustainable performance

The last step of the Fuzzy Delphi is the finalization of the smart circularity practices and circularity-based sustainable performance. To obtain the significant smart circularity practices and their corresponding circularity-based sustainable performance, the weights obtained for each factor are compared with a threshold value (λ). The logic behind the significant smart circularity practices and their corresponding circularity-based sustainability performance selection process is as follows:

If $S_\text{i} \geq \lambda$, then the practice/performance i is selected.

If $S_\text{i} < \lambda$, then the practice/performance i is rejected.

AA3: Steps of BWM

Step 1. Identification of smart circularity practices

The significant smart circularity practices ("n" number of smart circularity practices: SCP1, SCP2, SCP3,…,SCPn) are identified as a result of Fuzzy Delphi.

Step 2. Determine the best and worst smart circularity practices.

The experts specify the best and the worst smart circularity practices among the finalized smart circularity practices. The best and worst smart circularity practices is indicated as cB, and cW respectively.

Step 3. Implement the reference comparisons with smart circularity practices.

The preference of the best smart circularity practices is determined over all the other smart circularity practices utilizing 9-point scale (1-9) by expert input and characterized by the AB vector as:

AB = (aB1, aB2, ..., aBn)

Where AB the Best-to-Others (BO) vectors, aBj refers the preference of the best smart circularity practices B over smart circularity practices j and aBB=1

Step 4. Implement the reference comparisons with worst smart circularity practices

The preference of all the other smart circularity practices is determined over the worst smart circularity practices utilizing 9-point scale (1-9) by expert input and characterized by AW vector as:

AW = $(a_{1W}, a_{2W}, ..., a_{nW})$T

Where AB the Others-to-Worst (OW) vector, a_{jW} denotes the preference of the smart circularity practices j over the worst smart circularity practices W and $a_{WW} = 1$

Step 5. Determine the optimal weights

The optimum weight for each smart circularity practice is the one where, for each pair wB/wj and wj/wW, it must have wB/wj = aBj and wj/wW = ajW. For satisfying these conditions for all j, maximum absolute differences minimized of the set {|wB −aBjwj|, |wj − ajWwW|}. The problem could be represented as follow:

min max {|wB −aBjwj|, |wj − ajWwW|}.

Subject to:

$$\sum_j w_j = 1 \tag{A7}$$

$$w_j \geq 0 \; ; \forall j$$

Model (A7) can be transformed into following linear problem.

min ξ^L

s.t.

$$\left| \frac{w_B}{w_j} - a_{Bj} \right| \leq \xi^L \text{ for all } j$$

$$\left| \frac{w_j}{w_W} - a_{jW} \right| \leq \xi^L \text{ for all } j$$

$\sum_j w_j = 1$

$w_j \geq 0$ for all j (A8)

The optimum weights of each smart circularity practices (w_1^*,w_2^*, w_3^*..... w_n^*) and optimal value of ξ^Lobtained by solving the linear problem Equation (A8). Also, the consistency ratio (CR) of the comparisons is checked.

AA4: Steps of FUCOM

Step 1. Ranking of criteria

The criteria from the predefined criteria set $C = \{C_1, C_2, ..., C_n\}$ are ranked. Ranking is done according to the importance of the criteria; beginning from the criterion that is predicted to have the highest weighting coefficient to the criterion of the least importance. Therefore, the criteria ordered according to the expected weight values are obtained.

$$C_{j(1)} > C_{j(2)} > ... > C_{j(k)} \quad \text{(A9)}$$

where k presents the order of the mentioned criterion. If there are more than one criterion with the same importance, the " = " sign is positioned between these criteria instead of the " > " sign in Expression (A9)

Step 2. Determining the importance of the criteria

A comparison of the ranked criteria is performed and the comparative importance $\varphi_{k/(k+1)}$ of the criteria is determined. $\varphi_{k/(k+1)}$ presents the importance (priority) of $C_{j(k)}$ rank compared to $C_{j(k+1)}$ rank. The vectors of the comparative importance (priorities) of the evaluation criteria are got as;

$$\phi = (\varphi_{1/2}, \varphi_{1/2}, \ldots, \varphi_{k/(k+1)}) \quad \text{(A10)}$$

The FUCOM method permits pairwise comparison of criteria utilizing integer values, decimal values, or values of a predefined scale.

Step 3. Finding the final values of the weight coefficients

The final weight coefficients values of the evaluation criteria $(w_1, w_2, ..., w_n)^T$are calculated. They must meet the following two conditions:

The weight coefficients ratios should equal to the comparative priority among the criteria, i.e., the following condition is met:

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} \quad \text{(A11)}$$

The final weight coefficients values must meet the mathematical transitivity condition, i.e., $\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$. Since $\varphi_{k/(k+1)} = \frac{w_k}{w_{k+1}}$ and $\varphi_{(k+1)/(k+2)} = \frac{w_{k+1}}{w_{k+2}}$, that $\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$ is obtained. Thus, another condition is obtained,

$$\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \quad \text{(A12)}$$

Full consistency i.e., minimum deviation from full consistency (χ) is satisfied only if transitivity is completely respected, i.e., when both conditions given above are met. In this way, the requirement for maximum consistency is fulfilled, i.e., $\chi = 0$ for the obtained the weight coefficient values. In order for the conditions to be met, the weight coefficient values $(w_1, w_2, ..., w_n)^T$ must meet the condition $\left|\frac{w_k}{w_{k+1}} - \varphi_{k/(k+1)}\right| \leq \chi$ and $\left|\frac{w_k}{w_{k+2}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \leq \chi$ with the minimization of the value χ. In this way, the maximum consistency requirement is satisfied. In this way, the requirement for maximum consistency is fulfilled. Based on the settings defined, the final model can be defined as follows to determine the final the weight coefficients values of the criteria.

Min χ

s.t.

$$\left|\frac{w_k}{w_{k+1}} - \varphi_{k/(k+1)}\right| \leq \chi, \text{ for all } j$$

$$\left|\frac{w_k}{w_{k+2}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \leq \chi, \text{ for all } j$$

$$\sum_{j=1}^{n} w_j = 1, \text{ for all } j$$

$$w_j \geq 0 \text{ for all } j \quad \text{(A13)}$$

By solving the model (A13), the final values of $(w_1, w_2, ..., w_n)^T$ and the degree of χ are obtained (Pamučar *et al.*,2018).

AA5: Steps of CoCoSo

Step 1. The initial decision matrix is formulated with linguistic terms according to the evaluation criteria/applications as indicated in Table A3. This matrix is as follows:

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}; i = 1,2,....n, j = 1,2,....m \quad \text{(A14)}$$

The matrix $[X]_{m\times n}$ represents the initial decision-making matrix that contains the m: number of alternatives (performances) and n: evaluation criteria(practices). In this context, "x_{ij}" contains that the ith "circularity-based sustainable performances" are realized by adopting the jth smart circularity practices.

Table A3: Linguistic scale with associated crisp value

Linguistic Scale	**Crisp Value**
Very Low (VL)	1
Low (L)	2
Medium (M)	3
High (H)	4
Very High (VH)	5

Step 2. The normalization of the initial decision-making matrix is executed by the Equations (A15 -A16) (Zeleny, 1973):

For benefit criteria

$$r_{ij} = \frac{x_{ij} - \min\limits_i x_{ij}}{\max\limits_i x_{ij} - \min\limits_i x_{ij}}; \qquad \text{(A15)}$$

For non-benefit/cost criteria

$$r_{ij} = \frac{\max\limits_i x_{ij} - x_{ij}}{\max\limits_i x_{ij} - \min\limits_i x_{ij}}; \qquad \text{(A16)}$$

Step 3. The weighted comparability sequence (S_i) and its' power weight (P_i) for each alternative are calculated by the Equations (A17-A18) respectively.

$$S_i = \sum_{j=1}^{n} (w_j r_{ij}) \qquad \text{(A17)}$$

$$P_i = \sum_{j=1}^{n} (r_{ij})^{w_j} \qquad \text{(A18)}$$

Step 4. Relative weights of each alternative are calculated by three aggregation approaches that are provided as Equations (A19–A21):

$$k_{ia} = \frac{S_i + P_i}{\sum_{i=1}^{m} (P_i + S_i)}; \qquad \text{(A19)}$$

The Equation (A19) indicates the arithmetic mean of sums of scores, weighted sum measure (S_i) and weight power measure (P_i)

$$k_{ib} = \frac{S_i}{\min\limits_i S_i} + \frac{P_i}{\min\limits_i P_i} \qquad \text{(A20)}$$

The Equation (20) delivers a sum of S_i and P_i compared to the best.

$$k_{ic} = \frac{\lambda(S_i)+(1-\lambda)(P_i)}{(\lambda \max_i S_i + (1-\lambda) \max_i P_i)} \tag{A21}$$

The Equation (A21) signifies the balanced compromise of S_i and P_i scores. The value of λ is usually 0.5 or it may be chosen by experts according to need.

Step 5. The weight of the alternatives is based on the value of k_i, it is calculated by Equation (22).

$$k_i = (k_{ia}k_{ib}k_{ic})^{\frac{1}{3}} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic}) \tag{A22}$$

The final ranking is achieved according to the descending order of $k_i$values i.e., the alternative (performance) with the larger value of k_i is more important.

AA6: Steps of Sensitivity Analysis

The following equation was used for the sensitivity analysis to be applied to the relevant criteria (Triantaphyllou and Sanchez, 1997; Triantaphyllou, 2000):

$$\mathrm{w}_j = (1 - w_i) * \left(\frac{w_j^0}{(1-w_i^0)}\right) \tag{A23}$$

w_j shows the new weight value to be used in the sensitivity analysis of criterion j.

w_i is the new weight value of criterion i, subjected to weight increase or decrease in the sensitivity analysis.

Table A4: Questionnaire results

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
Smart circularity practices										
PR1	4	5	5	4	5	4	5	4	5	4
PR2	2	2	3	2	4	4	5	4	4	4
PR3	4	5	4	4	5	4	5	4	5	4
PR4	4	5	5	4	5	4	5	4	5	5
PR5	1	3	2	3	2	3	2	3	2	2
PR6	4	5	5	4	5	4	5	4	5	5
PR7	4	5	5	4	5	4	5	4	5	4
PR8	4	5	4	4	4	4	5	4	5	4
PR9	1	3	1	3	1	3	2	3	2	3
PR10	1	3	1	2	1	2	2	1	2	2
PR11	4	5	5	4	5	4	5	4	5	5
PR12	4	5	5	4	4	4	5	4	4	4
Circularity-based sustainable performance										
PE1	4	5	5	4	5	4	5	4	5	4
PE2	1	3	1	3	1	3	2	3	2	3
PE3	4	5	5	4	5	4	5	4	5	4

PE4	1	3	1	3	1	3	2	3	2	3
PE5	4	5	5	4	5	4	5	4	5	4
PE6	4	5	5	4	5	4	5	4	5	4
PE7	4	5	5	4	5	4	5	4	5	4
PE8	4	5	5	4	5	4	5	4	5	4
PE9	4	5	5	4	5	4	5	4	5	4
PE10	4	5	5	4	5	4	5	4	5	4
PE11	1	3	1	3	1	3	2	3	2	3
PE12	4	5	5	4	5	4	5	4	5	4
PE13	4	5	5	4	5	4	5	4	5	4
PE14	4	5	5	4	5	4	5	4	5	4

Table A5: The same data in the questionnaire results matrix transformed into ranks

	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**E10**	
Smart circularity practices											R_i
PR1	4.5	4.5	3.5	4.5	3.5	5	5	5	4	6.5	46
PR2	9	12	9	11.5	8	5	5	5	8.5	6.5	79.5
PR3	4.5	4.5	7.5	4.5	3.5	5	5	5	4	6.5	50
PR4	4.5	4.5	3.5	4.5	3.5	5	5	5	4	2	41.5
PR5	11	10	10	9.5	10	10.5	11	10.5	11	11.5	105
PR6	4.5	4.5	3.5	4.5	3.5	5	5	5	4	2	41.5
PR7	4.5	4.5	3.5	4.5	3.5	5	5	5	4	6.5	46
PR8	4.5	4.5	7.5	4.5	8	5	5	5	4	6.5	54.5
PR9	11	10	3.5	9.5	11.5	10.5	11	10.5	11	10	98.5
PR10	11	10	11.5	11.5	11.5	12	11	12	11	11.5	113
PR11	4.5	4.5	11.5	4.5	3.5	5	5	5	4	2	49.5
PR12	4.5	4.5	3.5	4.5	8	5	5	5	8.5	6.5	55
Circularity-based sustainable performance											R_i
PE1	6	6	6	6	6	6	6	6	6	6	60
PE2	13	13	13	13	13	13	13	13	13	13	130
PE3	6	6	6	6	6	6	6	6	6	6	60
PE4	13	13	13	13	13	13	13	13	13	13	130
PE5	6	6	6	6	6	6	6	6	6	6	60
PE6	6	6	6	6	6	6	6	6	6	6	60
PE7	6	6	6	6	6	6	6	6	6	6	60
PE8	6	6	6	6	6	6	6	6	6	6	60
PE9	6	6	6	6	6	6	6	6	6	6	60
PE10	6	6	6	6	6	6	6	6	6	6	60
PE11	13	13	13	13	13	13	13	13	13	13	130
PE12	6	6	6	6	6	6	6	6	6	6	60
PE13	6	6	6	6	6	6	6	6	6	6	60
PE14	6	6	6	6	6	6	6	6	6	6	60

Table A6: Initial decision Matrix

Performance Measures	**SC P1**	**SC P2**	**SC P3**	**SC P4**	**SC P5**	**SC P6**	**SC P7**	**SC P8**
Increase in resource circularity **(CEISP1)**	3.3	3.4	3.2	2.4	3.4	2.8	2.5	2.5
Improve human efficiency **(CEISP2)**	3.9	3.3	3.5	2.3	2.4	2.1	1.8	2.3
Increase in profit from green products **(CSP3)**	1.9	4.6	3.8	2.3	2.1	2.2	2.5	1.7
Improved usage of green logistics **(CEISP4)**	3.6	3.2	3.3	2.4	3.9	3.4	3.4	3.9
Better employees and community health **(CEISP5)**	3.3	4.7	3.8	2.3	2	2.8	2.6	1.7
Improved green purchasing **(CEISP6)**	2.1	3.1	3.4	2.8	3.2	3.6	2.8	2.5
Better usage of green warehousing **(CEISP7)**	3.4	3.2	3.4	2.7	2.6	4	3.6	2.4
Better/improved market demand **(CEISP8)**	2.3	3.3	2.5	2.1	2.7	3.2	3.1	2.1
Increase in cost saving through product quality **(CEISP9)**	3.1	2.8	2.8	2.3	4	3.6	3.2	4.2
Decrease in emission, waste, and pollution monitoring **(CEISP10)**	3.3	3.4	3.9	2.4	3.4	3.6	4	2.9
Improved incentives and government legislation support and incentives **(CEISP11)**	3.2	3.5	3.7	3.2	3.5	3.3	3.3	2.7

Table A7: Normalized decision Matrix

Performance Measures	**SCP1**	**SCP2**	**SCP3**	**SCP4**	**SCP5**	**SCP6**	**SCP7**	**SCP8**
CEISP1	0.70	0.32	0.50	0.27	0.70	0.37	0.32	0.32
CEISP2	1.00	0.26	0.71	0.18	0.20	0.00	0.00	0.24
CEISP3	0.00	0.95	0.93	0.18	0.05	0.05	0.32	0.00
CEISP4	0.85	0.21	0.57	0.27	0.95	0.68	0.73	0.88
CEISP5	0.70	1.00	0.93	0.18	0.00	0.37	0.36	0.00
CEISP6	0.10	0.16	0.64	0.64	0.60	0.79	0.45	0.32
CEISP7	0.75	0.21	0.64	0.55	0.30	1.00	0.82	0.28
CEISP8	0.20	0.26	0.00	0.00	0.35	0.58	0.59	0.16
CEISP9	0.60	0.00	0.21	0.18	1.00	0.79	0.64	1.00
CEISP10	0.70	0.32	1.00	0.27	0.70	0.79	1.00	0.48
CEISP11	0.65	0.37	0.86	1.00	0.75	0.63	0.68	0.40

Table A8: Weighted comparability sequence matrix

Performance Measures	**SCP1**	**SCP2**	**SCP3**	**SCP4**	**SCP5**	**SCP6**	**SCP7**	**SCP8**
CEISP1	0.15	0.06	0.03	0.04	0.09	0.03	0.02	0.04
CEISP2	0.22	0.05	0.04	0.02	0.02	0.00	0.00	0.03
CEISP3	0.00	0.17	0.05	0.02	0.01	0.00	0.02	0.00
CEISP4	0.19	0.04	0.03	0.04	0.12	0.06	0.05	0.11
CEISP5	0.15	0.18	0.05	0.02	0.00	0.03	0.02	0.00
CEISP6	0.02	0.03	0.04	0.08	0.07	0.07	0.03	0.04
CEISP7	0.17	0.04	0.04	0.07	0.04	0.09	0.05	0.04
CEISP8	0.04	0.05	0.00	0.00	0.04	0.05	0.04	0.02
CEISP9	0.13	0.00	0.01	0.02	0.12	0.07	0.04	0.13

CEISP10	0.15	0.06	0.06	0.04	0.09	0.07	0.07	0.06
CEISP11	0.14	0.07	0.05	0.13	0.09	0.06	0.05	0.05

Table A9: Exponentially comparability sequence matrix using BWM weights

Performance Measures	**SCP1**	**SCP2**	**SCP3**	**SCP4**	**SCP5**	**SCP6**	**SCP7**	**SCP8**
CEISP1	0.924	0.813	0.962	0.845	0.957	0.911	0.926	0.863
CEISP2	1.000	0.787	0.981	0.801	0.819	0.000	0.000	0.832
CEISP3	0.000	0.990	0.996	0.801	0.689	0.760	0.926	0.000
CEISP4	0.965	0.756	0.969	0.845	0.994	0.965	0.979	0.984
CEISP5	0.924	1.000	0.996	0.801	0.000	0.911	0.935	0.000
CEISP6	0.601	0.718	0.976	0.943	0.939	0.978	0.949	0.863
CEISP7	0.938	0.756	0.976	0.924	0.861	1.000	0.987	0.848
CEISP8	0.700	0.787	0.000	0.000	0.878	0.950	0.965	0.789
CEISP9	0.893	0.000	0.918	0.801	1.000	0.978	0.970	1.000
CEISP10	0.924	0.813	1.000	0.845	0.957	0.978	1.000	0.909
CEISP11	0.909	0.836	0.991	1.000	0.965	0.958	0.975	0.888

Table A10: Exponentially comparability sequence matrix using FUCOM weights

Performance Measures	**SCP1**	**SCP2**	**SCP3**	**SCP4**	**SCP5**	**SCP6**	**SCP7**	**SCP8**
CEISP1	0.927	0.826	0.898	0.838	0.962	0.914	0.929	0.838
CEISP2	1.000	0.802	0.949	0.793	0.839	0.000	0.000	0.801
CEISP3	0.000	0.991	0.989	0.793	0.721	0.768	0.929	0.000
CEISP4	0.966	0.773	0.916	0.838	0.994	0.967	0.980	0.980
CEISP5	0.927	1.000	0.989	0.793	0.000	0.914	0.937	0.000
CEISP6	0.614	0.737	0.933	0.940	0.946	0.979	0.951	0.838
CEISP7	0.941	0.773	0.933	0.921	0.877	1.000	0.987	0.821
CEISP8	0.711	0.802	0.000	0.000	0.892	0.952	0.967	0.752
CEISP9	0.898	0.000	0.786	0.793	1.000	0.979	0.972	1.000
CEISP10	0.927	0.826	1.000	0.838	0.962	0.979	1.000	0.892
CEISP11	0.913	0.848	0.976	1.000	0.969	0.960	0.976	0.867

Table A11: Circularity-based sustainable performance rank in the first experiment set

CSPs	**Original Rank by BWM**	**Test-1**	**Test-2**	**Test-3**	**Test-4**	**Test-5**	**Test-6**	**Test-7**	**Test-8**	**Test-9**
CEISP1	6	7	6	6	5	5	5	6	6	5
CEISP2	9	10	9	9	7	7	6	3	2	1
CEISP3	10	9	10	10	11	11	11	11	11	11
CEISP4	2	2	2	1	1	1	1	1	1	2
CEISP5	8	8	8	8	8	8	8	8	7	7
CEISP6	7	6	7	7	9	9	9	9	9	10

CEISP7	4	4	4	4	4	4	4	2	3	3
CEISP8	11	11	11	11	10	10	10	10	10	9
CEISP9	5	5	5	5	6	6	7	7	8	8
CEISP10	3	3	3	3	3	3	2	4	4	4
CEISP11	1	1	1	2	2	2	3	5	5	6

Table A12: Circularity-based sustainable performance rank in the second experiment set

CSPs	**Original Rank by FUCOM**	**Test-1**	**Test-2**	**Test-3**	**Test-4**	**Test-5**	**Test-6**	**Test-7**	**Test-8**	**Test-9**
CEISP1	5	7	5	5	5	5	5	6	6	5
CEISP2	9	10	9	9	8	7	6	5	2	1
CEISP3	10	9	10	10	10	10	10	11	11	11
CEISP4	2	3	2	2	1	1	1	1	1	2
CEISP5	8	8	8	7	7	8	8	8	7	7
CEISP6	7	5	7	8	9	9	9	9	9	10
CEISP7	4	4	4	4	4	4	4	3	3	3
CEISP8	11	11	11	11	11	11	11	10	10	9
CEISP9	6	6	6	6	6	6	7	7	8	8
CEISP10	3	2	3	3	3	3	2	2	4	4
CEISP11	1	1	1	1	2	2	3	4	5	6