Sustainability Assessment of Textile and Apparel Sector: A Review of Current Approaches and Tools

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ABSTRACT: The purpose of this study is to provide an overview of sustainability evaluation techniques in textile and apparel sector. The review studies are divided into two namely product relate assessment methods and integrated assessment methods which summarizes the different dimension covered, weightage, number of indicators involved, and highlight the weakness and strength of the previous developed sustainability assessment methods in the textile industry. The analysis revealed that majority of the product-related assessment methods focused on environmental factors only, while all the studies reviewed in this category neglected triple bottom line (TBL) in their assessment approach. Nevertheless, there is still a need to focus more on integrated assessment tools to fulfil the TBL goals. This current study offers comprehensive details of product related assessment and integrated assessment methods that was published from 2010 to 2022. Furthermore, examined current sustainability evaluation methods and offered insights into how sustainability assessment techniques have evolved in the textile and apparel industry. The review showed the product related assessment tools are impact assessment techniques are frequently used as an independent tool for evaluating the specific impact of one sustainability measurement, also have no weights attached to them because most indicators assessed were more generic. While integrated assessment method revealed that results would be less reliable if weighting and data collection were non-standardized and inconsistent. However, from the uncertainty's perspectives, only integrated assessment tools considered fuzziness, grey and stochastic ambiguities in some of their methods, whereas product related assessment tools studied, ignored fuzziness and grey uncertainties completely.

KEYWORDS: Textile and apparel sector, Assessment methods, Environmental assessment, Triple bottom line, Fuzzy, stochastic uncertainties.

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I. INTRODUCTION

Textile and apparel sector is one of the largest and polluted industries in the world (Boström and Micheletti, 2016) and one of the most essential areas for countries' economic development worldwide (de Souza *et al*., 2010), thus causes huge sustainability issues. The textile and apparel industry are now playing a more significant role in the nation's economy. It does not only meet the people's diverse and growing needs, but also generates several jobs and plays an important role to the public finances to foster economic development (Ho and Watanabe, 2020; Poursoltan *et al*., 2021). At present global textile consumption and production increased, thereby stimulating global economic growth (Gbolarumi *et al*., 2021), in spite of the reality that textile manufacturing is linked with a variety of sustainability problems. The sudden development of the textile sector appears with huge social and environmental problems (Lee, 2017). Because of severe environmental pollution, rapid depletion of natural resources, and a lack of employee well-being, industries all over the world are under intense pressure from governments, non-governmental organizations (NGOs), the media, legislative bodies, and other interested parties to ensure the continued viability of their supply chains (Brito *et al*., 2008; Ghahremani Nahr *et al*., 2020).

Furthermore, the textile sector is the most crucial industrial area, accounting for the majority of developed and developing countries' total GDP and export revenue. However, because of its extensive hazardous discharge into the environment, this industry is also regarded as highly polluting (Raian *et al*., 2022). In Vietnam, for example the textile industry has grown significantly, with an average annual growth rate of about 30%, and it accounts for 20% of the country's export revenue (Wang *et al*., 2020). Furthermore, the Brazilian textile industry is the largest and most comprehensive textile chain in the Western world. The sector has been recognized as a reference in some apparel industry sectors, such as jeanswear and beachwear. US Environmental Protection Agency (USEPA) described textile waste as a dissolvable hazardous sludge that is large in volume and hard to treat by the (Foo and Hameed, 2010). Among the toxic pollutants existing in the effluent, dyes are the main and uncooperative pollutants that are carcinogenic and toxic in

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nature (Zhou *et al*., 2019). The release of fresh effluent into waterways or sewage pipes reduces dissolved oxygen, hinders the biological treatment process, raises turbidity, and aesthetically unappealing, influencing the overall quality of the river's water and natural landscape (Singh *et al*., 2019; Srinivas and Singh, 2018).

The textile industry has been proven as the most affected sector in Nigeria today, it is seen as one of the key drivers of unemployment and poverty and a clear index of underemployment in the country (Akintayo, 2020). Furthermore, despite many advantages of the three pillars of sustainability, most of the recent assessment studies on textile industries in developing countries focused only on the environmental dimension (Zhao *et al*., 2021; Majumdar *et al*., 2020; Nakhate *et al*., 2020; Yang *et al*., 2020; Zhou and Zhou, 2019; Zhu *et al*., 2018; Liu *et al*., 2012). A study conducted by Le and Wang (2017) is mainly concerned with economic consequences whereas some studies focused on the environmental and economic dimensions (de Oliveira Neto *et al*., 2019; Garcia *et al*., 2019; Pattnaik and Dangayach, 2019; Shiwanthi *et al*., 2018; Zhang *et al*., 2018; Lau *et al*., 2009). Though the textile industry has an influence on all three dimensions of sustainability, prior sustainability assessment methods for the textile industry were primarily based on environmental dimension (Peters *et al*., 2021; Majumdar *et al*., 2020; Nakhate *et al*., 2020).

However, the triple bottom line (TBL) concept of sustainability requires textile industries to take into account a wide range of environmental, economic, and social factors (Bait *et al*., 2022; Fidan *et al*., 2021b; Tseng *et al*., 2019). The majority of textile industry sustainability assessment studies focused on life cycle assessment (Zhao *et al*., 2021; Ajila, 2019; Garcia *et al*., 2019) and greenhouse management (Zhu *et al*., 2018). In general, some recent sustainability assessment methodologies for the textile industry include all three sustainability dimensions (Bait *et al*., 2022; Gustina *et al*., 2019; Guarnieri and Trojan, 2019). As a result, a few of the reviewed studies include all the three dimensions of sustainability in their assessment methods, whereas the majority of the reviewed studies were limited to environmental impact assessment methods (Yousef *et al*., 2019; Durotoye *et al*., 2018; L'Abbate *et al*., 2018; Busi *et al*., 2016). The study of (Fidan *et al*., 2021b; Gustina *et al*., 2019; Tseng *et al*., 2019) conducted the TBL assessment in their studies with limited economic dimension criterion which was focused only on cost related, furthermore this research concentrated mostly on employees from their social facets. Also, (Bait *et al*.,2022) conducted sector-based assessment study that focused on the three dimensions of sustainability with comprehensive indicators to assess all aspects.

Nevertheless, the detailed concept of a sustainable textile and apparel industry focused on TBL framework of sustainability is becoming increasingly popular these days. As a result, several new assessment methods are considering all aspects of sustainability. Furthermore, current environmental assessment methods are being enhanced to account for the TBL concept of sustainability. To measure and assess sustainability, a variety of methodologies have been developed (Zijp *et al*., 2015). These methods are evolving at a rapid pace, but a recent review study that could establish the methodological progress of these tools for the textile and apparel industries is lacking. For many years, life cycle costing (LCC), life cycle assessment (LCA), and social life cycle assessment (S-LCA) have been used to evaluate the many aspects of sustainability in accordance with this perception (Sala *et al.*, 2013). In addition, Klöpffer (2014) reported that the science of LCA approach has greatly advanced over the last decades. Although a common method for assessing the environmental effects of the entire life cycle of the production of clothing is life LCA (Roos *et al*., 2016; Baydar *et al*., 2015). Similarly, Ness *et al*. (2007) developed a thorough framework for sustainability evaluation and categorized the approaches into three groups, namely indicator and indices, product related assessment and integrated assessment. This study's objective is to provide a perspective on sustainability assessment methods, drawing on their conventional features and limits. This work assessed the applicability of several sustainability assessment approaches, nature of tools and dimension covered in the evaluation of the textile and apparel sector. Only papers chosen from journals indexed in reputable databases and that were released after year 2000 were examined in-depth in a review of the scientific literature for earlier approaches of sustainability assessment in the textile and apparel industry.

Therefore, it should come as no surprise that many researchers, planners, and policy makers have prioritized improving the sustainability assessment methods in the textile sector over the past three decades. Hence, a study on emerging methods for assessing sustainability in the textile and apparel industries is required to guide both academics and practitioners. The preceding literature and outlined research gaps highlight the importance of reviewing recent sustainability assessment methods for the textile and apparel industries while incorporating the TBL concept of sustainability. The remaining sections of this study are organized as follows: the methodology is described in the next section. The findings of the results are discussed in the results and discussion section. Implications are provided in the section on future research opportunities. Finally, the paper's conclusions.

II. METHODOLOGY

Systematic review approach was utilised in this research and was carried out between November 2021 and May 2022. This involved searching the major online databases of scholarly literature, which compile academic studies published in peer-reviewed journals, for pertinent publications. The databases employed for this study were Web of Science, Scopus, Springer Link and Science Direct, which compile pertinent academic publications in the textile and apparel sectors, assessment tools, and enable precise and specialised searches. The words "assessment method," "textile industry," "sustainability performance," and "sustainability assessment" were chosen as the review's primary keywords without considering any restrictions on document type, time, or field content, in a total of four searches. Therefore, given the scope of the present review, it was impractical to rely simply on the information from the bibliometric analysis.

Hence, it was necessary to consider the country, criteria, dimension covered, indicators, and nature of tools that were specifically designed for the textile and apparel industry when conducting a thorough review of sustainability assessment methods. These papers' titles and abstracts were scrutinised to separate studies that are relevant to the textile and apparel industry's assessment methods from those that are not. After this screening process, 50 articles were still available for examination in the database. Works that were cited in these papers were also reviewed to add additional pertinent articles that were missed during the initial literature search. Additionally, Scopus' alert feature was turned on so that users may get weekly information on newly published pertinent papers. 13 additional articles were consequently added to the review database. The following part explains the steps for a thorough review of these 63 chosen articles. The papers under consideration must also offer quantitative findings for at least one impact category in product related assessment. Additionally, the studies included publications that dealt qualitatively with integrated assessment and mixed method in the textile and clothing industries.

III. RESULTS AND DISCUSSION

Several assessment methods have been used in the past to measure sustainability. One of the most difficult forms of appraisal procedures is sustainability assessment (SA) (Sala *et al*., 2015). LCA is a method of examining and evaluating the environmental impacts of a product, process, or activity over the course of its whole life cycle (Strantzali and Aravossis, 2016). Thus, during the first wave of sustainability the environment was the only priority for the development of these technologies (Bhamra and Lofthouse, 2016).

Sustainability should be determined by concurrently integrating the environmental, economic, and social components (Rosen and Kishawy, 2012). In hindsight, the majority of the (partial sustainability-based) tools only required a basic economic study to consider. In other circumstances, for example, cost analysis was used instead of a thorough examination of the economic aspects of sustainability. To address these problems, the LCC method was adopted from cost accounting and implemented in sustainability assessment tools (Finkbeiner *et al*., 2010).

LCC studies' main objective is to accurately account for the costs of life-cycle environmental features and consequences that occur from a decision. Because all the inventory data in LCC is measured in a single unit of measure that is currency, there is no analogous effect assessment step in LCC. The traditional LCA methodology was widened to incorporate social and economic evaluations (Van Kempen *et al*., 2017). Unlike conventional assessment methods, LCSA can determine a product's long-term viability from a life cycle perspective (Ren *et al*., 2015). Many LCSA applications lacked a final phase of integration for the many aspects of sustainability (Visentin *et al*., 2020). Because of this omission, practitioners are forced to analyze the LCSA without any methodological support; the influence of sustainability was examined holistically (Ekener *et al*., 2018). LCSA is a multi-criteria decision, or at least a multi-criteria interpretation, because the LCSA provides results for all three aspects of sustainability and may include multiple indicators (Tarne *et al*., 2019). Furthermore, the LCSA strategy still has a long way to go when it comes to integrating outcomes.

Some sustainability assessment methods on the other hand, were based on applying multiple sustainability indicators when calculating sustainability indices. Indicators have been identified as critical to achieving sustainable development (Feng *et al*., 2010). Till date, analyzing an organization's sustainability has required the use of indicators to assess its progress toward sustainable manufacturing (Trianni *et al*., 2019), numerous research have documented indicator-based assessment methods. Furthermore, some of these methods have incorporated the use of sustainability indicators. Similarly, Garbie (2015) presented and evaluated an indicator-based sustainability optimization model at the level of manufacturing firms to generate the sustainability index.

In this research, the recent assessment methods in textile and apparel sectors are divided into two categories: products related assessment tool and integrated assessment tools.

A. Product Related Assessment Tools

Several sustainability assessment tools have been used in the past to measure sustainability in textile and apparel sectors. LCA is a method of analyzing and assessing the environmental impacts of a product, process, or activity over the course of its whole life cycle (Strantzali and Aravossis, 2016). Thus, during the first wave of sustainability, the environment was the only priority for the development of these methods (Bhamra and Lofthouse, 2016). Majority of the software tools use LCA methodology to evaluate how a product and its related services may affect the environment over the course of their full life. (Krishnan *et al*., 2013). More direction has been provided by LCA, but its weakest point is the time and effort required to gather information that adequately depicts the life cycle.

B. Life Cycle Assessment

LCA is a process for assessing the environmental impact of products and services across their whole life cycle, from raw material extraction to waste extraction, including each stage of the life cycle, end-of-life operations, distribution, maintenance, raw material acquisition, and product design or development. Recently, the science of LCA approach has matured and progressed tremendously. In addition, Yasin *et al*. (2016) used principal component analysis to assess many research and discovered that the country of use had the greatest influence on energy use. Kim *et al*. (2015) developed a model to calculate the energy consumption of textiles during use. The scenario analysis provided reveals significant changes based on washing temperature, washing machine load, and whether the items are ironed.

Shen *et al*. (2010) conducted additional research into how to determine toxicity using LCA methods. As previously stated, the use-phase is important when considering the environmental implications of textile products. The implications of failing to integrate environmental and economic analyses can include missed opportunities or a limited influence of LCA on decision-making, particularly in the private sector (Shapiro, 2001). Nowadays, LCA is the most often used method for calculating a product's or service's environmental effect throughout its life cycle phases. However, data gathering is time consuming and frequently complex, even even though the LCA application is not a simple operation, and scope definition is not always obvious (Ciroth and Srocka, 2008, Bhander *et al*., 2003).

C. Life Cycle Costing

LCC is defined as the process of calculating the whole cost of an asset, including acquisition, installation, operation, maintenance, refurbishment, and disposal costs (Daylan and Ciliz, 2016; Luo *et al*., 2009; Silalertruksa *et al*., 2012). LCC has been utilized as a decision-making tool in the selection of various bio-based products over synthetic alternatives. LCC allows choices to be made regarding acquisition, upkeep, remodeling, or disposal after careful study of the effects. Similarly, decision-makers see LCA, Life Cycle Cost Analyses (LCCA), as an appropriate tool for assessing economic and socio-environmental sustainability. LCCA is used in the decision-making process during the planning and design stages to examine all project constraints (Shahin *et al*., 1985).

All economic actions and practices must be assessed over the course of a project's life cycle to meet sustainability objectives. The net present value (NPV) is a popular technique of LCCA (Shahin *et al*., 1985, Jung *et al*., 2002) in which the cost is discounted. The discount rate is a crucial component of LCCA because it directly affects the final costs. LCC studies' main objective is to accurately calculate the costs of life-cycle environmental features and impacts that result from decisions. LCC method was adopted in sustainability assessment tools by cost accounting (Finkbeiner *et al*., 2010). Because all inventory data in LCC is measured in just one unit currency, there is no analogous effect assessment step in LCC. Other variations of LCC were also established such as financial LCC, environmental LCC, social LCC, and full environmental LCC.

D. Social Life Cycle Analysis

The controversy began with the publishing of The Society of Environmental Toxicology and Chemistry (SETAC) Workshop report on addressing social and socioeconomic issues measurements in life cycle, which focused on social consequences rather than environmental and resource implications. According to UNEP (2009) S-LCA is a social impact assessment technique that strives to examine the socio-economic product components and their possible benefits and drawbacks consequences throughout their life cycle. Similarly, Benoît *et al.* (2010) revealed that the S-LCA framework was derived from the ISO-standardized Environmental LCA framework. Goal and scope definition, inventory analysis, impact assessment, and interpretation are the four stages of the S-LCA methodology. Table 1 reveals the reviewed sustainability assessment methods in textile and apparel industry, while Table 2 reveals analysis of the reviewed sustainability assessment methods in textile and apparel sectors.

The literature has employed a variety of strategies to study sustainability in the textile industry. However, LCA has also been employed to measure the sustainability of the industries, quantify the overall sustainability of a manufacturing system, and highlight sustainability hotspots along the supply chain. LCA was used in a case study by Nakhate *et al*. (2020) to determine the sustainability of a textile water treatment plant. Van der Velden and Vogtländer (2017) focused on workers' socioeconomic burdens using a social-LCA. Yousef *et al*. (2019) employed LCA to analyzed textile waste in other to achieved sustainable source of recovered cotton. While LCA is a valuable tool to assess the sustainability of the industry, most LCA studies are focused on measuring the environmental impact only, devoid of the economic and social factors. Further, while LCA provides a precise picture of the environmental impact of the current system, it does not delineate the managerial factors, nor prioritize them or assign weights, to support long-term strategic decision-making for mainstreaming sustainability.

The necessity for a thorough examination of the research on this subject matter is demonstrated by an analysis of the literature that reveals numerous sustainability assessment methods in the textile and apparel sector. However, observations were not comprehensive and inclusive. As shown in Table 2, a total of 15 textile and apparel sectors sustainability assessment studies techniques were investigated. According to Table 2, most of the tools tested (12 out of 15) were LCA, followed by the use of SLCA (2 out of 15). Several approaches, such as TODIM/ MRIO/ EEIOA/ WFA were made less usage (1 out of 15) each. LCA has been employed by several techniques to create a new, modified methodology for specific goals that just addresses the environmental side of sustainability, such as LCA-based impact assessment (Durotoye *et al*., 2018), water footprint-based LCA method (Yang *et al.*, 2020), and ecological footprint LCA (Costa *et al*., 2019).

LCA has also been used in conjunction with other methodologies for other sustainability characteristics (economic and/or social). Examples include life cycle sustainability assessment (Peters *et al*., 2021), which focuses on environmental and social factors, and (de Oliveira Neto *et al.*, 2019), which exclusively combines economic and environmental elements. However, LCA-based approaches tended to concentrate solely on environmental issues. Because of its maturity in terms of the standardisation of indicators, databases, impact assessment methodologies.

From the perspective of sustainability, the inclusion of the environmental dimension was ranked first, since it was considered by (13 out of 15) of the analysed studies. It was followed by the social (4 out of 15) and economic (1 out of 15) sustainability dimension. This demonstrates that despite the concept of TBL has gained widespread recognition; however, for a number of reasons, the incorporation of social and economic factors into sustainability assessments for the textile and apparel sector in product related assessment method is really not very encouraging. The fact that various sustainability dimensions are included indicates how comprehensive sustainability evaluation techniques are, and another factor is the amount of indicators used for the assessment will reflect the comprehensive nature of these methods. The studies with greatest number of indicators used in the reviewed studies was conducted by (Zamani *et al.*, 2018). The number of indicators in most of the studied methods ranged between 1-9 indicators in about 5 of the assessment studies. As a result, it is critical to

Table 1 Sustainability assessment methods in textile and apparel industry

No.	Tool/Method	Description	Strength	Weakness	Dimensions	Reference
1	Multi-region input-output model (MRIO Model) and environmentally extended input-output analysis (EEIOA)	EEIOA offers a useful, detailed database to examine the worldwide fashion sector. MRIO was used to determine the social and environmental impacts of global fashion consumption, using the full supply chain network.	Due to its high sector resolution, adherence to the original data source, and high country detailed, the EORA MRIO database provided the data for the analysis.	EEIOA is less specific than conventional LCA It is less suitable for evaluating and contrasting engineering processes. No weight was assigned to the data.	Environmental Social	Peters *et al.* (2021)
2.	Life cycle assessment (LCA) and water footprint analysis (WFA)	This study used life-cycle analysis and water footprint analysis to quantify water flows, virtual carbon, and denim production footprints in the world market for denim goods. The study revealed that increasing the usage of polyester-blend denim will reduce carbon emissions while also saving water.	Sensitivity analysis was done on the polyester fibre content of denim to reflect the relationship between water and carbon	No case study was conducted. No weight was assigned to the data.	Environmental	Zhao *et al.* (2021)
3	Life cycle assessment (LCA)	LCA-based sustainability assessment was conducted revealed that the recycled polyester fibre has less tensile strength and crystallinity than its virgin equivalent.	Primary data were used during the process	Sensitivity analysis was missed out. No case study was conducted. No weight was assigned to the data.	Environmental	Majumdar *et al.* (2020)
4.	Life cycle assessment (LCA)	The LCA assessments outcome of the investigation showed that the ozonation process is essential for producing environmental load.	Real-time operational data were utilized. Sensitivity analysis was carried out	No weight was assigned to the data.	Environmental	Nakhate *et al.* (2020)
5	WFA and Life cycle assessment polygon (LCA-polygon)	The method uses WFA approach and LCA polygon's environmental impact assessment technique. The calculations of all related values of inputs and outputs were based on units	The method is easy to understand and produce a single score for the total environmental impacts. It makes use of primary data from the company	No weight was assigned to the data. Both fuzzy and stochastic uncertainty were ignored.	Environmental	Yang *et al.* (2020)

		It involves large amount of multi-dimensional data relating to inputs and output on the process				
6	Life cycle assessment (LCA)	The usage stage sustainability assessment of the textile product waste disposal management among the household. The study revealed that the level of awareness of the dangers posed by an inadequate waste disposal system was low.	The assessment is good for internal reporting because it focused on textile waste process. The study made use of primary data	The assessment is too generic and limited. Both social and economic data were missed out	Environmental	Ajila (2019)
7	Life cycle assessment (LCA)	The LCA analysis shows the potential for Ecological Footprint reduction for each proposed mitigation approach. The investigation revealed that a significant amount of the textile facility's overall energy factor is taken up by energy usage.	It makes use of real factory data from the textile industry. Case study was conducted	The assessment is not an inclusive one. Sensitivity analysis was neglected.	Environmental	Costa *et al*. (2019)
8	Material input per service unit	The work was developed in Brazilian textile industry to identify the economic and environmental gain resulting from cleaner production utilization to meet sustainable development goal. Semi structured interview was used to gather the data from manufacturing manager The study used the data on the amount of resource and emission that were used before and after the adoption of cleaner production	The adopted method reveals that cleaner production adoption generates lower cost and reduce environmental.	Social aspects of sustainability were missed out No weight was assigned to the survey data	Economic Environmental	de Oliveira Neto *et al*. (2019)
9	Life cycle assessment (LCA)	A unit-level sustainability study of three different technological processes for extracting cotton from textile wastes, including leaching, bleaching, and dissolution, and revealing that landfilling will result in serious environmental issues.	The LCA technology was compared with three different scenarios for treating textile waste.	Economic and social aspect were missed out. Sensitivity analysis was neglected. No weight was assigned to the survey data.	Environmental	Yousef *et al*. (2019)

10	Life cycle assessment (LCA)	Examining the environmental impact of textile industry wastewater discharge to the environment. All the samples surpassed the stipulated standard limit for textile sector effluents.	The impact assessment method is detailed because it focused on a unit process.	Sensitivity analysis was neglected.	Environmental	Durotoye *et al*. (2018)
11	Life cycle assessment (LCA)	A product-level environmental sustainability assessment that evaluated developments in fabric production stages using six criteria in a semi-quantitative examination of overall data quality from the Life Cycle Inventory	The four steps outlined by the ISO for the LCA were followed strictly. Sensitivity analysis was carried out.	No weight was assigned to the indicators. Economic and social aspects were missed out	Environmental	L'Abbate *et al*. (2018)
12	Input and output model	The approach is to evaluate a service or product's societal impacts over the course of its life cycle. The GTAP input and output base model was employed to determine the apparel industry's supply chain. The priorities of Swedish apparel consumers were used to choose social indicators.	The method is good for internal reporting the policy maker	No weight was assigned to the indicators Economic and environmental aspect were missed out	Social	Zamani *et al.* (2018)
13	Social life cycle assessment (S-LCA)	The study is focused on the worker's issues only out of the five stake-holder categories of UNEP/SETAC.	The method makes use of quantitative indicator system. The data used is measured based on current production conditions.	Sensitivity analyses were neglected. The method is limited to internal assessment of the company.	Social	Van der Velden and Vogtländer (2017)
14	Life cycle impact assessment method	CED, GWP100 and Recipe was used to perform the environmental characterization Sensitivity analysis was carried out to check the influence of methodological choice on the results The energy consumption data of a commercial washing machine was used	The method helps the policy maker in external and internal policy reporting	Water consumption and energy requirement are the main environmental weakness	Environmental	Busi *et al*. (2016)

		Monte Carlo analysis was performed on the inventory data of finishing process only				
15	Life cycle assessment (LCA)	The method combines LCA and SLCA sustainability assessment The data used were not weighted It was developed for Swedish textile company The method ignored both fuzzy and stochastic aspect of sustainability	The method increased decision makers understanding on sustainability	Economic indicators were missed out Due to lack of data social sustainability is commonly not yet measurable	Environmental Social	Roos *et al.* (2016)

Table 2 Analysis of the reviewed sustainability assessment methods in textile and apparel sectors

No	Tool	Product related assessments				Dimension covered			Number of Indicator				Weight of indicator		Source of indicator			Country		Nature of the tool			References
		LCA	LCC	TODIM/MRIO/EEIOA/WFA	S-LCA	Economic	Environmental	Social	1-9	10-19	20-29	30 and above	Yes	No	Literature based	Primary data	Expert validated	Developed	Developing	Fuzzy	Grey	Stochastic	
1	MRIO and EEIOA			X			X	X						X		X		X					Peters et al. (2021)
2	LCA and WFA	X		X			X							X		X			X				Zhao *et al*. (2021)
3	LCA	X					X							X		X			X				Majumdar *et al*. (2020)
4	LCA	X					X		X					X	X				X				Nakhate *et al*. (2020)
5	WFA and LCA polygon	X		X			X							X		X			X				Yang et al. (2020)
6	LCA	X					X							X		X			X				Ajila (2019)
7	LCA	X					X		X					X	X			X					Costa et al. (2019)
8	Material input per service unit	X				X	X							X	X				X				de Oliveira Neto *et al*. (2019)
9	LCA	X					X							X		X		X					Yousef *et al*. (2019)
10	LCA	X					X		X					X		X			X				Durotoye *et al*. (2018)
11	LCA	X					X		X					X	X			X					L'Abbate *et al*. (2018)
12	Input and output model				X			X			X			X	X			X					Zamani *et al*. (2018)
13	S-LCA				X			X	X					X	X			X					Van der Velden and Vogtländer (2017)
14	Life cycle impact assessment method	X					X							X	X				X			X	Busi *et al*. (2016)
15	Life cycle assessment (LCA)	X					X	X						X	X			X					Roos *et al*. (2016)
	Frequency usage	12	00	03	02	01	13	04	05	00	01	00	00	15	08	07	00	07	08	00	00	01	

include more relevant indicators to present a comprehensive picture of sustainability.

Furthermore, the use of relevant and comparatively weighted indicators is essential for raising the degree of development in sustainability assessment and enabling a more precise, uniform, and comparable evaluation. Weighting indicators, aspect categories, and dimensions would help to produce evaluation results that are more precise and accurate. However, all the reviewed methodology studied indicators (15 out of 15) have no weights attached to them because most of the indicators assessed were more generic. Hence, more specified sustainability indicators must be developed, prioritized, and applied in textile and apparel industry assessments.

The indicators based on the literature are often general in character and possibly not appropriate to all production activities. Several sustainability indicators may vary as the textile and apparel industry location evolve. As a result, it is essential to allow experts to validate and achieve an agreement to provide more credible and useful indicators. Based on the analysis as seen in Table 2, only (8 of the 15) studies used literature based and (7 out of 15) studies utilized primary data as indicators for sustainability evaluation methodologies. However, none of the studies used expert validated indicators, which makes those indicators less credible and useful indicators.

Moreover, sustainability concerns are often difficult to meet due to complexity, as well as a slew of uncertainties and vagueness (Chen *et al.*, 2015). Fuzziness (imprecise data), stochastic (randomness) and grey (limited amount of data) are two primary sources of uncertainty in real-world situations, both of which relate to sustainability evaluation issues. However, all the tools assessed for sustainability assessment in Table 1 above neglected grey, fuzzy and stochastic uncertainties, except Busi *et al.* (2016) whom incorporated stochastic uncertainties in their assessment model. As a result, all the reviewed assessment studies of textile and apparel sector methods that are product related assessment tools are open to subjectivity and biased due to the presence of uncertainties.

Similarly, most of the reviewed studies (8 out of 15) were from developing nations, while (7 out of 15) of the reviewed methods were launched in developed countries. When the review time duration was examined, an exciting discovery was made. Most of the examined studies (13 out of 15) were published within the last five years, with the majority (7 out of 13) of the methodologies described in developing nations, while just (6 out of 13) were launched in the developed world. Currently, the developing countries is focusing more on sustainability challenges in the textile and apparel sectors, as well as establishing assessment methodologies for these problems.

Finally, during the examination of the methodologies analyzed, it was discovered that LCA, LCC, and SLCA are impact assessment techniques that are frequently used as an independent tool for evaluating the specific impact of one sustainability measurement. However, when the development of triple-bottom-line sustainability performance evaluation tools is the primary concern, these tools unlike (MCDM) methodologies become less appropriate. When three dimensions of sustainability are examined, the LCSA can be used. LSCA, like LCA, is an impact assessment approach rather than a performance assessment instrument (Valdivia *et al.*, 2013). LCSA is still a novel concept, and its applications in sustainability assessment research are quite limited. The LCSA is not yet a mature approach and is not widely used.

E. Integrated Assessment Method

Multi-criteria decision making (MCDM) tools have been widely applied to support managers in identifying and prioritizing influential factors in the decision-making vis-a-vis sustainability of textile industry. Specifically, analytic hierarchy process (AHP) has shown to be capable of prioritizing sustainability-related factors viably, mostly in combination with other tools and techniques. Zhu *et al.* (2018) identified the environmental indicators to evaluate the textile industry's greenhouse emission performance using an integrated AHP-Monte Carlo method. The results suggest that their evaluation approach can accurately reflect textile companies' actual greenhouse gas emission performance. Guarnieri and Trojan (2019) developed a paradigm for sustainable supplier selection for the textile industry using an integrated AHP-ELECTRE-TRI methodology. Their study found that when it comes to making long-term business decisions, consumer perception should be prioritized over other factors.

Fidan *et al*. (2021b) used a social LCA to examine the environmental and social implications of the Indigo Rope Dyeing (IRD) process, followed by a hesitant fuzzy analytic hierarchical process (HF-AHP) to establish the weights for each dimension’s criteria. The LCA results demonstrate that the green IRD process outperformed the conventional indigo IRD process for all environmental impacts studied. While AHP delivers reliable results based on pairwise comparison, it loses its utility as the number of criteria increases. Therefore, it would not be best suited to evaluate many sustainability criteria for textile industry in the volatile context of developing countries.

Other decision-making methods were used in the literature to address the sustainability of textile industry. Le and Wang (2017) used a grey prediction approach to examine plant-level sustainability in the textile’s sustainable value chain. Their study identified technological improvement as the primary driver of productivity growth. Tseng *et al.* (2019) used a hybrid fuzzy synthetic technique and decision-making trial and evaluation laboratory (DEMATEL) to evaluate a gate-to-gate assessment of 21 sustainability criteria related to corporate sustainability performance. Their results showed that social responsibility was limited in the case study. Taçoğlu *et al.* (2019) used a combined Delphi-fuzzy and DEMATEL approach to identify 15 essential competitive variables relevant to small and medium-sized enterprises’ competitiveness in the textile business at the plant-level.

More recently, Gbolarumi and Wong (2021) used the Best-Worst Method (BWM) to assess environmental performance parameters in the textile sector. Raw materials, chemical oxygen demand, and freshwater were found to be the most essential criteria, whereas fabric waste, methane, and non-biodegradable material were found to be the least important ones. Table 3 summarizes the reviewed literature on the sustainability of textile industry in developing countries from a methodological viewpoint.

A total of 15 sustainability assessment methods in the textile and apparel industry were investigated, as indicated in Table 4 AHP was utilized most (7 out of 15), followed by Grey, ANP, DEMATEL, and PROMETHEE II (2 out of 15 each) as presented in Table 4. Numerous studies have reported the use of hybrid AHP to meet the three pillars of sustainability, including the risk-based hybrid multi-criteria approach (Bait *et al.*, 2022), supplier selection criteria (Guarnieri and Trojan, 2019), and others. Three sustainability pillars have been addressed by combining AHP with additional methods. For instance, while a hybrid approach by Ali *et al.* (2020) concentrated only on the economic and social aspects of sustainability, integrated methods by (Fidan *et a*l., 2021b; Bait *et al.*, 2022) addressed all three aspects of sustainability. The rising use of AHP may, however, be attributable to its maturity and benefits in pairwise comparison over other (MCDM) approaches, such as standardization. Grey/ANP/DEMATEL/PROMETHEE II usage was also found to be low (2 out of 15) in the reviewed studies. Then, DEPHI, WSM, MPI, COPELAND, SCOR, FSM, FAD, BWM, MC, TODIM, K-MEANS, SAM, WINDOW ANALYSIS, and WPM were less used (1 out of 15) each.

The incorporation of the economic dimension was placed first from the perspective of the sustainability aspect because it was considered by (13 out of 15) of the studies that were analysed. The social dimension was next with (12 out of 15) and environmental (11 out of 15) sustainability factors. This demonstrates that the idea of TBL has become widely accepted. The fact that various sustainability dimensions are included illustrates how broad sustainability evaluation methods are, and the quantity of indicators used is another evidence of how thorough these analyses are. 35 indicators is the highest that were used in the studies that were reviewed (Bait *et al.*, 2022). In about 5 of the assessment studies, the bulk of the methods were assessed with 20–29 indicators, followed by 3 studies with 10–19 indicators. Therefore, it is essential to used more pertinent indicators to offer a complete picture of sustainability.

To further advance the state-of-the-art in sustainability assessment through more accurate, standardized, and comparative assessment, the use of pertinent and comparably weighted indicators is essential (Zhu *et al*., 2018; Tseng *et al*., 2019). Weighting of indicators, dimensions covered, nature of tools and number of indicators involved would help to produce evaluation results that are more precise and accurate. However, 13 out of the 15 methodological assessment studies employed weighted indicators, whereas only 2 out of the 15 studies did not. The development of sustainability assessment methods must therefore consider the importance of having weighted sustainability performance indicators for more thorough and reliable evaluations. Furthermore, it is necessary to design, rank, and use more specialised weighted indicators for textile industry rather than using general indicators.

The indicators based on the literature are sometimes generic in nature and might not be applicable for all manufacturing activities. Therefore, it is crucial to permit experts to validate and come to a consensus to produce more reliable and helpful indicators. Fuzzy set theory was designed to address this vagueness and inaccuracy in decision-making problem since expert judgments are biased and contain certain ambiguities and inaccuracies in real-world situations (Seçme *et al*., 2009). Although the bulk of the examined sustainability evaluation methods focused on either literature or expert opinion, only 5 out of the 15 studies used both literature and expert validated indicators.

However, it might be challenging to address sustainability concerns due to complexity, a plethora of ambiguities and vagueness (Chen *et al.*, 2015). The major causes of uncertainty in real-world circumstances are fuzziness (imperfect data), stochastic (randomness) and greyness (incomplete data), both of which are related to problems with sustainability evaluation. Nonetheless, most of the tools assessed for sustainability assessment neglected stochastic, grey, and fuzzy uncertainties. Fairly (6 out of 15) were based on fuzziness, only (1 out of 15) utilized grey and stochastic uncertainties respectively. Furthermore, fuzzy logic can accommodate the vagueness and uncertainties inherent in the context of decision-making, but its usefulness in all the reviewed study in textile and apparel sector were scant indicating that further research in this area is still required. As a result, developing a system that integrates fuzzy uncertainties into a single evaluation method will be of tremendous value in the textile and apparel sector.

Similarly, most of the reviewed studies (10 out of 15) were published from in developing nations, while (5 out of 15) of the reviewed studies were published in developed countries. When the review time duration was examined, an exciting discovery was made. Most of the examined studies (14 out of 15) were published within the last five years, with the majority (9 out of 14) of the methodologies described in developing nations, while just (5 out of 14) were launched in the developed world.

Finally, BWM, DEMATEL, AHP, ANP, PEOMETHEE II, grey method and other approaches were utilized to assess sustainability in multi-criteria decision-making challenges. When compared to most other MCDM approaches, the BWM method requires far less comparison data, resulting in more consistent comparisons and more reliable outcomes (Rezaei, 2015). Because of its pairwise comparison weightage calculation methods, the AHP is a significant method (Roshanaei *et al.*, 2013). Also, ANP because it overcomes the drawback of the AHP linear hierarchy structure, the technique has become a desirable tool for understanding more of the difficult decision problem (Saaty, 2005). However, Ju-Long (1982) recognized grey as another method for dealing with ambiguity that can effectively indicate a system's incompleteness.

IV. FUTURE RESEARCH OPPORTUNITIES

There are numerous chances for additional research in this field. Only a few research in the textile and clothing sectors have used methodologies that comprehensively address all three dimensions of sustainability, according to the analysis of the reviewed studies shown in Tables 2 and 4. There is still lack of a well-established and inclusive method that takes

Table 3 Sustainability assessment methods in manufacturing and industry

No.	Tool/Method	Description	Strength	Weakness	Dimensions	Reference
1.	Hybrid AHP-TOPSIS-K-means	The hybrid methodology combines the traditional AHP-TOPSIS methodology with the K-means procedure. The assessment made use of 12 experts, 7 criteria, 34 sub criteria, 23 indicators, and 11 sub criteria have missing indicators. Delphi approach was used for criteria validation	The method offers a high degree of adaptability and is simple to use at different degrees of detail and in different circumstances.	The method did not consider both fuzzy and stochastic uncertainties. The method used only quantitative data	Environmental Economic Social	Bait *et al*. (2022)
2.	The hesitant fuzzy analytical hierarchy process (HF-AHP) method	The criteria weights were established using the hesitant fuzzy analytical hierarchy process (HF-AHP) method. This method integrates LCA, S-LCA, LCC, SAM and product quality. The expert opinion was collected through questionnaire. The method was developed and implemented for Turkish textile industry	The technique determines the weight of the criterion using expert opinion. The method was useful for internal reporting	The method overlooked the stochastic aspects of sustainability.	Environmental Economic Social	Fidan *et al*. (2021b)
3.	LCA and TODIM	LCA was used to assessed environmental impacts Quality tests were conducted to evaluate the product. Primary data was collected from the fabric company.	The criteria's relative weights are determined.	LCA was conducted from cradle to factory gate without considering production, use and end-of-life of the garment.	Environmental Economic	Fidan *et al*. (2021a)
4.	Best worst method	Best worst method (BWM) multi criteria decision making was employed to analyse the criteria. A total of 5 main criteria and 20 sub criteria were employed in the method Ten experts were incorporated in this assessment method to validate the criteria.	It helps in decision making for effecting the improvement and development of energy efficiency measure in building	Fuzzy and stochastic aspect were missed out. Social and economic dimension were missed out.	Environmental	Gbolarumi and Wong (2021)
5.	Analytic network process (ANP)	ANP multi-criteria decision-making framework was used to choose production lines in the apparel industry. ANP was used to calculate the criteria weights A total of 5 criteria and 20 sub criteria were employed in the method	The approach used both qualitative and quantitative features. Experts involved were carefully selected from 5 different apparel firm, thus makes their opinion very valid	The approach neglected both fuzzy and stochastic uncertainties. Sensitivity analysis was all missed out. Environmental dimension was also neglected.	Economic Social	Thalagahage *et al*. (2021)
6.	Fuzzy AHP-TOPSIS-based decision support system	A novel Fuzzy AHP-TOPSIS-based decision support system for supplier selection in the Pakistani textile industry was developed using a subjective approach and fuzzy logic Fuzzy AHP was used to obtain the criteria weights TOPSIS was used to rank the suppliers	The method was highly consistent Expert knowledge or opinion was involved	Environmental dimension was neglected Sensitivity and case study were missed out	Social Economic	Ali *et al*. (2020)
7.	SCOR, ANP, FAHP and PROMETHEE II	The method integrates the supply chain operations reference model (SCOR), analytic network process (ANP), fuzzy analytic hierarchy process (FAHP), and the preference ranking organization method for enrichment of evaluations (PROMETHEE II). FAHP was used to calculate the weight of the criteria. PROMETHEE II was used to rank the suppliers.	Quantitative research aids in modelling, data and statistical analysis, and unambiguous results. The method is useful for internal decision-making purpose	Stochastic aspect of the assessment was ignored. Sensitivity analysis was ignored too.	Economic Social	Wang *et al*. (2020)
8.	AHP, WSM, and WPM	The AHP, WSM, and WPM methodologies were used to convey the capability of the operators in an objective manner. AHP was used to calculate the weight of the criteria. This task is completed by six operators in eight operations	This approach works well for internal and external reporting. The approach can deconstruct complex, unstructured situations into their constituent elements.	The method was not put to test through case study. Sensitivity analyses were missed out	Economic Social	Chourabi *et al*. (2019)
9.	MCDA approaches (Copeland/AHP/ELECTRE-TRI)	The method integrates Copeland's, Analytic Hierarchy process (AHP) and ELECTRE-TRI methodologies in a single assessment method.	The MCDM method incorporates both quantitative and qualitative criteria	Stochastic and fuzzy aspect of assessment were ignored	Economic Social Environmental	Guarnieri and Trojan (2019)

		AHP was utilised to determine the weight of the criteria based on the initial data gathered. A total of 28 indicators were develop for the textile industry. The model was developed and implemented for textile industry in Brazil.	The method is useful for internal decision-making purpose			
10.	The Fuzzy Axiomatic Design (FAD) method	The FAD-MCDM method offers the correct and ideal answer for choosing green suppliers A total of 5 criteria and 20 sub criteria were used in the model	The approach used both qualitative and quantitative assessment The method is inclusive, and both inter and external reporting.	Weights were not assigned. Stochastic aspects were missed out	Environmental Economic Social	Gustina *et al*. (2019)
11.	A hybrid model composed of Delphi and fuzzy DEMATEL	The hybrid model comprises of integrating Delphi and fuzzy Dematel methods A total of 15 competitive variables were used for this method based on expert validation The model was developed for SMEs in the textile industry.	The model used fuzzy method to enhance the decision-making process of SMEs manager The variables were selected based on literature review and expert judgement.	Environmental variables were left out The method covers fuzzy aspects only while stochastic aspects were missed out	Economic Social	Taçoğlu *et al*. (2019)
12.	Hybrid fuzzy synthetic method-DEMATEL	The method combines Fuzzy synthetic method (FSM) and DEMATEL methodologies The selection of 3 perspectives, 6 aspects and 21 criteria based on literature review and expert validation and judgement The method was developed and implemented for Taiwanese textile industry	Weight was assigned to the perspectives, aspects, and criteria. The method is useful for external policy reporting among the sectors.	Fuzzy aspects of the assessment were considered and neglect stochastic aspects.	Economic Environmental Social	Tseng *et al*. (2019)
13.	The Monte Carlo- analytical hierarchy process model (MC-AHP model)	The method combines Monte Carlo and analytic hierarchy process methodologies to determine the weight of the criteria. The method was based on 4 dimensions, 9 criteria and 42 indicators Literature based and expert knowledge were employed in the evaluation of the indicator	Combination of AHP and MC improves the integrity and rationale behind the set of weighting	It focused only on environmental aspects while social and economic dimensions were left out Both fuzzy and stochastic aspect were not considered	Environmental	Zhu *et al.* (2018)
14.	The grey prediction, MPI and window analysis model	The methods combine the hybrid model of grey prediction, Malmquist productivity index (MPI) and window analysis to analyse the performance of the of the entire textile and apparel industry Both qualitative and quantitative indicators were employed in the model It was developed and tested in Vietnam textile and apparel industry	The approach provides empirically meaningful and helpful results to the sustainable development of the industry The method is more useful for external reporting by the decision maker	Indicator used were not weighted and validated The method was a conceptual method needs further validation Social indicators were left out	Economics Environmental	Le and Wang (2017)
15.	Grey based approach method	The method was based on social and environmental criteria whereby the garment manufacturer and ancillary suppliers were grouped into three based on grey possibilities value calculated A total of 63 suppliers and 6 sustainability criteria were used for the case study Decision makers identifies the criteria weight of supply Grey possibilities value guides the decision-makers to select the best suppliers	Grey approach can deal with subjective criteria The approach was based on both qualitative and quantitative criteria	Economic aspects were missed out in the method The validation and demonstration of the method is needed.	Environmental Social	Baskaran *et al*. (2012)

Table 4 Analysis of the reviewed sustainability assessment methods

No	**Tool**	**Integrated assessment tools**														**Dimension covered**			**Number of Indicator**				**Weight of indicator**		**Source of indicator**			**Country**		**Nature of the tool**			**References**
		Lca/Lcc/Slca	Topsis	Todim/Sam/K-Means	Promethee II	Window Analysis/Sam	Anp	Fahp/Ahp/Hf-Ahp	Bwm	Scor/Fsm/Wsm/Fad	Grev/Mc	Mpi/Copeland	Topsis/ Electre-Tri	Delphi/Wpm	Dematel	Economic	Environmental	Social	1-9	10-19	20-29	30 and above	Yes	No	Literature based	Primary data	Expert validated	Developed	Developing	Fuzzy	Grev	Stochastic	
1	Integrated AHP, TOPSIS and K-means		X	X				X								X	X	X				X	X				X	X					Bait *et al*. (2022)
2	The hesitant fuzzy analytical hierarchy process (HF-AHP) method	X			X			X								X	X	X			X		X		X			X		X			Fidan *et al*. (2021b)
3	LCA and TODIM	X		X												X	X						X			X		X					Fidan *et al*. (2021a)
4	BWM								X								X				X		X				X		X				Gbolarumi and Wong (2021)
5	ANP						X									X		X					X				X		X				Thalagahage *et al*. (2021)
6	FAHP and TOPSIS		X					X								X		X					X				X		X	X			Ali *et al.* (2020)
7	SCOR, ANP, FAHP and PROMETHEE II				X		X	X		X						X		X		X			X				X		X	X			Wang *et al*. (2020)
8	AHP, WSM, WPM							X		X				X		X		X					X			X			X				Chourabi *et al*. (2019)
9	MCDA approaches (Copeland/AHP/ELECTRE-TRI)							X				X	X			X	X	X			X		X		X		X		X				Guarnieri and Trojan (2019)
10	Fuzzy Axiomatic Design FAD									X						X	X	X			X			X	X				X	X			Gustina *et al.* (2019)
11	A hybrid model composed of Delphi and fuzzy DEMATEL													X	X	X		X		X			X		X		X	X		X			Taçoğlu *et al*. (2019)

12	Hybrid fuzzy synthetic method-DEMATEL									X					X	X	X	X			X		X		X		X	X		X			Tseng *et al*. (2019)
13	The MC-AHP model							X			X					X	X	X		X			X		X		X		X			X	Zhu *et al*. (2018)
14	The grey prediction, MPI and window analysis model					X					X	X				X	X							X					X		X		Le and Wang (2017)
15	Grey based approach method										X						X	X	X				X		X		X		X		X		Baskaran *et al*. (2012)
	Frequency usage	2	2	2	2	1	2	7	1	4	3	2	1	2	2	13	11	12	1	3	5	1	13	2	7	2	10	5	10	6	1	1	

uncertainties into account in the textile and apparel industry, though many sustainability assessment methods have been used in the textile industry. Tables 2 and 4 revealed that the industry's acceptance of these methods that incorporate uncertainty is still not encouraging. Majority of the studies in our review used MCDM techniques without considering fuzzy set theory or fuzzy logic (Thalagahage *et al*., 2021; Chourabi *et al*., 2019; Gbolarumi and Wong, 2021).

Nevertheless, the issues facing the textile and apparel sectors are characterised by ambiguity and uncertainty, it is crucial to take fuzzy ideas into account in future study. This would result in a better ranking of criteria and alternatives in a particular scenario. Additionally, our evaluation found that many researchers in the reviewed study neglected to conduct sensitivity analysis to check the robustness and the stability of the findings, a flaw that should be corrected in subsequent research. The three sustainability dimensions were reported to be taken into account by recently developed integrated assessment methods such the hesitant-fuzzy AHP (Fidan *et al*., 2021b) and FAD (Gustina *et al*., 2019), although these methods are still in their infancy because the studies utilized literature and generic indicators. This might deter stakeholders from evaluating the textile and apparel industry's sustainability. Future studies may therefore consider environmental, economic, and social dimensions, and place more emphasis on developing consistent or standard indicators, and weights for various sustainability issues.

The aforementioned is a clue that in-depth knowledge of the industry is required to significantly improve it. Because of this, developing sustainability indicators and evaluating them are crucial steps in creating plans that might have a positive impact on the textile industry. Additionally, more work is needed in developing nations where sustainability-related database development is not promising. How to handle fuzzy and stochastic uncertainties is a major problem in product design and development. Decision-makers must deal with uncertainty and the dangers that go along with them in the prior studies. Future studies might therefore focus on how to develop assessment methods that can measure and handle all uncertainty. Some tools in this study, such as BWM (Gbolarumi and Wong, 2021) and integrated AHP, WSM, and WPM (Chourabi *et al*., 2019), do evaluations based on expert-adjusted subjective weights, because altering the experts could alter the outcomes.

Results would be less reliable if weighting and data collection were not standardized and inconsistent. Addressing these challenges is a future research focus. This problem is anticipated to be addressed in future research to improve the usefulness and applicability of such methodologies. There are several ways to deal with uncertainty from statistical methods to collaborative decision-making strategies. To enhance sustainability evaluation methodologies and their performance for this industry, incorporating fuzzy reference relation with best-worst method as reported by Xu *et al.* (2021) or other fuzziness approaches is possibly a significant research path.

A. Managerial Implications

The results of this study have several managerial implications for both categories of assessment methodologies, namely product-related and integrated assessment tools in the textile and apparel industry. Majority of prior assessment studies reviewed on product related assessments focused on environmental only, or combination of two dimensions, because they are not developed to meet all the three aspects of sustainability, which make the method to be limited, likewise integrated assessment tools. Practitioners in textile and apparel sectors will benefit from the outcomes of strength and weakness of these assessment methods. Thirty articles were classified into two (product related assessment and integrated assessment methods) groups in this study.

To ensure that all researchers and practitioners are given a thorough study and analysis of product-related and integrated assessment methodologies, this classification scheme acts as a reference. Practitioners and stakeholders can use this assessment to determine their future paths and efforts in fostering inclusive sustainability assessment methods in textile and apparel sector. Furthermore, the most suitable approach for their goals, needs, and settings can be chosen by practitioners based on analysis of the examined methodologies.

B. Theoretical Implications

This review study was comprehensively focused on sustainability assessment methods and their applications in textile and apparel sector. This study has provided a fresh perspective on or enhanced earlier research on sustainability assessment methods in textile and apparel industry that could aid academics in their efforts to further research, comprehend, and combat all types of uncertainties while incorporating all the three facets of sustainability. It synthesizes the variety of studies in the textile and apparel industry assessment methods in several areas including dimension covered, number of indicators involved, source of indicators, country, and nature of the methods, which prior assessment methodologies reviews lacked. Researchers can use this study as a practical guide to select sustainable assessment methods in textile and apparel sector.

V. CONCLUSION

The review of current sustainability assessment methods that are mostly used in this study focused on textile and apparel industry. Although there are various sustainability performance measurement techniques, only few of them integrate the environmental, economic, and social dimensions concurrently. It was also necessary to outline the primary strengths and weaknesses of each sustainability evaluation methods considering recent developments. This study examined current sustainability evaluation techniques (reported from 2012 to 2022) in textile and apparel sector to close the knowledge gap. The study used different assessment mode to differentiate each assessment methods under review based on different dimension covered, number of indicators, weight of indicator, source of indicator, country, and nature of the tool.

Product related assessment methods tends to concentrate solely on environmental issues most time. Because of its maturity in terms of the standardization of indicators, databases, impact assessment methodologies. The study noticed that the indicators used in product related assessment tools were basically literature-based or primary data. This demonstrates that despite the concept of TBL has gained widespread recognition for several reasons, the incorporation of social and economic factors into product related assessment methods for the textile and apparel industry is not very encouraging. However, none of the studies used expert validated indicators, which makes those indicators less credible and useful. As a result, all the reviewed assessment of textile and apparel sector on product related assessment methods are open to subjectivity and biased due to the presence of uncertainties.

Integrated assessment tools are an essential method that integrate more pertinent indicators in their assessments to offer a complete picture of sustainability. Also, the methods used weighted sustainability indicators for more thorough and reliable evaluations. Although the bulk of the examined sustainability evaluation approaches focused on both literature and expert validated indicators.

As a foundation for future research in developing countries, in particular Nigeria, it is vital to engaged in reviewing the methodological processes. Due to the dearth of sustainability evaluation tools in the textile and apparel industry, a thorough examination of current sustainability assessment techniques is necessary. Accordingly, a comprehensive integrated assessment technique that incorporates all the three facets of sustainability is needed and adaptable for textile and apparel sector.

AUTHOR CONTRIBUTIONS

T. G. Fadara: Conceptualization, Methodology, Software, Validation, Writing – original draft, Writing – review & editing. **K. Y. Wong:** Supervision, Writing – review and editing. **M. I. Maulana:** Writing – review and editing.

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