

A Comprehensive Performance Scorecard for Sustainable Ergonomics Assessment of Textile-based Organizations

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Abstract

This study proposes a comprehensive performance scorecard for sustainable ergonomics assessment of textile-based organizations, contributing to socially sustainable global supply chain practices. The framework integrates sustainability and ergonomics principles, considering economic, social, and environmental dimensions equally. A systematic literature review was conducted to extract sustainability indicators, which were then adopted as ergonomics indicators (EIs). The weights of the 20 newly proposed EIs were determined using subjective (expert opinions) and objective (entropy) methods. Data was collected from 23 textile-based organizations using a performance scorecard sheet, and the Grey Relational Analysis (GRA) method was employed for normalization and aggregation of the EIs scores. A performance benchmarking tool was constructed to classify the sustainable ergonomic performance of the participating organizations. The proposed EIs were mapped to the United Nations Sustainable Development Goals (SDGs) and targets using a Sankey diagram, highlighting their contributions to the sustainability agenda 2030. The empirical study revealed that 73.91% of the participating organizations were average performers, while 13.04% were developing performers, indicating the need for improvement in sustainable ergonomic practices. The proposed framework provides a viable tool for decision-makers to assess and benchmark the performance of supplier organizations, promoting transparent and consistent socially sustainable supply chain practices.

Keywords

Sustainability, Ergonomics indicators, Performance scorecard, Supply chain, Benchmarking

1. Introduction

The increasing complexity of global supply chains has raised concerns regarding their environmental, social, and economic impacts. Frequent labor rights scandals (Business & Human Rights Resource Centre 2020; Peter 2021; United States Department of State 2025) in global supply chains reveal regulatory gaps, as multinational companies (Western buyers) face legal accountability. In Europe, “*sustainability due diligence*” has emerged as a cornerstone of corporate sustainability policy (Ciacchi 2024). Some researchers have measured corporate sustainability performance (Searcy 2012; Nicolăescu et al. 2015; Engida et al. 2018; Rosiani et al. 2024), but most have been applied at the corporate level (Moldavska and Welo 2019) and often lack data at the workplace decision-maker level (Utama et al. 2022). Recent studies have primarily focused on manufacturing sustainability in the border context (Machado et al. 2020; Ching et al. 2022), while a few studies (Bonvoisin et al. 2017; Swarnakar et al. 2021) have emphasized the integration of sustainability principles into manufacturing processes to overcome environmental harm and enhance economic benefits. Consequently, the gap in the literature calls for a viable sustainable ergonomics performance assessment framework to effectively measure the performance of supplier organizations at the workstation level. Manufacturing sustainability assessment has been conducted in the literature (Lee et al. 2014; Huang and Badurdeen 2018) using many frameworks and indicators, but these frameworks lack a comprehensive view of sustainable manufacturing (Bhakar et al. 2018). Thus, a methodology to measure manufacturing sustainability performance at the production line level is required. The Triple Bottom Line (TBL) concept remains central to this approach as it integrates economic, social, and environmental sustainability concerns (Sethi and Rajesh 2022).

Ergonomics is a “*scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance,*” as defined by the International Ergonomics Association (IEA 2023). Thus, both sustainability and ergonomics are aligned in their focus on human well-being (considering the social aspect), system performance (considering the economic characteristics of organizations), and reduction of harmful impacts (focusing on the environmental aspect) (Amjad et al. 2023), reinforcing their interrelated roles in achieving sustainable and efficient manufacturing processes. Recently, the ILO reported that over 270 million workers experienced injuries and approximately 160 million were affected by work-related illnesses (ILO 2023). Within this context, the assessment of the working conditions of supplier organizations based on the ergonomics paradigm not only enhances worker performance and satisfaction, but also mitigates the risk of injuries and promotes long-term viability. Koberg and Longoni (2019) defined performance as “*the successful execution or outcome of work,*” whereas Ahmad et al. (2018) described an indicator as a parameter used to provide information about or describe states. Consequently, performance indicators are crucial for quantitatively outlining an organization’s processes, focusing primarily on the critical aspects of organizational success (Badawy et al. 2016). A performance measurement system that employs these indicators is instrumental in assessing various organizational functions, including strategic, managerial, financial, operational, quality, and employment. The selection of indicators is a complex process that significantly influences performance (Liberati et al. 2020).

Table 1 summarizes several publicly available indicator sets for sustainability assessment, including their application level, TBL dimension coverage, sustainable development goals (SDGs) incorporation, indicator weighting methods, and their interaction. It is evident from Table 1 that indicators are weights subjectively based on a person’s experience, using surveys or questionnaires (Hafezalkotob and Hafezalkotob 2016), introducing uncertainty due to high dependency on judgments. Similarly, subjective weighting methods and scoring processes rely on the direct aggregation of weighted sums that ignore interactions and interdependencies between indicators, affecting the accuracy of assessment tools. An indicator such as the CO₂ equivalent is linked to an organization's energy consumption and affects employee or public health satisfaction. These indicators fall under different TBL dimensions; therefore, they should not be treated independently (Mardani et al. 2015; Mulliner et al. 2016). It is essential to address the interdependencies among indicators during the weight assignment and assessment stages to ensure the reliability of the results. Furthermore, the limited integration of the SDGs into sustainability assessment tools is a profile. The 17 SDGs emphasize the need to balance social, economic, and environmental sustainability, recognizing that actions in one area can influence outcomes in others (UN 2020). The full integration of the SDGs into sustainability assessments allows decision makers to see how their organizations directly contribute to the SDGs and to establish benchmarks for improvement to achieve the SDGs.

The aim of this study is to develop a comprehensive performance scorecard to measure the performance of supplier organizations using a systematic approach to construct a viable framework. The performance assessment of supplier organizations considers all TBL dimensions to select suitable sets of indicators from the literature. As both disciplines

(sustainability and ergonomics) share the same ethos, the sustainability literature is investigated to propose Ergonomics Indicators (EIs), which can be used for organizational sustainability assessment (Sarbat and Oz Mehmet Tasan 2020). Guidelines for proposing EIs from the sustainability literature are presented in the framework (Section 2), and each TBL dimension is considered equally important. Subjective and objective methods are deployed for weight identification and to account for possible interdependencies and interactions among EIs. Multi-criteria decision-making (MCDM) methods are used for normalization and aggregation. Furthermore, SDGs are not directly related to available assessment tools found in the relevant literature, so SDGs are mapped to the proposed EIs for achieving the sustainability agenda 2030. Another original contribution of this study is the construction of a performance benchmarking tool, which would be helpful for decision-makers to reward their good practices. This tool can also be useful for Western buyers to assess their supplier organizations to develop transparent and consistent socially sustainable supply chain practices.

Table 1. Summarized list of publicly available sustainability assessment tools

Assessment Tools and Reference	Application Level	# Ind	TBL Dim Coverage			SDGs	Ind Wts	Int Ind
			<i>Ec</i>	<i>En</i>	<i>So</i>			
Global Reporting Initiative (Global Reporting Initiative 2011)	Organization	70	●	●	●	◐	○	○
Dow Jones Sustainability Indexes (Schmiedeknecht 2013)	Organization	12	●	◐	◐	◐	Subj	○
Environment Performance Index (Block et al. 2024)	Country	19	○	●	○	◐	○	○
Core Environmental Indicators (OECD CEI 2003)	Country	46	◐	●	◐	◐	Subj	○
Ford Product Sustainability Index (Schmidt and Taylor 2006)	Product	8	●	●	●	◐	Subj	○
ISO 14031: Environment Performance Evaluation Standard (ISO 2021)	Organization	3	○	●	○	◐	○	○
The Institute of Chemical Engineering (Labuschagne et al. 2005)	Factory	9	●	●	●	○	○	○

Key: # Ind: Number of indicators, TBL Dim: Tripple bottom line dimensions, Ec: Economic, En: Environment, So: Social, SDGs: Sustainable development goals, Ind Wts: Indicators weights, Int Ind: Interdependencies among indicators, ●: covered, ◐: partially covered, ○: not covered, Subj: Subjective

2. Construction of Framework

The construction of a framework for assessing supplier organization ergonomic sustainability consists of three main stages (Figure 1). In the first pre-assessment stage, relevant literature was studied to extract sustainability indicators with respect to TBL dimensions, after which selected sustainability indicators were adopted as EIs. The connection between ergonomics and sustainability is already established in Section 1. The second stage was data collection and quantification, which was divided into two steps: identification of weights for each EIs based on both subjective (expert opinions) and objective methods, that is, entropy. After calculating the combined weight of the EIs, a performance scorecard-based sheet was used to quantify the data values collected from the workstations. In the last assessment stage, MCDM –Grey Relational Analysis (GRA)– is used to calculate the performance score of the participating supplier organizations. Finally, all the participating organization scores are shown graphically (performance benchmarking tool) to classify sustainable ergonomics performance. The detailed procedure for the sustainable ergonomics performance evaluation stages is explained below.

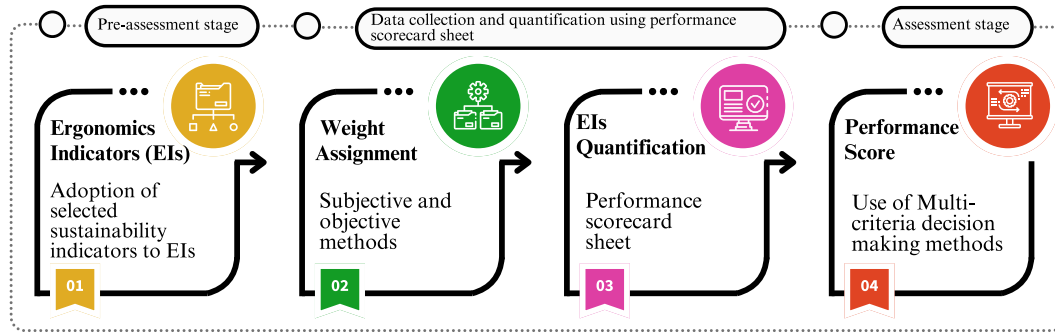


Figure 1. Sustainable ergonomics performance assessment framework

2.1. Pre-Assessment Stage

A systematic literature search was conducted using the keywords "ergonomics", "human factors", and "occupational health and safety" combined with "sustainability," "sustainable development," "manufacturing performance," and "indicator." The search was conducted in January 2024 and November 2024 across multiple databases, including Google Scholar, Taylor and Francis, Wiley, ScienceDirect, Emerald, and Springer. Duplicate records were removed, and non-peer-reviewed sources, such as conference papers, dissertations, working papers, technical reports, books, and book chapters, were excluded. Only SCI-, SCI-E-, and SSCI-indexed journal articles published in English from 2015 to 2024 were included. After full-text review, 90 relevant papers were selected for further analysis. Furthermore, the fundamental elements of ergonomics –*job/task design, workplace and equipment design, and work organizations*, considering humans in the center– presented by Scott et al. (Scott et al. 2010), in addition to the sustainability concept, were further included in the inclusion criteria. The selected studies were examined in terms of their proposed sustainability indicators. Selecting and consolidating sustainability indicators relevant to the theoretical background (fundamental elements of ergonomics) for proposing EIs is the main focus. The evaluation criteria (e.g., 'measurable', 'relevant', 'understandable', 'reliable/ usable', 'data accessible', 'timely manner', and 'long term-oriented') of selected indicators primarily established by 'Sustainable Measures Group' are also kept in indicator selection process (Joung et al. 2013).

Table 2 presents the reference studies, their level of analysis, TBL focused listed and selected indicators. The total number of selected indicators across all dimensions is 1340 out of 4242, with 169 out of 1226 for economic, 509 out of 1594 for environmental, and 662 out of 1422 for social indicators. A 'merging' approach was used to consolidate the selected sustainability indicators. This approach has been widely used by various researchers, (Chan and Lee 2019; Karji et al. 2019; Opon and Henry 2019), who combined indicators based on similar meanings to overcome the complexity of the indicator by creating thematic indicators. More recently, Sarbat and Oz Mehmet Tasan (2020, 2022) adopted the same approach to propose 25 EIs.

Table 2. Literature analysis for adoption of indicators

Level of Analysis	Reference Studies	TBL Focused Indicators	
		Selected	Listed
Industrial sustainability	(Feil et al. 2015)	17	26
Industrial buildings	(Heravi et al. 2015)	15	42
Service and manufacturing	(Loeppke et al. 2015)	16	19
Process	(Marnika et al. 2015); (Valenzuela-Venegas et al. 2016); (Lin et al. 2020); (Swarnakar et al. 2022); (Yan et al. 2024)	89	424
Product	(Santiago-Brown et al. 2015); (Van Schoubroeck et al. 2018); (Lin et al. 2019); (Rafiaani et al. 2020); (Lund et al. 2023)	74	256
Farm	(Allahyari et al. 2016)	11	62

Level of Analysis	Reference Studies	TBL Focused Indicators	
		Seelcted	Listed
Corporate	(Dočekalová and Kocmanová 2016); (Kocmanová et al. 2017); (Pavláková Dočekalová et al. 2017); (Ruiz-Pérez et al. 2021)	48	108
Facility location	(Govindan et al. 2016)	25	48
Firms	(Long et al. 2016)	4	17
Supply chain	(Manning and Soon 2016); (Li and Mathiyazhagan 2018); (Popovic et al. 2018); (Sangwan et al. 2018); (Kumar and A 2020); (Narimissa et al. 2020); (Shidpour et al. 2023); (Singh et al. 2023)	148	396
Factory	(Winroth et al. 2016)	14	27
Asia-Pacific	(Bui et al. 2017)	9	20
System	(Büyüközkan and Karabulut 2017); (Gillespie-Marthaler et al. 2019); (Karnauskaitė et al. 2019); (Munyanza et al. 2019); (Torabizadeh et al. 2020); (Gopi and P.G. 2024); (Regragui et al. 2024)	62	261
Industry	(Helleno et al. 2017); (Feil et al. 2019); (Ahmad and Wong 2019); (Trianni et al. 2019); (Van Schoubroeck et al. 2019); (Hojnik et al. 2020); (Roy et al. 2020); (Mengistu and Panizzolo 2021); (Contini et al. 2023); (Harikannan et al. 2023); (Mengistu and Panizzolo 2023a); (Mengistu and Panizzolo 2023b); (Mengistu and Panizzolo 2023c); (Mubin et al. 2023); (Saygili et al. 2023)	297	843
Product/ process/ plant/ global	(Ahmad et al. 2018)	39	147
Healthcare	(Chang et al. 2018)	7	19
Transport systems	(Danielis et al. 2018)	1	27
Materials	(Danso 2018)	3	24
Building production	(Pan et al. 2018)	21	60
Design and operation	(Popovic and Kraslawski 2018)	8	22
Aquaculture	(Valenti et al. 2018)	3	56
Rural areas	(Egenolf and Bringezu 2019)	4	45
Urban systems	(González-García et al. 2019)	6	38
Company	(Hristov and Chirico 2019); (Hutchins et al. 2019); (Kravchenko et al. 2019); (Bhanot et al. 2020); (Lin et al. 2021); (Contini and Peruzzini 2022); (Eskandari et al. 2022); (Zharfpeykan and Akroyd 2022); (Rinaldi et al. 2023)	150	513
Regional	(Shi et al. 2019)	2	51
Business	(Arianpoor and Salehi 2020); (Dissanayake 2021)	29	107
Organization	(Sarbat and Ozmehmet Tasan 2020); (Lee et al. 2021); (Swarnakar et al. 2021); (Feil et al. 2022); (Sarbat and Ozmehmet Tasan 2022); (Saad et al. 2023)	79	190
Design	(Taddese et al. 2020)	25	68
Life cycle sustainability assessment	(Visentin et al. 2020)	10	39
Maintenance	(Franciosi et al. 2021); (Olugu et al. 2021)	26	72
ISO 14001 companies'	(Abdul-Rashid et al. 2022)	9	22
Life Cycle Assessment	(Barni et al. 2022)	11	32

Level of Analysis	Reference Studies	TBL Focused Indicators	
		Seelcted	Listed
Product's lifecycle	(Saihi et al. 2022)	33	64
Green supply chain	(Susitha and Nanayakkara 2023)	11	21
Lean Six-sigma	(Utama and Abirfatin 2023)	14	16
Department	(Esteghamat et al. 2024)	6	17
Product design	(Mengistu et al. 2024)	14	43
Total		1340	4242

This study further strengthens the work of Sarbat and Ozmehmet (2020, 2022) in proposing new 20 EIs, considering the limitations presented in the structural framework. Moreover, empirical evidence is exhibited in textile-based organizations by quantitatively calculating their scores (details in Section 2.2). Finally, sustainability indicators could be assigned to more than one EIs. The proposed list of new 20 EIs is shown in Figure 2. In this study, the weights of TBL dimensions (economic, environment, and social) were considered the same to ensure that none of the dimensions were prioritized or undermined; therefore, bias was minimized (Escrig-Olmedo et al. 2019). A summary of the year-wise mapping of the new 20 EIs to the selected indicator studies is shown in Figure 3.

Sustainable ergonomics performance assessment using EIs	Economic	El-1: Annual monetary loss occurred due to accidents and injuries relative to the total hours worked
		El-2: Annual expenditure on medical treatments for accidents, injuries and occupational diseases
		El-3: Annual cost of EHS non-compliance due to organizational deficiencies
		El-4: Annual investment in designing an ergonomically and environmentally friendly system
		El-5: Annual investment in employee development
	Environmental	El-6: Annual impact of unfavorable physical working conditions on employees
		El-7: Annual number of complaints from the community
		El-8: Annual number of volunteer activities made for improving working conditions, and implementing procedures for ergonomics interventions and EHS
		El-9: Annual number of activities for improving human-machine interaction within an ergonomically designed processes
		El-10: Annual percentage of recycled products/raw materials used in ergonomically designed processes
		El-11: Annual percentage of bio-degradable packaging materials used in ergonomically designed processes
		El-12: Annual percentage of CO ₂ emissions due to energy consumed by ergonomically designed processes
		El-13: Annual percentage of wastewater treatment processes completed in accordance with ergonomically designed processes
	Social	El-14: Annual number of suggested improvements made by employees
		El-15: Annual percentage of incentives and promotions made for stakeholders to contribute ergonomically and environmentally-friendly designed
		El-16: Annual percentage of employees participating in managerial decisions related to ergonomics interventions and EHS issues
		El-17: Annual percentage of pre- and post- EHS issue improvement after conducting employee trainings
		El-18: Annual turnover rate of employees
		El-19: Annual percentage of employees who are satisfied with their work
		El-20: Annual number of complaints due to working conditions not covered by decent work

Figure 2. Proposed list of EIs based on TBL dimensions

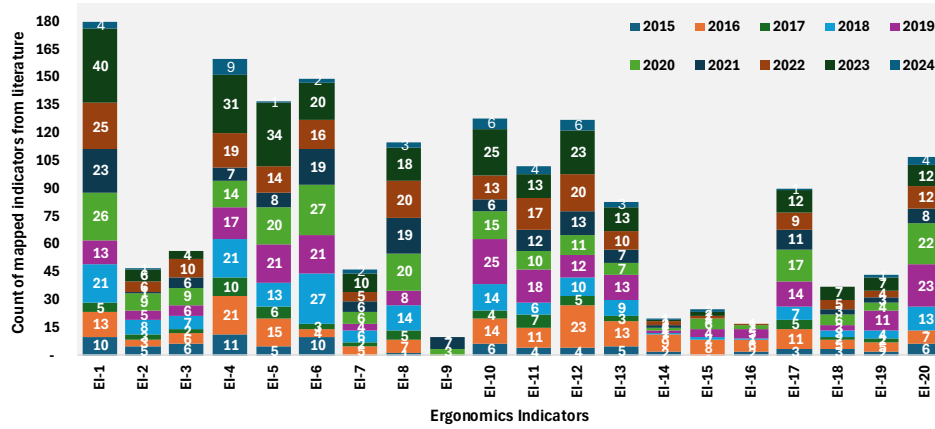


Figure 3. Mapping of new 20 EIs to selected indicators studies from year 2015 to year 2024

2.2. Data Collection and Quantification Stage

This stage consisted of two steps: weight assignment and EIs quantification. The details of each step are presented below.

Weight Assignment: Newly proposed EIs relative importance was established by assigning the weights of each EIs using a mix of subjective and objective weighting methods. Subjective weighting methods include the Delphi method, analytical hierarchy process, questionnaire, survey, and/or decision maker experience, while some objective weight methods include the entropy weight method, criteria importance through inter-criteria correlation method, principal component analysis, and/or mean square deviation method. Both methods have advantages and disadvantages. Subjective weight methods are usually dependent on decision maker judgement and often contain bias while being closer to reality. Conversely, objective weight methods are dependent on real values (quantitative sample data) and obtain more scientific results calculated using mathematical algorithms or models (Zardari et al. 2015). Although both methods exhibit a certain degree of information loss, the combination of these methods can minimize the loss of information, and the weights are closer to the actual possible results. Based on this, this study used both methods to calculate the weights of 20 newly proposed EIs. For the subjective and objective weighting questionnaire approaches, the entropy weight method was used to calculate the weights of each EIs.

In the subjective weighting method, a questionnaire was used to collect expert opinions based on 20 newly proposed EIs. Sixteen experts participated in this study using convenience sampling. The number of experts differs in various indicator selection studies, but a range of 9 to 13 experts was considered appropriate by many researchers (Ahmad and Wong 2019). The questionnaire consisted of two parts: demographic details and experts' opinions on the importance of EIs. A 5 point Likert-scale was used to collect the data (1 = not important and 5 = most important). The selected experts were working as senior managers, health and safety officers, and managers at various textile-based organizations with an average experience of 12.62 years, while the maximum and minimum years of experience were 8 and 15, respectively. Of the 16 experts, 12 were male and 4 were female, and all had a minimum master's degree. The minimum and maximum experience of the selected experts in sustainability and ergonomics were 8 and 12 years, respectively. The reliability of the Likert-scale type (Croasmun and Ostrom 2011) questionnaire was measured using Cronbach's α coefficient (Cronbach 1951). As proposed in literature, having value of Cronbach's α coefficient greater than 0.70 represent the survey acceptable reliability (Yuan et al. 2009), in this study the Cronbach's α coefficient value is 0.9632. The mean score method was employed to determine the weights of the EIs based on expert evaluations, using a five-point Likert scale. The mean score (\bar{Y}_i) for each indicator (EI_i) is calculated as follows:

$$\bar{Y}_i = \frac{\sum_{a=1}^R Y_{aj}}{R} \quad (1)$$

where, Y_{aj} represents the score given by the expert a for indicator j , and R is the total number of experts. The normalized weight M_j for each indicator was computed as:

$$M_j = \frac{\bar{Y}_i}{\sum_{j=1}^l \bar{Y}_i} \quad (2)$$

where, l is the total number of indicator.

In the objective weighting method, an entropy weight method was used because it is easy in nature and helpful for preventing uncertainties associated with subjective-based judgments (Shannon 1948). It assigns weights to the indicator based on the diversity captured. Low weights were assigned to the indicator if values were too close to each other, while high weights were assigned because of large deviations (Jahan et al. 2012). The weights of the EIs (E_j) for n indicators and m alternatives were calculated using Equations 3 and 4, respectively.

$$E_j = \frac{1-E_j}{n - \sum_{j=1}^n E_j} \quad (3)$$

$$E_j = -k \sum_{i=1}^m P_{ij} \log_e(P_{ij}) \quad (4)$$

where, E_j is the weight of EI obtained by entropy method, $k = \frac{1}{\log_e(m)}$, $P_{ij} = \frac{x_{ij}}{\sum_{i=1}^m x_{ij}}$, x_{ij} is the value of the j^{th}

indicator of the i^{th} alternative, and assuming that $P_{ij} = 0$ when $\log_e(P_{ij}) = 0$.

The combined weight Cw_j was obtained by combining the subjective and objective weights with the weighted arithmetic average operator (Zhu et al. 2019). The formula is:

$$Cw_j = \alpha M_j + \beta E_j \quad (5)$$

where α and β are the objective preference coefficients, $\alpha, \beta \in [0,1]$, and $\alpha + \beta = 1$. This study considers two types of information (weights from subjective and objective methods) are equally important –a most reasonable setting method– thus, α and β are set to 0.5.

EIs Quantification: The score of each EI is calculated using the performance scorecard sheet consisting of EIs, unit of measurements, trend information (higher is better or lower is better), indicator type, maximum and minimum range values, and quantitative formulas, presented in Table 3, according to the ISO template (ISO 2014).

Table 3. Performance scorecard sheet for quantification of 20 newly proposed EIs

EIs	Units	Tr	Ind Type		Range		Formulas	Reference	
			Led	Lag	Min	Max			
1	\$	LB		✓	0	DV	$L_a = T_i \times C_h$ L_a = Annual monetary loss, T_i = Total lost time in hours due to accidents and injuries, C_h = Cost per hour loss of production	(Marnika et al. 2015), (Loeppke et al. 2015), (Popovic et al. 2018), (Kalenga 2022), (Mengistu and Panizzolo 2021), (Rezagholi 2023), (Takala et al. 2014), (Swarnakar et al. 2021), (Mengistu and Panizzolo 2023a)	
2	\$	LB		✓	0	DV	$Exp_t = Exp_a + Exp_i + Exp_o$ Exp_t = Total expenditure on medical treatments, Exp_a = Expenditure on accidents, Exp_i = Expenditure on injuries, Exp_o = Expenditure on occupational diseases	(Popovic et al. 2018), (Schögggl et al. 2016), (Dočekalová and Kocmanová 2016), (Rosiani et al. 2024), (Rezagholi 2023), (Feil et al. 2022), (Mengistu and Panizzolo 2023b)	
3	\$	LB		✓	0	DV	$C_{nc} = C_f + C_i + C_p$ C_{nc} = Total cost of non-compliance, C_f = Fines and penalties imposed by regulatory bodies, C_i = Insurance premiums and potential litigation expenses, C_p = Costs of lost productivity due to workplace accidents or environmental incidents	(Richy et al. 2013), (Scott et al. 2024), (Dočekalová and Kocmanová 2016), (Kocmanová et al. 2017), (Schögggl et al. 2016), (Feil et al. 2022)	
4	\$	HB	✓			DV	UL	$Inv_{sys, total} = I_{erg} + I_{EHS} + I_{R\&D} + I_{tech} + I_{inn}$ $Inv_{sys, total}$ = Total system investment, I_{erg} = Investment in ergonomics intervention, I_{EHS} = Investment in Environmental, Health, and Safety (EHS), $I_{R\&D}$ = Investment in Research & Development (R&D), I_{tech} = Investment in technology, I_{inn} = Investment in innovation	(Kocmanová et al. 2017), (Kravchenko et al. 2019), (Schögggl et al. 2016), (Popovic et al. 2018), (Hristov and Chirico 2019), (Mengistu and Panizzolo 2021)
5	\$	HB	✓			DV	UL	$Inv_{emp, total} = I_{EHS} + I_{ps} + I_{ws}$ $Inv_{emp, total}$ = Total employee investment, I_{EHS} = Investment in EHS (Environmental, Health, and Safety) training, I_{ps} = Investment in personal skills training, I_{ws} = Investment in work-related or occupational skills training	(Kocmanová et al. 2017), (Popovic et al. 2018), (Rosiani et al. 2024)

EIs	Units	Tr	Ind Type		Range		Formulas	Reference
			Led	Lag	Min	Max		
6	#	LB		✓	0	DV	$I_{phys} = \frac{C_y}{E_t} + \frac{C_d}{D_t} + \frac{C_e}{E_t}$ <p>I_{phys} = Impact of unfavorable physical working conditions, C_y = Number of complaints due to noise, temperature, odor, dust, physical working conditions etc. in the year, E_t = Total employees involved in manufacturing of goods in the year, C_d = Number of complaints (noise, temperature, odor, dust, physical working conditions etc.) occurring in days, D_t = Total number of working days in the year, C_e = Complaints per affected employee in the year (count of distinct employees who reported complaints)</p>	(Popovic et al. 2018), (Kravchenko et al. 2019), (Feil et al. 2022)
7	#	LB		✓	0	DV	$C_{total, comm} = C_d + C_c + C_g + C_o$ <p>$C_{total, comm}$ = Total number of complaints from the community, C_d = Complaints from distributors, C_c = Complaints from customers, C_g = Complaints from the government, C_o = Complaints from others in the community</p>	(Popovic et al. 2018), (Mengistu and Panizzolo 2021), (Mengistu and Panizzolo 2023a), (Mengistu and Panizzolo 2023b)
8	#	HB	✓		DV	UL	$V_{total} = V_a + V_r + V_m + V_s + V_c + V_o$ <p>V_{total} = Total number of volunteer activities, V_a = Number of audits, V_r = Number of reports, V_m = Number of meetings, V_s = Number of assessments, V_c = Number of charitable contributions related to EHS, V_o = Number of other activities</p>	(Loeppke et al. 2015), (Kocmanová et al. 2017), (Popovic et al. 2018), (Mengistu and Panizzolo 2021), (Swarnakar et al. 2021), (Mengistu and Panizzolo 2023a), (Mengistu and Panizzolo 2023b)
9	#	HB	✓		DV	UL	$HMI_{total} = HMI_a + HMI_r + HMI_m + HMI_s + HMI_o$ <p>where: HMI_{total} = Total number of activities for improving human-machine interaction, HMI_a = Number of audits, HMI_r = Number of reports, HMI_m = Number of meetings, HMI_s = Number of assessments, HMI_o = Number of other activities</p>	(Cao et al. 2016), (Bridger 2017), (Czerniak et al. 2017), (Lin et al. 2020), (Lin et al. 2021)
10	%	HB	✓		0	100	$P_r = \frac{R_e}{G_t} \times 100$ <p>P_r = Percentage of recycled products/raw materials used in ergonomically designed processes in the year, R_e = Number of recycled products/raw materials used in ergonomically designed processes in the year, G_t = Total number of commercial goods produced in the year</p>	(Dočekalová and Kocmanová 2016), (Schögggl et al. 2016), (Kravchenko et al. 2019), (Hristov and Chirico 2019), (Swarnakar et al. 2021), (Feil et al. 2022), (Mengistu and Panizzolo 2021), (Mengistu and Panizzolo 2023a), (Mengistu and Panizzolo 2023b)
11	%	HB	✓		0	100	$P_b = \frac{B_p}{P_t} \times 100$ <p>P_b = Percentage of bio-degradable packaging materials used in ergonomically designed processes in the year, B_p = Total weight or volume of bio-degradable packaging materials used, P_t = Total weight or volume of all packaging materials used</p>	(Dočekalová and Kocmanová 2016), (Swarnakar et al. 2021), (Mengistu and Panizzolo 2021), (Feil et al. 2022), (Utama and Abirfatin 2023), (Mengistu and Panizzolo 2023a), (Mengistu and Panizzolo 2023b)
12	kg	LB		✓	0	100	$P_{CO_2} = \frac{\frac{D_w \times T_m \times C_m \times N_m \times F_e}{1000}}{\frac{D_w \times T_o \times C_t \times F_e}{1000}} \times 100$ <p>P_{CO_2} = Percentage of CO₂ emissions from ergonomic processes, D_w = Number of working days (days), T_m = Machines running time per day (hours), C_m = Average energy consumption per machine involved in producing manufacturing goods (KWh), N_m = Number of machines involved in producing manufacturing goods, F_e = Average emissions factor (~0.45 kg CO₂/kWh), 1000 =</p>	(Schögggl et al. 2016), (Marnika et al. 2015), (Kocmanová et al. 2017) (Helleno et al. 2017), (Swarnakar et al. 2021), (Mengistu and Panizzolo 2021), (Mengistu and Panizzolo 2023a), (Mengistu and Panizzolo 2023b), (Utama and

EIs	Units	Tr	Ind Type		Range		Formulas	Reference
			Led	Lag	Min	Max		
							Conversion factor to metric tons, T_o = Operational time per day (hours), C_t = Average per day total energy consumption (KWh)	Abirfatin 2023), (Rosiani et al. 2024)
13	%	HB		✓	0	100	$P_w = \frac{W_t}{W_g} \times 100$ P_w = Annual Percentage of Wastewater Treated, W_t = Amount of treated wastewater for reuse or disposal (Liters), W_g = Total annual wastewater generated (Liters)	(Marnika et al. 2015), (Schögggl et al. 2016), (Kocmanová et al. 2017), (Helleno et al. 2017), (Kravchenko et al. 2019), (Swarnakar et al. 2021), (Mengistu and Panizzolo 2021), (Feil et al. 2022), (Mengistu and Panizzolo 2023a), (Utama and Abirfatin 2023), (Rosiani et al. 2024)
14	#	HB	✓		DV	UL	$I_{total} = I_{erg} + I_{EHS}$ I_{total} = Total number of suggested improvements, I_{erg} = Number of suggested improvements in ergonomics interventions, I_{EHS} = Number of suggested improvements in EHS (Environmental, Health, and Safety) issues	(Kravchenko et al. 2019), (Mengistu and Panizzolo 2021), (Mengistu and Panizzolo 2023a)
15	%	HB	✓		0	100	$P_{iep} = \frac{I_e}{I_t} \times 100$ P_{iep} = Percentage of incentives and promotions related to ergonomically and environmentally friendly designed processes, I_e = Number of incentives and promotions related to ergonomically and environmentally friendly designed processes in the year, I_t = Total number of incentives and promotions in the year	(Dočekalová and Kocmanová 2016), (Helleno et al. 2017), (Kocmanová et al. 2017), (Swarnakar et al. 2021)
16	%	HB	✓		0	100	$P_m = \frac{E_m}{E_t} \times 100$ P_m = Percentage of employees participating in managerial decisions, E_m = Number of employees participating in managerial decisions, E_t = Total employees involved in the manufacturing of goods in a year	(Kravchenko et al. 2019), (Schögggl et al. 2016)
17	%	HB	✓		0	100	$P_i = \frac{I_{preEHS} - I_{postEHS}}{I_{preEHS}} \times 100$ P_i = Improvement Percentage, I_{preEHS} = Number of EHS (Environmental, Health, and Safety) issues before training, $I_{postEHS}$ = Number of EHS issues after training	(Loeppke et al. 2015), (Schögggl et al. 2016), (Popovic et al. 2018), (Mengistu and Panizzolo 2021), (Feil et al. 2022), (Utama and Abirfatin 2023), (Mengistu and Panizzolo 2023a), (Mengistu and Panizzolo 2023b), (Rosiani et al. 2024)
18	%	LB		✓	0	100	$P_t = \frac{E_r}{E_t - E_{rt}} \times 100$ P_t = Percentage of turnover rate of employees, E_r = Number of employees resigning, E_t = Total employees involved in the manufacturing of goods, E_{rt} = Number of employees retiring	(Kocmanová et al. 2017), (Helleno et al. 2017), (Popovic et al. 2018), (Kravchenko et al. 2019), (Mengistu and Panizzolo 2021), (Swarnakar et al. 2021)
19	%	HB	✓		0	100	$P_s = \frac{E_s}{E_t} \times 100$ P_s = Percentage of employees who are satisfied with their work, E_s = Number of employees satisfied with their work, E_t = Total employees involved in the manufacturing of goods	(Valenzuela-Venegas et al. 2016), (Swarnakar et al. 2021), (Mengistu and Panizzolo 2021), (Feil et al. 2022), (Mengistu and Panizzolo 2023a), (Mengistu and Panizzolo 2023b), (Utama and Abirfatin 2023), (Rosiani et al. 2024)

EIs	Units	Tr	Ind Type		Range		Formulas	Reference
			Led	Lag	Min	Max		
20	#	LB		✓	0	DV	$C_{ndw} = C_p + C_{ps} + C_o$ C_{ndw} = Total number of complaints due to working conditions not covered by decent work, C_p = Complaints due to physical working conditions, C_{ps} = Complaints due to psychosocial working conditions, C_o = Complaints due to other working conditions	(Popovic et al. 2018), (Kravchenko et al. 2019), (Mengistu and Panizzolo 2021), (Mengistu and Panizzolo 2023b), (Utama and Abirfatin 2023)

Key: EIs: Ergonomics indicators, Tr: Trend, Ind: Indicator, Led: Leading, Lg: Lagging, DV: Define value, UL: Unlimited

2.3 Assessment Stage

The score of each EIs is normalized into dimensionless quantities owing to the different units of measurements. This step is essential for joint comparison and analysis of EIs. The sustainable ergonomic evaluation of a manufacturing system is a complex MCDM process that comes with interactions and interdependencies among the indicators. For example, the cost of environmental, health, and safety (EHS) non-compliance (economic) is directly related to complaints from community indicators (environmental). Higher non-compliance will lead to more community complaints, and vice versa. Therefore, in a sustainable ergonomics performance assessment framework, EIs values must be normalized and aggregated into a single score using the MCDM method. This step accounts for the interactions and interdependencies between the EIs. In this study, the Grey Relation Analysis (GRA) method was used for normalization and aggregation. A comparative analysis of various MCDM methods has been reported in the literature (Saad et al. 2019; Saad et al. 2020; Saad et al. 2021), and it was concluded that the GRA method is easy to use and useful for evaluating organizational performance. Furthermore, the GRA method shows minimal sensitivity to negligible variations in indicator values that may occur during the evaluation process. The GRA method assesses the performance of alternatives by quantifying the similarity or discrepancy between the two sequences (Zhao et al. 2016). When working with m alternatives and n indicators, the GRA method follows a specific set of steps (Kuo et al. 2008).

1. Normalization of EIs score values

$$x_{ij} = \frac{y_{ij} - \min\{y_{ij}, i=1,2,\dots,m\}}{\max\{y_{ij}, i=1,2,\dots,m\} - \min\{y_{ij}, i=1,2,\dots,m\}} \quad (6)$$

for $i = 1, 2, \dots, m$ $j = 1, 2, \dots, n$

$$x_{ij} = \frac{\max\{y_{ij}, i=1,2,\dots,m\} - y_{ij}}{\max\{y_{ij}, i=1,2,\dots,m\} - \min\{y_{ij}, i=1,2,\dots,m\}} \quad (7)$$

for $i = 1, 2, \dots, m$ $j = 1, 2, \dots, n$

where, y_{ij} is the value i^{th} alternative under j^{th} indicator, and x_{ij} is the normalized value of i^{th} alternative under j^{th} indicator. For higher the better (HB) and lower the better (LB), EIs Equations 6 and 7 are used, respectively.

2. Determine the ideal (reference) sequence

The ideal sequence (X_0) is defined as

$$(x_{01}, x_{02}, x_{03}, \dots, x_{0j}, \dots, x_{0n}) = (1, 1, 1, \dots, 1, \dots, 1)$$

3. Computation of GRA coefficient

The following Equation 8 is used for calculating the relative closeness of x_{ij} to x_{0j} by calculating the GRA coefficient.

$$\gamma(x_{0j}, x_{ij}) = \frac{\Delta_{min} + \zeta \Delta_{max}}{\Delta_{ij} + \zeta \Delta_{max}} \quad (8)$$

for $i = 1, 2, \dots, m$ $j = 1, 2, \dots, n$

where, $\gamma(x_{0j}, x_{ij})$ is the GRA coefficient lies between the x_{0j} and x_{ij} , $\zeta \in [0,1]$ is the distinguishing coefficient typically set to 0.5, $\Delta_{ij} = |x_{ij} - x_{0j}|$, and Δ_{min} and Δ_{max} are the minimum and maximum values of Δ_{ij} across all alternatives and criteria.

4. Computation of GRA grade (aggregation)

$$\Gamma(X_o, X_i) = \sum_{j=1}^n w_j \gamma(x_{0j}, x_{ij}) \quad (9)$$

for $i = 1, 2, \dots, m$

where, w_j is the weight of indicator j , and $\Gamma(X_o, X_i)$ is the aggregated score.

Performance Benchmarking Tool: Another contribution of this study is the design of a performance benchmarking tool that can be used to evaluate and compare the sustainable ergonomics performance of manufacturing organizations. This tool is not only helpful for Western buyers to monitor their supplier performance, and a reference point(s) can be defined against which company is evaluated. Furthermore, this benchmarking tool is very important because it guides decision makers and policymakers on best practices, enhances transparency and consistency in organizational performance, and raises awareness to drive improvements and competitiveness.

The absence of a benchmarking tool may lead to the recognition of low performing organizations, resulting in undesirable and misleading results (Alliance 2020). In the proposed performance benchmarking tool, a standard deviation is used to determine the scatter of the performance scores of the participating manufacturing organizations. The standard deviation (σ) is calculated as follows:

$$\sigma = \sqrt{\frac{\sum_{i=1}^N (x_i - \mu)^2}{N}} \quad (10)$$

Where, N is the size of participated manufacturing organizations, x_i is the performance score, and μ is the mean of performance score. The σ creates the thresholds values as shown in Figure 4. These values helps to determine the performance level of participated organizations either meet the specific value, based on this value a performance rating is awarded to the organizations. This approach is vital and it can be used to evaluate the performance of similar types of organizations and then order them from highest to lowest against the benchmark. These benchmark results also allow participating organizations to analyze their deficiencies in workstation practices.

Organizations are rated based on aggregated scores using σ from the average. The standard deviation measures data dispersion around the average but does not indicate the magnitude of the sample data, offering insights into specific data characteristics (Montgomery 2020). Figure 4 shown the rating categories as ‘top performer’, ‘valued performer’, ‘average performer’, ‘developing performer’, and ‘early stage performer’. Organizations with scores within one standard deviation above or below the average are considered average performers. Organizations with scores greater than the average by one standard deviation but less than two standard deviations are classified as high-valued performers. Organizations that exceed the average by more than two standard deviations are considered top performers. Conversely, organizations with scores lower than the average by one–two standard deviations are regarded as developing performers, indicating the need for improvement. Those scoring more than two standard deviations below the average were classified as early stage developing performers, requiring significant enhancements in their EIs to improve their overall sustainable ergonomics performance. Western buyers can establish a socially sustainable supply chain by giving orders to organizations whose ratings fall below the average, valued, or top performer range. This encourages them to further improve their performance.

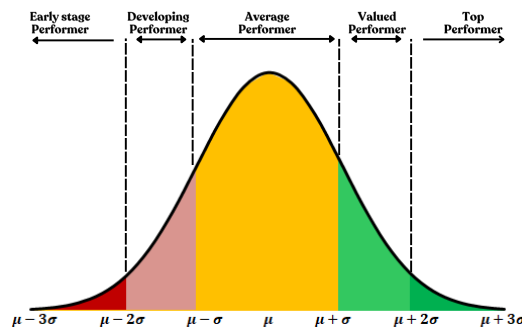


Figure 4. Organizations rating categories based on statistical benchmarking method

3. Case Study

This section presents an empirical study to test the sustainable ergonomics performance assessment framework for textile-based organizations. All the participating organizations are exporters of goods to Western buyers, hold international certifications of ISO 9001, ISO 14001, ISO 45001, ISO 5001, or SA 8000, and have more than 500 employees. A purposive sampling technique (Patton 2002) was employed, involving the human resource departments of manufacturing organizations in the data collection process. This study specifically targeted textile-based organizations that were willing to provide data based on performance scorecard sheet (Table 3). The sample frame consisted of 50 potential textile-based organizations in Pakistan. All shortlisted organizations were approached

through their human resource departments for data collection, and 23 organizations responded. The responding organizations produce various goods (such as apparel, denim jeans, T-shirts, polo shirts, sportswear and activewear, knitwear, hosiery, industrial worker uniform, and safety fabrics) for export to Western buyers, including Germany, Spain, the Netherlands, the United Kingdom, and the United States.

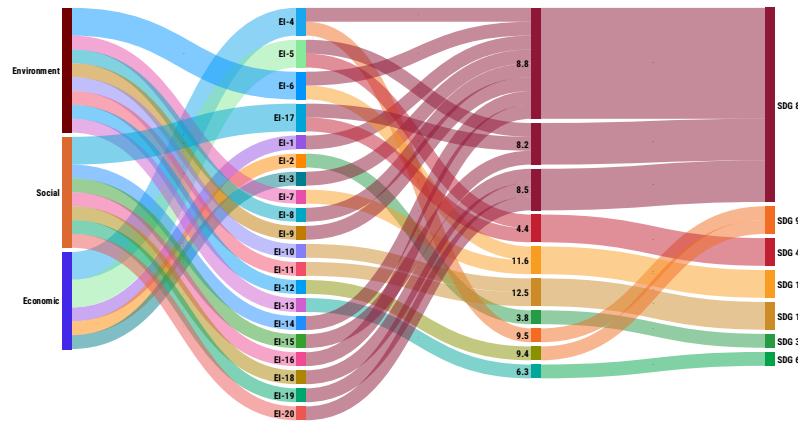


Figure 5. Relationship between EIs and SDGs

Twenty new EIs are proposed in this study, as shown in Figure 3. The proposed indicators are simple and easy to understand by non-experts, and they are easily quantifiable using a performance scorecard sheet (Table 3). Furthermore, these newly proposed EIs contribute directly to achieving the sustainability agenda 2030. A four-level Sankey diagram was created to visualize the relationship between the newly proposed EIs and the United Nations 2030 Agenda SDGs and targets. The nodes represent the main dimensions of the TBL, EIs, sustainable development targets, and goals. Figure 5 shows the direct linkages, highlighting the contributions to ten SDG targets and seven goals. The social dimension, with seven indicators, provided the most information for the SDGs, contributing to four targets and two SDGs. The environment and economic dimensions also make significant contributions, impacting six targets and five SDGs, and five targets and four goals, respectively. Data from EIs measuring sustainable ergonomics assessment significantly support SDG 8 ("decent work and economic growth"), followed by SDGs 4, 9, 11, 12, 3, and 6. The Sankey diagram effectively shows how assessing TBL dimensions through their indicators contributes to sustainable development, suggesting that it may be easier to manage manufacturing sustainability through these dimensions rather than directly through the SDG framework.

The summarized information of the collected data, such as mean, standard deviation, maximum, and minimum values of each newly proposed 20 EIs from different textile-based organizations are presented in Table 4. The details of the subjective (expert opinions), objective (entropy weight method), and combined (weighted arithmetic average method) methods are also presented in Table 4. The subjective weights were calculated using a questionnaire (Section 2.2), and objective weights were calculated based on the collected data values against each EIs from textile-based organizations. Finally, the GRA method was used to calculate the normalized and aggregated scores of the participating organizations (Table 5). Organization *NC* performed best in terms of overall sustainable ergonomic practices, with a score of 0.714. Conversely, the organization's *SP* score was poor (0.478) and performed the worst in applying sustainable ergonomic practices.

Table 4. Summary of twenty newly proposed EIs with descriptive statistics and assigned weights

EIs	Units	Mean	Standard Deviation	Max	Min	M_j	E_j	Cw_j
1	\$	1034	1538	6480	0	0.0630	0.0461	0.055
2	\$	5	14	69	0	0.0588	0.0880	0.073
3	\$	2	2	7	0	0.0521	0.0346	0.043
4	\$	18	41	191	0	0.0504	0.0746	0.063
5	\$	11	29	126	0	0.0538	0.0916	0.073
6	#	2	1	5	0	0.0580	0.0076	0.033

EIs	Units	Mean	Standard Deviation	Max	Min	M_j	E_j	Cw_j
7	#	76	71	333	12	0.0538	0.0197	0.037
8	#	345	665	2630	4	0.0487	0.0619	0.055
9	#	88	117	500	0	0.0521	0.0376	0.045
10	%	0	1	6	0	0.0395	0.0983	0.069
11	%	1	1	3	0	0.0345	0.0127	0.024
12	%	76	4	82	69	0.0445	0.0001	0.022
13	%	11	3	16	6	0.0437	0.0017	0.023
14	#	31	44	150	0	0.0479	0.0514	0.050
15	%	24	39	100	0	0.0504	0.0719	0.061
16	%	1	1	2	0	0.0479	0.0505	0.049
17	%	65	19	100	34	0.0462	0.0024	0.024
18	%	9	14	60	0	0.0471	0.0528	0.050
19	%	12	28	98	0	0.0479	0.1036	0.076
20	#	23	52	200	0	0.0597	0.0928	0.076

Table 5. Aggregated score of participated 23 textile-based organizations

Organizations	$\Gamma(X_o, X_t)$	Organizations	$\Gamma(X_o, X_t)$
MD	0.607	SP	0.478
MY	0.529	SH	0.565
UD	0.669	SF	0.558
NS	0.567	NM	0.583
KL	0.631	IH	0.533
IL	0.563	TI	0.579
CF	0.514	NG	0.602
EA	0.601	NC	0.714
IT	0.562	TY	0.549
MT	0.503	AI	0.512
MK	0.555	AA	0.595
ST	0.502		

After calculating the score of each participating organization, a statistical benchmarking method was used for benchmarking the participating organizations, as explained in Section 2.3 (Figure 6). There is only one organization, *NC*, which lies under the top performer rating, while organizations *ST*, *MT*, and *SP* are under developing performer rating ranges, indicating that these organizations need significant improvement for improving sustainable ergonomic practices. It is evident from Figure 6 that most of the organizations lie under average performer ratings, indicating that organizations need to further enhance their scores by focusing on weak workstation areas, as highlighted by EIs scores. Thus, this tool is useful for Western buyers to assess their suppliers to comply with the *sustainability due diligence* directive.

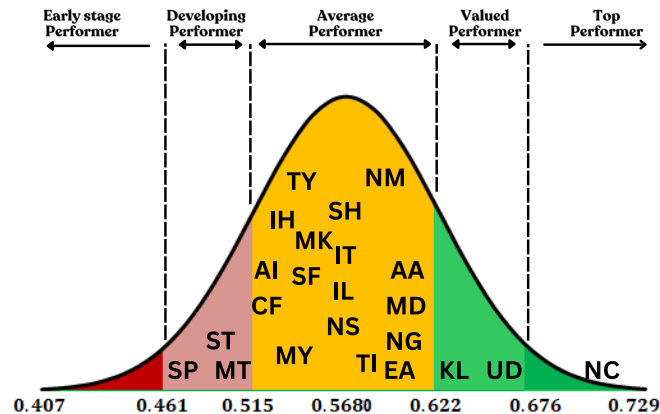


Figure 6. Participated textile-based organizations rating based on aggregated performance score calculated by GRA

4. Conclusion

This study proposed and successfully implemented a sustainable ergonomics assessment framework based on EIs to measure organizational performance. A novel approach was used to investigate and calculate the textile-based organization score based on EIs and rank them for benchmarking purposes. The data values were calculated based on the performance scorecard sheet, and weights were assigned by combining subjective and objective weight methods to overcome the biases and variations in the data values. Later, an MCDM technique, GRA, was used to measure the scores and rankings of organizations.

The findings indicate that 73.91% of the participating organizations lie under the average performer range with score values between 0.515 and 0.622, while 13.04% of the participating organizations lie under the developing performer range with score values between 0.461 and 0.515. Notably, only one organization attained a high performance score (0.714). These findings provide valuable insights for industry stakeholders/ western buyers, highlighting areas requiring improvement and guiding strategic actions to enhance sustainable ergonomics performance in manufacturing organizations.

This study had some limitations. The fundamental limitation is that this study only considered textile-based organizations for the empirical validation of the proposed framework. In future work, this can be extended to other types of manufacturing organization evaluations and benchmarking. Inclusion and exclusion criteria can be revisited for the proposal of EIs. Finally, other weighting methods can be incorporated, and sensitivity analysis can be performed to optimize the weighting of the EIs.

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