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Key Performance Indicators (KPIs) for Sustainable Manufacturing Evaluation in Apparel Industry

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Abstract

Currently, the garment industry in Bangladesh accounts for 78% of all foreign revenues. This industry employs more than 4.2 million people, and there are roughly 5000 garment manufacturers located all throughout the nation. About 80% of the employees are women, and they work from dawn to dusk or, in cases where working conditions are subpar. In many cases, companies lack facilities for child care, health care, and sufficient training. Competitiveness and uncertainties are increasing because of the Fourth Industrial Revolution (IR 4.0) as well as climate change. Amelioration in the global market could be fulfilled by practicing sustainable manufacturing in production. Sustainability or sustainable development in manufacturing and services has attracted the attention of various business practitioners. The concept of sustainable manufacturing (SM) is becoming increasingly mature due to the focus on many of its research topics for a long time. In this connection, this research study has been conducted with the purpose of identifying the most important key performance indicators (KPIs) of SM for the apparel industry. To measure the importance or priority ranking of these KPIs, Analytic Hierarchy Process (AHP) method has been used. Finally, all the KPIs have been evaluated with respect to the subjected field and a ranking has been performed amongst the relevant KPIs based on the global priority vector.

Keywords
Sustainable Manufacturing (SM), Ready-made Garments (RMG), Key Performance Indicators (KPIs) and Analytic Hierarchy Process (AHP).

1. Introduction
The primary economic mainstay for many years was agriculture in Bangladesh. But during the past few decades, the industrial sector has experienced substantial growth and improved prospects. This industrial sector is the key to contributing to Bangladesh becoming a developing country and the economy is now greatly dependent on industrial products. Among all these numerous types of industry, the garments and textile sector make up the major part. The tremendous growth in the garments sector in this country over the last few years has dramatically changed the proportion of export composition in the country. Once the export was heavily dependent on the products of jute, but the economy of Bangladesh in 2021-2022 is experiencing almost 81.82% export contribution worth $42.61 billion from the garment sector (The Bangladesh Garments Manufacturer and Exporters Association (BGMEA)). This clearly indicates that this sector has occupied a prominent place in Bangladesh's economy. With the blessing of cheap labor, Bangladesh has become one of the global players in international trade in readymade garments. Again, the competition with other Asian countries like China, India, and Vietnam is getting harder day by day as technological advancement is availing to meet the high productivity with high quality at a low price. Hence, Sustainable manufacturing efforts generally aim to decrease resource consumption through improved efficiency in manufacturing processes, eliminate unnecessary resource use, and decrease the amount of waste and emissions produced through manufacturing activities. There is a growing interest by companies to discover the benefits of sustainable manufacturing throughout their manufacturing processes. Sustainable manufacturing is an important concerning issue in every manufacturing industry. Companies pursue sustainable manufacturing for the following main reasons:

1. The economic gains that are realized as a result of their, initiatives
2. The social commitment it demonstrates to their community and tostakeholders
3. To meet regulatory requirements and to use fewer resources and hazardouschemicals

4. To meet consumer expectations
5. Awards and media attention garnered by initiatives, and
6. Hiring gains due to being a successful sustainable manufacturing company.

Sustainable manufacturing is now playing an important role in every manufacturingindustry.Many ofBangladeshiRMG factories are being concerned on sustainablemanufacturing and some of these are practicing that. Economic growth, social wellbeing and environmental performance are the three main dimensions andtechnological advancement is also considered as additional dimension of sustainablemanufacturing. These are divided into different sub-dimensions in sustainablemanufacturing hierarchical framework.

1.1 Objectives

This study attempted to address several objectives, regarding sustainable manufacturing in readymade garments. The key objectives of this research work are as follows:

i. to study the sustainable manufacturing practice of selected RMG factories,
ii. to find out the KPIs for the woven apparel manufacturing industry to gain sustainability,
iii. to evaluate and rank among the bottom-level KPIs of the hierarchical framework based on their global priority vector, and
iv. to compare the result with other manufacturing industrial sectors.

2. Literature Review

2.1 Sustainable Manufacturing

Sustainable Manufacturing is defined as the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers, and are economically sound (United States Environmental Protection Agency). For every industry to remain viable in the global market, sustainable manufacturing practices are crucial. The sustainability or sustainable development in manufacturing and services has attracted the attention of various business practitioners and several research projects and many documents related to them have been published (Rosen and Kishawy 2012). Sustainable Manufacturing is also defined as a systematic approach to the creation and distribution (supply chain) of innovative products and services that: “minimizes resources (inputs such as materials, energy, water, and land); eliminates toxic substances; and produces zero waste that in effect reduces greenhouse gases, e.g., carbon intensity, across the entire life cycle of products and services” (Rachuri et al. 2010).

2.2 Sustainable Manufacturing Indicators

An indicator set is a collection of indicators that together form a comprehensive picture of sustainability. Indicators can point out ways to advance the company's sustainability. NIST divides sustainability into five categories: technological advancement and performance management are two additional aspects, in addition to the three core categories of economic, environmental, and social as shown in Figure 1 (Joung 2013).

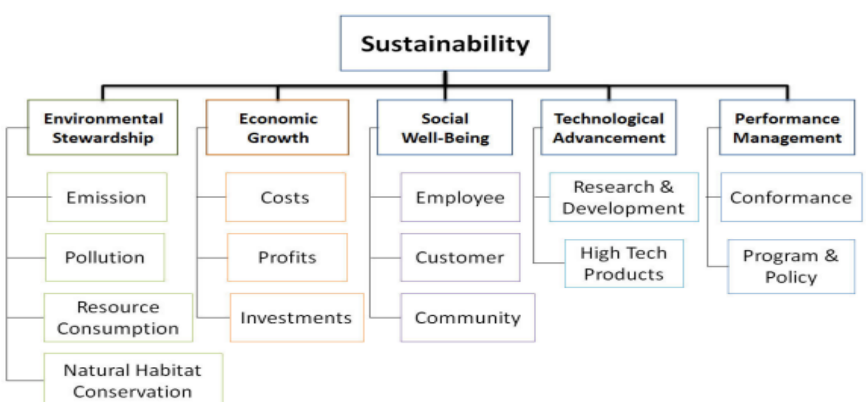

Figure 1. NIST indicator categorization structure of sustainability.

2.3 Concept of Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a theory of measurement based on pairwise comparisons, and it uses expert opinions to determine priority scales (Saaty 2000). When comparing two elements, an absolute judgment scale is used to quantify how much more one element predominates over the other in terms of a particular attribute. The judgments may be inconsistent, and how to measure inconsistency and improve the judgments, when possible, to obtain better consistency is a concern of the AHP. The derived priority scales are synthesized by multiplying them by the priority of their parent nodes and adding for all such nodes.

An AHP hierarchy is a structured means of modeling the decision at hand. It consists of an overall goal, a group of options or alternatives for reaching the goal, and a group of factors or criteria that relate the alternatives to the goal. The criteria can be further broken down into sub-criteria, sub-sub criteria, and so on, on as many levels as the problem requires.

The AHP is frequently utilized for making complicated decisions. The AHP aims to support organizational decisions (Li et al. 2011; Baykasolu et al. 2009), shared decision-making (Dolan et al. 2013; Kitamura 2010), decisions on clinical guidelines (Singh et al. 2006, van Til et al. 2008), decisions on the development of new technology (Hilgerink et al. 2011; Kim et al. 2009), and decisions on the healthcare system (Hummel et al. 2012; Smith et al. 2010). However, AHP is also utilized by manufacturing companies to evaluate their sustainable manufacturing practices (Ocampo et al. 2015).

3. Methods

The research has been conducted as a series of activities performed step by step as shown in Figure 2.

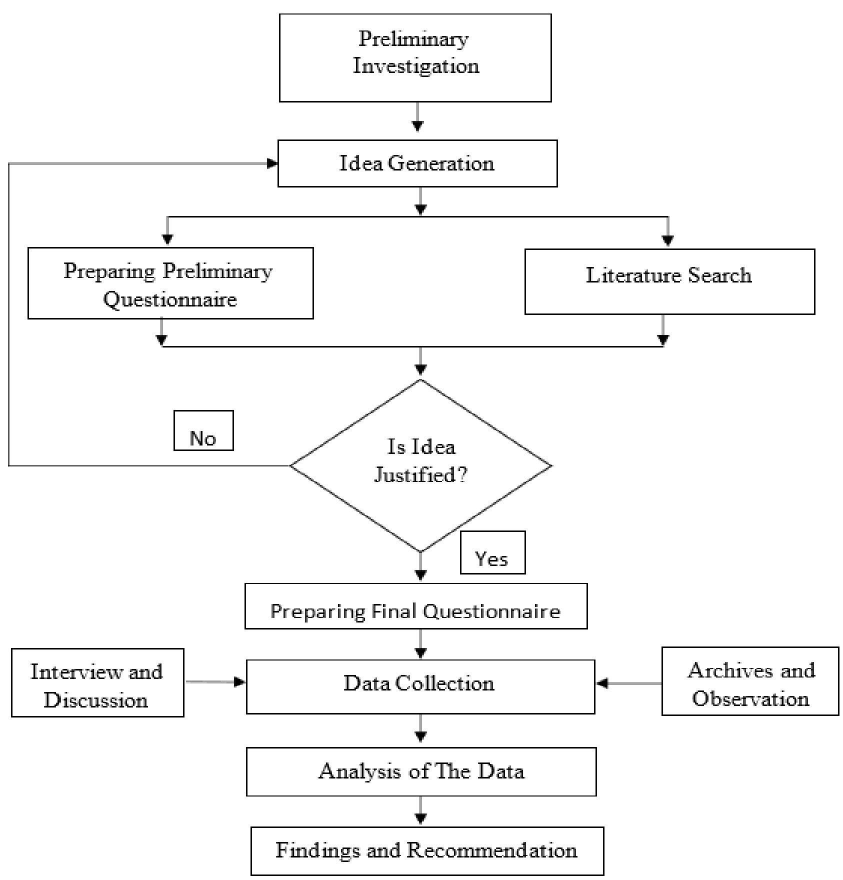

Figure 2. Methodology of study

4. Data Collection and Analysis

Data were gathered from two industries in this sector. Senior representatives of the organization's production engineering, operation planning, and research disciplines offered their opinions. Based on their opinions, the NIST's framework has been redesigned. The redesigned hierarchical framework of sustainable manufacturing, depicted in Figure 4, served as the foundation for the questionnaire.

The scored values (judgments) have been systematically formatted for ease of calculation. The AHP method was applied to analyze the data. In order to select the most appropriate KPIs of sustainable manufacturing practice, the AHP methodology has been used for data analysis. Based on the guidelines, an AHP framework has been developed for facilitating the study as shown in Figure 3 (Saaty 2008).

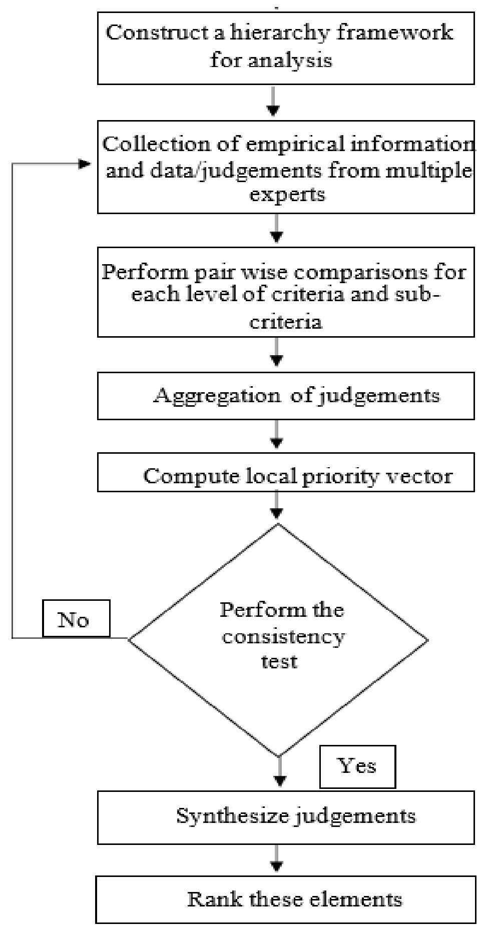

Figure 3. Steps for conducting an AHP study

4.1 Hierarchical Framework for Analysis

The dominance hierarchy is commonly used, which states that an item at the top of the hierarchy dominates items at levels below it, which in turn dominates items at levels below that, and so on. This kind of hierarchy is comparable to the widely used organograms that are used to describe organizational systems and may also be seen as a pyramid structure. The framework contains four levels. The top level (level 0) of the hierarchy represents the defined objective of sustainable manufacturing practice of the selected woven apparel manufacturing industry. The second level (level 1) has four main criteria followed by various sub-criteria which are environmental performance, economical performance, and social performance technological advancement. Level 2 contains 13 sub-criteria, and level 3 contains an additional 23 sub-criteria.

4.2 Collection of Empirical Information

Data have been obtained through the judgments of the evaluators from the selected industry. Two teams of top-positioned members scored in the questionnaire. The first team was from the main unit of the industry and the other team was from another unit of this industry. The questionnaire followed a pairwise comparison process, where the element in each row was compared with the elements in each column, one by one, with regard to a common element in the next higher level (entered in the top left corner of the matrix). Two questions require answers: (1) Is the importance of the element in the row greater or less than that of the element in the column? (Does it carry more or less weight or does it matter more or less?); and (2) How much more or less important is it? (By how much does it matter more or less?). For the second question, a value is assigned according to the Fundamental Scale of the AHP for pairwise comparisons, as presented in Table 1.

Table 1.Scale of relative preference for pairwise comparison

AHP Scale of Importance for comparison pair (aij)	Numeric Rating	Reciprocal (decimal)
Extreme Importance	9	1/9 (0.111)
Very strong to extremely	8	1/8 (0.125)
Very strong Importance	7	1/7 (0.143)
Strongly to to very strong	6	1/6(0.167)
Strong Importance	5	1/5(0.200)
Moderately to Strong	4	1/4(0.250)
Moderate Importance	3	1/3(0.333)
Equally to Moderately	2	1/2(0.500)
Equal Importance	1	1 (1.000)

4.3 Pairwise Comparisons for Each Level of Criteria and Sub-Criteria

Two sets of pairwise comparisons have been judged by decision-makers from two different units of the industry. 3rd level elements with respect to 2nd level parent element, 2nd elements with respect to 1st level parent element, and 1st level elements with respect to 0th level parent elements were judged in the questionnaire. These sum up to 27 pairwise comparison matrices. Sustainable manufacturing is decomposed into four criteria of environmental performance, economical performance, social performance, and technological advancement as shown in Figure 4. Tables 2 and 3 show pairwise comparison matrices of sustainable manufacturing in terms of pairwise comparison matrices by 1st unit's and 2nd unit's decision makers of the industry respectively.

Table 2. Pairwise comparison matrix of sustainable manufacturing (1st unit)

Sustainable Manufacturing	Environmental Performance	Economical Performance	Social Performance	Technological Advancement
Environmental Performance	1	1/8	1/7	1/5
Economical Performance	8	1	5	4
Social Performance	7	1/5	1	1/3
Technological Advancement	5	1/4	3	1

Table 3. Pairwise comparison matrix of sustainable manufacturing (2nd unit)

Sustainable Manufacturing	Environmental Performance	Economical Performance	Social Performance	Technological Advancement
Environmental Performance	1	1/7	1/5	1
Economical Performance	7	1	6	7
Social Performance	5	1/6	1	2
Technological Advancement	1	1/7	1/2	1

4.4 Aggregation of Judgements

The judgments were then aggregated using the weighted geometric mean method (WGMM) at each hierarchy level of the framework. This follows,

$$a_{ij} = \prod_{k=1}^{m} \left(a_{ij}^{k}\right)^{a_k} \qquad (1)$$

Here,
a_{ij}= the aggregated judgment,
a_k= the decision-maker's importance to the decision making process (with $a_k>0$ and $\Sigma a_k = 1$)
In aggregating judgments of decision-makers, equation (1) is used with $\alpha_1 = 0.6$ and $\alpha_2= 0.4$

For example, the aggregate value of Environmental Performance vs Economical Performance is calculated as-

$$a_{ij} = \prod_{k=1}^{2} \left(a_{ij}^{k}\right)^{a_k}$$
$$= \left(\frac{1}{8}\right)^{0.6} \times \left(\frac{1}{7}\right)^{0.4}$$
$$= 0.131835$$

The aggregated values of various sustainable manufacturing criteria are shown in Table 4 below in an aggregated pairwise comparison matrix.

Table 4. Aggregated pairwise comparison matrix of sustainable manufacturing

Sustainable Manufacturing	Environmental Performance	Economical Performance	Social Performance	Technological Advancement
EnvironmentalPerformance	1	0.131858	0.163438	0.380731
EconomicalPerformance	7.583911	1	5.378269	5.003515
Social Performance	6.118526	0.185933	1	0.333333
TechnologicalAdvancement	2.626528	0.199859	3	1

4.5 Local Priority Vector

The computation of local priority vector is performed through several steps.
Step 1: Sum the values in each column
Step 2: Divide each element of the matrix by its column total
Step 3: Average the elements in each row, which is called priority vector

The calculated priority vectors of various sustainable manufacturing criteria are tabulated in Table 5 below and it clearly shows that economical performance has the highest priority vector.The rest of the values in this matrix shown here in Table 5 were calculated from steps 1 and 2.

Table 5. Priority vector of first level elements

Sustainable Manufacturing	Environmental Performance	Economical Performance	Social Performance	Technological Advancement	Priority Vector
Environmental Performance	0.057707	0.086883	0.017129	0.056677	0.054599
Economical Performance	0.437644	0.658913	0.563659	0.744839	0.601264
Social Performance	0.353081	0.122514	0.104803	0.049621	0.157505
Technological Advancement	0.151569	0.13169	0.314409	0.148863	0.186633

4.6 Consistency Test

The consistency of the aggregated judgments is checked by the several steps. It is described for the aggregatedsustainable manufacturing criteria as follows:

Step 1: Multiply each value in the first column of the pairwise comparison matrix by the relative priority of the first item considered. The same procedures are for other items. Sum the values across the rows to obtain a vector of values labeled “weighted sum”.

$$0.054599\begin{bmatrix}0.057707\\0.437644\\0.353081\\0.151569\end{bmatrix} + 0.601264\begin{bmatrix}0.086883\\0.658913\\0.122514\\0.13169\end{bmatrix} + 0.157505\begin{bmatrix}0.017129\\0.563659\\0.104803\\0.314409\end{bmatrix} + 0.186633\begin{bmatrix}0.056677\\0.744839\\0.049621\\0.148863\end{bmatrix}$$

$$=\begin{bmatrix}0.230679\\2.796259\\0.665575\\0.5613\end{bmatrix}$$

Step 2: Compute the sum of the values (weighted sums) computed in step 1 as λ_{max}.

$$\lambda_{max} = 0.0230679 + 2.796259 + 0.665575 + 0.5613 = 4.253814$$

Step 3: Compute the consistency index (CI).

$$CI = \frac{\lambda_{max} - n}{n-1} = \frac{4.253814 - 4}{4-1} = 0.084605$$

Step 4: Compute the Random index (RI).
It is the consistency index of a randomly generated pairwise comparison matrix. RI depends on the number of elements being compared (i.e., size of pairwise comparison matrix).

$$RI = \frac{1.98\,(n-2)}{n} = \frac{1.98\,(4-2)}{4} = 0.99$$

Step 5: Compute the consistency ratio (CR).

$$CR = \frac{CI}{RI} = \frac{0.084605}{0.99} = 0.085459 \leq 0.10$$

CR should not be more than 0.10 or 10 percent. So, the degree of consistency exhibited in the pairwise comparison matrix for sustainable manufacturing criteria is acceptable.

4.7Other Aggregated Pairwise Comparison Matrices with Priority Vector & Consistency Ratio(CR)

The aggregated values of various environmental performance's elements and priority vectors are shown in Table 6 in an aggregated pairwise comparison matrix. The CR value of this matrix is 0.001306.

Table 6. Aggregated pairwise comparison matrix of environmental performance and priority vector of its elements

Environmental Performance	Pollution	Emission	Resource Consumption	Priority Vector
Pollution	1	1	0.166667	0.122642
Emission	1	1	0.151943	0.11892
Resource Consumption	6	6.581416	1	0.758438

The aggregated value of pollution's element and priority vector are shown in Table 7 in an aggregated pairwise comparison matrix. The CR value of this matrix is 0.00.

Table 7. Aggregated pairwise comparison matrix of pollution and priority vector of its elements

Pollution	Noise Emission	Priority Vector
Noise Emission	1	1

The aggregated value of emission's element and priority vector are shown in Table 8 in an aggregated pairwise comparison matrix. The CR value of this matrix is 0.00.

Table 8. Aggregated pairwise comparison matrix of emission and priority vector of its elements

Emission	Solid Waste Emission	Priority Vector
Solid Waste Emission	1	1

The aggregated values of resource consumption's elements and priority vectors are shown in Table 9 in an aggregated pairwise comparison matrix. The CR value of this matrix is 0.080173.

Table 9. Aggregated pairwise comparison matrix of resource consumption and priority vector of its element

Resource Consumption	Material Consumption	Energy Consumption	Land Use	Priority Vector
Material Consumption	1	5.596066	8.139256	0.748794
Energy Consumption	0.178697	1	3	0.176246
Land Use	0.122861	0.333333	1	0.074959

The aggregated values of economical performance's elements and priority vectors are shown in Table 10 in an aggregated pairwise comparison matrix. The CR value of this matrix is 0.044179.

Table 10. Aggregated pairwise comparison matrix of economical performance and priority vector of its elements

Economical Performance	Profit	Cost	Investment	Priority Vector
Profit	1	5.378269	8	0.749932
Cost	0.185933	1	2.550849	0.170124
Investment	0.125	0.392026	1	0.079943

The aggregated values of profit's elements and priority vectors are shown in Table 11 in an aggregated pairwise comparison matrix. The CR value of this matrix is 0.00.

Table 11. Aggregated pairwise comparison matrix of profit and priority vector of its elements

Profit	Revenue	Profit	Priority Vector
Revenue	1	4.704316	0.824694
Profit	0.212571	1	0.175306

The aggregated values of cost's elements and priority vectors are shown in Table 12 in an aggregated pairwise comparison matrix. The CR value of this matrix is 0.009957.

Table 12. Aggregated pairwise comparison matrix of cost and priority vector of its elements

Cost	Material Acquisition	Production	Product Transfer	EOL Handling	Priority Vector
Material Acquisition	1	1.37973	2.435829	2.832263	0.377044
Production	0.72478	1	3	3	0.339031
Product Transfer	0.410538	0.333333	1	0.333333	0.106724
EOL Handling	0.353075	0.333333	3	1	0.1772

The aggregated values of investment's elements and priority vectors are shown in Table 13 in an aggregated pairwise comparison matrix. The CR value of this matrix is 0.00.

Table 13. Aggregated pairwise comparison matrix of investment and priority vector of its elements

Investment	R & D	Community Development	Priority Vector
R & D	1	4.704316	0.824694
Community Development	0.212571	1	0.175306

The aggregated values of social performance's elements and priority vectors are shown in Table 14 in an aggregated pairwise comparison matrix. The CR value of this matrix is 0.024729.

Table 14. Aggregative pairwise comparison matrix of social performance and priority vector of its elements

Social Performance	Employee	Customer	Supplier	Community	Priority Vector
Employee	1	6.581416	8	2.297397	0.57998
Customer	0.151943	1	1.55185	0.280489	0.089944
Supplier	0.125	0.644394	1	0.333333	0.071668
Community	0.435275	3.565205	3	1	0.258408

The aggregated values of employee's elements and priority vectors are shown in Table 15 in an aggregated pairwise comparison matrix. The CR value of this matrix is 0.082497.

Table 15. Aggregated pairwise comparison matrix of employee and priority vector of its elements

Employee	OHS	Satisfaction	Career Development	Priority Vector
Overall Health & Safety (OHS)	1	0.33	0.14	0.085324
Satisfaction	3	1	0.25	0.213238
Career Development	7	4	1	0.701437

The aggregated values of customer's elements and priority vectors are shown in Table 16 in an aggregated pairwise comparison matrix. The CR value of this matrix is 0.084442.

Table 16. Aggregated pairwise comparison matrix of customer and priority vector of its elements

Customer	HSI	CS	ISRC	Priority Vector
Health & Safety Impacts (HIS)	1	0.33	0.14	0.08331
Customer Satisfaction (CS)	3	1	0.20	0.19319
Inclusion of Specific Right to Customer (ISRC)	7	5	1	0.72351

The aggregated values of supplier's elements and priority vectors are shown in Table 17 in an aggregated pairwise comparison matrix. The CR value of this matrix is 0.001101.

Table 17. Aggregated pairwise comparison matrix of supplier and priority vector of its elements

Supplier	Supplier Certification	Supplier Commitment	SI	Priority Vector
Supplier Certification	1	2.047673	4.373448	0.585119
Supplier Commitment	0.488359	1	1.933182	0.276504
Supplier Initiative (SI)	0.228653	0.517282	1	0.138378

The aggregated values of community's element and priority vector are shown in Table 18 in an aggregated pairwise comparison matrix. The CR value of this matrix is 0.00.

Table 18. Pairwise comparison matrix of community and priority vector of its elements

Community	Justice/Equity	Priority Vector
Justice/Equity	1	1

The aggregated values of technological advancement's elements and priority vectors are shown in Table 19 in an aggregated pairwise comparison matrix. The CR value of this matrix is 0.000003.

Table 19. Aggregated pairwise comparison matrix of technological advancement and priority vector of its elements

TechnologicalAdvancement	R & D Stuff	R & D Expenditure	Technology Import	Priority Vector
R & D Stuff	1	0.644394	2.220643	0.332861
R & D Expenditure	1.551846	1	3.465724	0.517528
Technology Import	0.45032	0.28854	1	0.149611

4.8 Synthesize Judgements

When a priority vector has been determined for each one of the matrices in the analysis, the process of synthesizing the information is carried out. Synthesizing judgments in AHP has been done by weighing the elements being compared in the lower level to an element in the next immediate level, referred to as the parent element, by the priority of that element and adding all parents for each element in the lower level. This is referred to as the distributive mode of the AHP. This can be represented in the form of a hierarchy by-

$$W^T = X^T_{m+3}(X^T_{m+2}\ I)\ X^T_{m+1}$$

Here,
W^T= the global (synthesized) priority vector of the elements in the lowest (or third level in this case), X^T_{m+1}= the local priority vector of the third level elements (the lowest level), X^T_{m+2}= the local priority vector of the second level elements, X^T_{m+3}= the local priority vector of the first level elements, and I= an identity matrix.

For instance, calculation of global priority vector of noise emission:
Here,

local priority vector of noise emission (third level element), X^T_{m+1}= 1 (see table 7)
local priority vector of pollution (second level element), X^T_{m+2}= 0.122642 (see table 6)
local priority vector of environmental performance (first level element), X^T_{m+3}= 0.054599 (see table 5)

So, the global priority vector of noise emission (third level element),

$$W^T = 1 \times 0.122642 \times 0.054599 = 0.006696131$$

4.9 Ranking of Elements

These last level elements are ranked in a decreasing order based on the global (synthesized) priority vector in order to find out the most impactful/critical elements of sustainable manufacturing. The ranking of the top five last-level (level 3) elements is shown in Table 20.

Table 20: Ranking of top five last level elements

Third Level Elements	**Global (synthesized) Priority Vector**	**Ranks**
Revenue	0.371860392	1
R &D Expenditure	0.096587803	2
Profit	0.079046723	3
Career Development	0.064980274	4
R & D Stuff	0.062122847	5

5. Results and Discussion

5.1 Sustainability Indicators

The NIST framework was used as a source of criteria and sub-criteria of sustainable manufacturing practice which is a general framework for all manufacturing industries. Further, the NIST framework was modified by eliminating some indicators which are not related to woven manufacturing based on visiting the selected industry, monitoring the production and business process, and discussing with the top-level employers. It was decomposed into four criteria (environment performance, economical performance, social performance, and technological advancement) and twenty-six sub-criteria as shown in Figure 4.

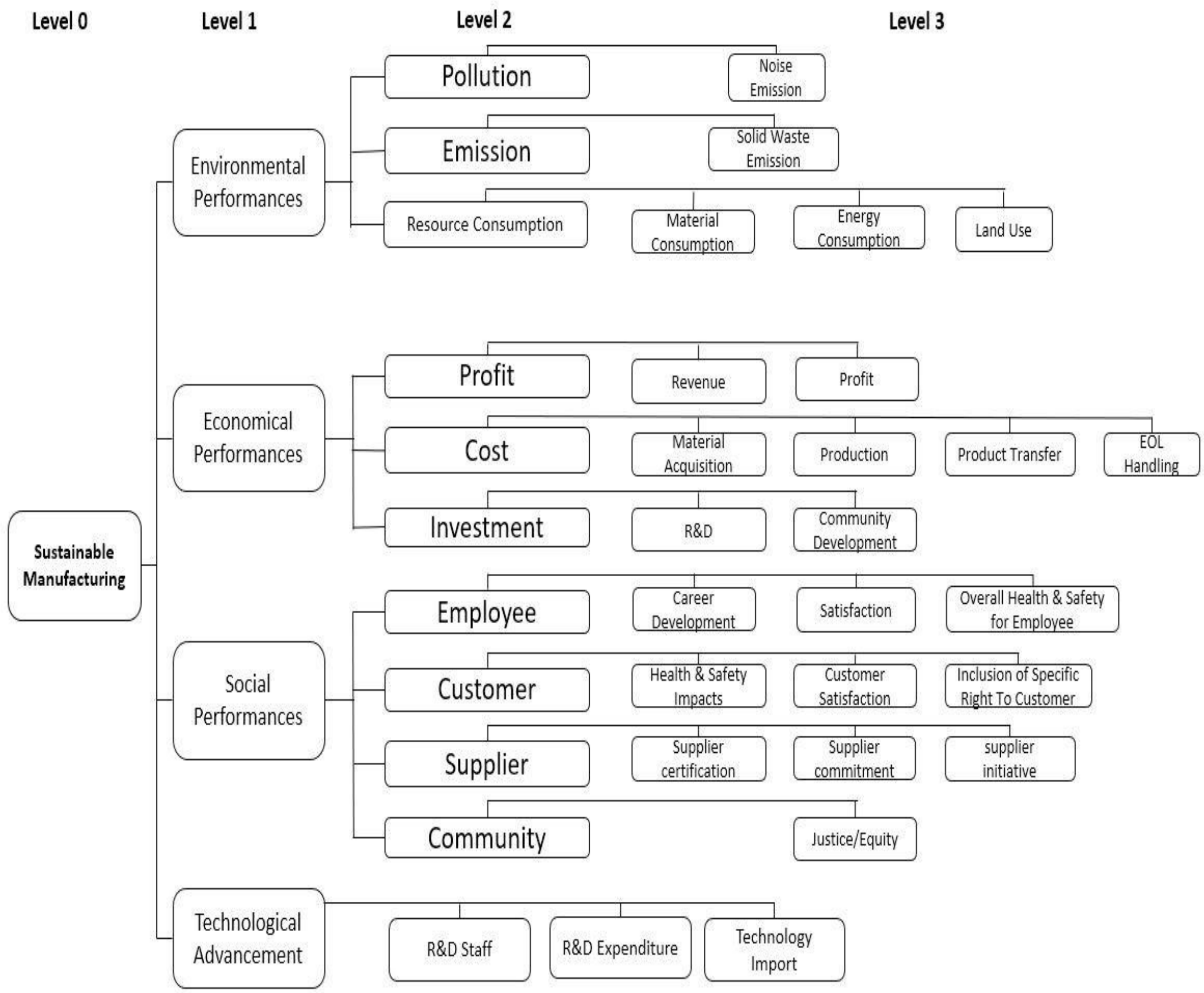

Figure 4. Hierarchical framework for sustainable manufacturing

Natural habitat conservation was eliminated from environment stewardship as it was not relevant. The supplier was also added to social performance. However, economical performance includes profit, cost, and investment; social performance includes employee, customer, supplier, and community; technological advancement includes R & D staff, technology import, and R & D expenditure. Thus, as shown in Figure 4, the second level of the sustainable manufacturing framework consists of pollution, emission, resource consumption, profit, cost, investment, employee, customer, supplier, community, R & D staff, technology import, and R & D.

Third level elements were also followed the NIST framework. Many indicators were eliminated from the framework like toxic substance, greenhouse gas emission, ozone depletion gas emission, acidification substance, effluent, air emission and waste energy those had no impact on this selected sector. The level 3 elements are noise emission, solid waste emission, material consumption, energy consumption, land use, revenue, profit, material acquisition cost, production cost, product transfer cost, EOL handling cost, investment on R & D, investment on community development, overall health & safety of employee, satisfaction of employee, career development of employee, health & safety impacts to customer, customer satisfaction, inclusion of specific right to customer, supplier certification, supplier commitment, supplier initiative, justice/equity for community, R & D stuff for technologicaladvancement, R & D expenditure for technological advancement, and technology import as shown in Figure 4.

5.2 Ranking of Last-Level Elements

As was previously noted, AHP was used to determine which KPIs were most important and to rank them. Two teams of specialists from two units within the chosen sector were given two sets of questionnaires. Three to four professionals from various fields of expertise comprised each team. These both unit ware woven manufacturing industry. The questionnaire was set on a 1 to 9 scale. The data analysis followed a step-by-step approach. Firstly, the judgments were aggregated using the weighted geometric mean method (WGMM) at each hierarchy level of the framework. Secondly, the computation of the local priority vector is performed through several steps like, (a) sum the values in each column of comparison matrix, (b) divide each element of the matrix by its column total, and (c) average the elements in each row. Thirdly, the consistency of the aggregated judgments was checked by several steps like computation of 'weighted sum', λ_{max}, Consistency Index (CI), Random Index (RI), and Consistency Ratio (CR). Then the degree of consistency was also checked. When a priority vector had been determined for each one of the matrices in the analysis the process of synthesizing the information was carried out.On the basis of the synthesized priority vector, these final-level items were sorted in decreasing order.

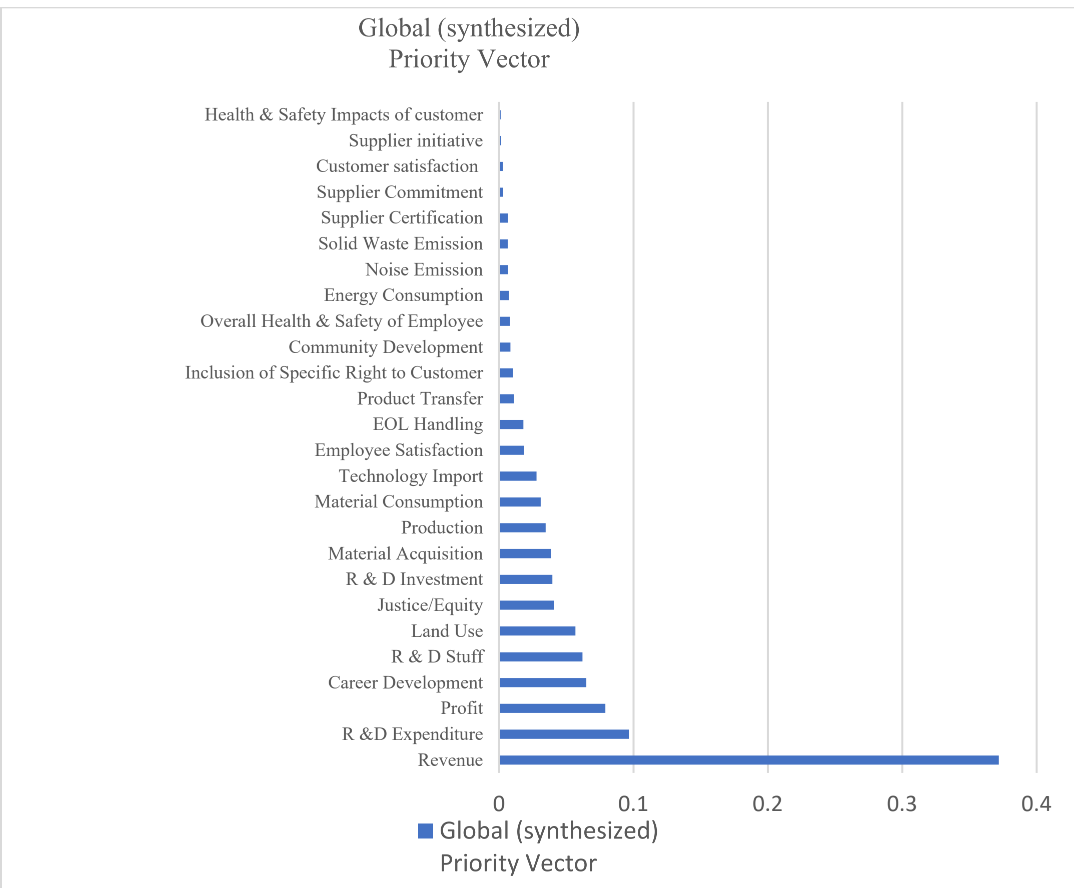

Figure 5. Bar chart showing position of last level elements

Based on the global (synthesized) priority vector, the last level elements of the sustainable manufacturing framework are shown in a bar chart in Figure 5. It is evident from the bar chart that elements with higher priority vectors are positioned in the bottom portion of the chart where every element is showing its individual position in terms of priority vector. Overall, the element 'revenue' has achieved the first rank having the highest score of the global priority vector of 0.371860392, whereas the element 'health & safety impacts of customer' is ranked last with the value of global priority vector of 0.001180194.

Profit is also in the third position. That indicates the importance of profit in economical performance. Second and sixth position was achieved by R & D Expenditure and R & D Stuff respectively which indicate the importance of technological advancement. Career development is also taking fourth place which means the career development of employees is a vital issue for sustainability. Land use, justice/equity for community, R & D investment, and material acquisition cost took seventh, eighth, ninth, and tenth respectively. The rest of the KPIs took different places.

5.3 Comparison with Previous Studies

The result has been compared with the manufacturing firm of the Philippines (Norman and MacDonald 2004). Also, it was compared with the cement manufacturing industry of Indonesia (Amrina and Vilsi 2015). There are both similarities and dissimilarities too among these bottom-level elements of sustainable manufacturing. Some of such final results are listed as shown in Table 21.

Table 21. Top ten bottom level elements of different industries

Ranks	**Bottom Level Elements**	**Selected factories**	
		Manufacturing firms	**Cement industry**
1	Revenue	Revenue	Energy consumption
2	R &D Expenditure	Profit	Material cost
3	Profit	Materials acquisition	Occupational health and safety
4	Career Development	Community development	Inventory cost
5	R & D Stuff	Production	Fuel consumption
6	Land Use	End-of-service-life product handling	Labor cost
7	Justice/Equity	Customer satisfaction from operations and products	Training and education
8	R & D Investment	Health and safety impacts from manufacturing/product use	Accident rate
9	Material Acquisition	Research and development	Raw material substitution
10	Production	Community development programs	Air emission

6. Conclusion

Every manufacturing sector has recognized the value of sustainable manufacturing. The three primary elements of sustainable manufacturing are economic growth, social well-being (performance), and environmental performance. Additionally, technical advancement is taken into consideration. The impact of manufacturing operations on the environment is evident, yet since things must be produced, manufacturing processes must also take place. Therefore, it is now necessary to minimize the negative effects of manufacturing on the environment. Adopting sustainable manufacturing methods or environmentally friendly manufacturing methods has become essential for this aim. On the other hand, profitability as a whole has been affected more by social well-being. Rapid technological advancement also increases the difficulty of the entire business system.

This study demonstrates how these indicators of sustainable manufacturing are related to improved decision-making, which can give businesses a competitive edge. To identify the pertinent key performance indicators (KPIs) and rank them among the bottom-level KPIs of the hierarchical framework based on their global priority vector to achieve sustainability in manufacturing, the research examined the KPIs of selected woven manufacturing industries

The context of the investigation was the woven manufacturing industry. Based on the results so far, additional research can be conducted in a number of directions to deal with more precise outcomes and other KPIs that would make a company more sustainable. Some more factors can be included, such as performance management as a potential additional component of sustainable manufacturing. Data collection for this exploratory study was occasionally hampered by participant's reluctance to provide quantitative information, and the survey's length was also constrained.

References

Amrina, E. and Vilsi, A. L., Key performance indicators for sustainable manufacturing evaluation in cement industry, *Procedia CIRP*, vol. 26, pp. 19-23, 2015.

Baykasoğlu, A., Dereli, T. and Yılankırkan, N., Application of cost/benefit analysis for surgical gown and drape selection: a case study, *American Journal of Infection Control*, vol. 37, no. 3, pp. 215-226, 2009.

Dolan, J. G., Boohaker, E., Allison, J. and Imperiale, T. F., Patients' preferences and priorities regarding colorectal cancer screening, *Medical Decision Making*, vol. 33, no.1, pp. 59-70, 2013.

Hilgerink, M. P., Hummel, M. J., Manohar, S., Vaartjes, S. R. and IJzerman, M. J., Assessment of the added value of the twente photoacoustic mammoscope in breast cancer diagnosis, *Medical Devices: Evidence and Research*, vol. 4,pp.107-115, 2011.

Hummel, M. J., Volz, F., van Manen, J. G., Danner, M., Dintsios, C. M., IJzerman, M. J. and Gerber, A., Using the analytic hierarchy process to elicit patient preferences, *The Patient: Patient-Centered Outcomes Research*, vol. 5, no. 4, pp. 225-237, 2012.

Joung, C. B., Carrell, j., Sarkar, P. and Feng, S. C., Categorization of indicators for sustainable manufacturing, *Ecological Indicators*, vol 24, pp. 148-157, 2013.

Kim, K., Kyung, T., Kim, W., Shin, C., Song, Y., Lee, M. Y., Lee, H. and Cho, Y., Efficient management design for swimming exercise treatment, *The Korean Journal of Physiology & Pharmacology*, vol. 13, no. 6, pp. 497-502, 2009.

Kitamura, Y., Decision-making process of patients with gynecological cancer regarding their cancer treatment choices using the analytic hierarchy process, *Japan Journal of Nursing Science*, vol. 7, no. 2, pp. 148-157, 2010.

Li, X. J., Bin, G. F. and Dhillon, B. S., Model to evaluate the state of mechanical equipment based on health value, *Mechanism and Machine Theory*, vol. 46, no. 3, pp. 305-311, 2011.

Norman, W. and MacDonald, C., Getting to the bottom of "triple bottom line", *Business Ethics Quarterly*, vol. 14, no. 2, pp. 243-262, 2004.

Ocampo, L., Vergara, V. G., Impas, C., Tordillo, J. A. and Pastoril, J., Identifying critical indicators in sustainable manufacturing using analytic hierarchy process (AHP), *Manufacturing and Industrial Engineering*, vol. 14, no. 3-4, pp 1-8, 2015.

Rachuri, S., Lee, J., A., Sarkar, P., Lyons, K., Sriram, R. and Kemmerer, S., Sustainable manufacturing: metrics, standards, and infrastructure - NIST workshop report, *National Institute of Standards and Technology (NIST), Gaithersburg, MD, NIST Interagency/Internal Report (NISTIR)*, 2010.

Rosen, M. A. and Kishawy, H. A., Sustainable manufacturing and design: concepts, practices and needs, *Sustainability*, vol. 4, no. 2, pp. 154-174, 2012.

Saaty, T. L., A scaling method for priorities in hierarchical structures, *Journal of Mathematical Psychology*, vol. 15, no. 3, pp. 234-281, 1977.

Saaty, T. L., Decision making with the analytic hierarchy process, *International Journal of Services Sciences*, vol. 1, no. 1, pp. 83-98, 2008.

Saaty, T. L., *Fundamentals of Decision Making and Priority Theory with The Analytic Hierarchy Process*, 1st Edition, RWS publications, 2000.

Singh, S., Dolan, J. G. and Centor, R. M., Optimal management of adults with pharyngitis – a multicriteria decision analysis, *BMC Medical Informatics and Decision Making*, vol. 6, no. 1, pp. 14, 2006.

Smith, J., Cook, A., and Packer, C., Evaluation criteria to assess the value of identification sources for horizon scanning, *International Journal of Technology Assessment in Healthcare*, vol. 26, no. 3, pp. 348353, 2010.

The Bangladesh Garments Manufacturer and Exporters Association (BGMEA), Available: https://www.bgmea.com.bd/page/Export_Performance, Accessed on Dec 10, 2022.

United States Environmental Protection Agency (EPA), Available: https://www.epa.gov/sustainability/sustainable-manufacturing#:~:text=Sustainable%20manufacturing%20is%20the%20creation,employee%2C%20community%20and%20product%20safety, Accessed on Dec 10, 2022.

van Til, J. A., Renzenbrink, G. J., Dolan, J. G. and IJzerman, M. J., The use of the analytic hierarchy process to aid decision making in acquired equinovarus deformity, *Archives of Physical Medicine and Rehabilitation*, vol. 89, no. 3, pp. 457-462, 2008.

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