







Figure 1. Identification and hierarchy of barriers under four major criteria

The methodology of the proposed model can be summarize through the following steps.

**Step 1: Identification of factors through establishing expert group**

In this step, a decision group consist of experts (both academics and practitioners) has to be selected to take opinions for both data entry or shortlisting factors. Questionnaire to collect these data has been made with linguistic options.

**Step 2: Establish hierarchical structure**

After identifying the factors through extensive literature review and further shortlisting them by expert opinion, a hierarchy with a goal which branches into levels and sublevel has to be established.

**Step 3: Defining fuzzy triangular scale of relative importance**

In this study, the triangular fuzzy numbers (TFN),  $\tilde{1}$  to  $\tilde{9}$ , have been used to replace conventional scaling points to take the uncertainty into consideration. As the qualitative assessment is replaced with numerical value, the five TFN ( $\tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9}$ ) are defined instead of sharp numbers to handle the imprecision. All these alternatives are linguistically listed in Table-1.

Table 1. Linguistic variable to triangular fuzzy conversion scale

Linguistic scale	Fuzzy numbers	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Just equal	$\tilde{1}$	(1,1,1)	(1,1,1)
Equally important	$\tilde{1}$	(1,1,3)	(1/3,1,1)
Weakly important	$\tilde{3}$	(1,3,5)	(1/5,1/3,1)
Strongly important	$\tilde{5}$	(3,5,7)	(1/7,1/5,1/3)
Very strongly important	$\tilde{7}$	(5,7,9)	(1/9,1/7,1/5)
Extremely Preferred	$\tilde{9}$	(7,9,9)	(1/9,1/9,1/7)

**Step 4: Establishing the pairwise comparison matrix**

Fuzzy pairwise comparison matrix is established for all criteria and sub-criteria for further approach. If factor i has fuzzy triangular numbers assigned to it when compared to factor j, then j has the reciprocal of the aforementioned value when compared to i.

**Step 5: Evaluate consistency ratio**

Consistency ratio for each matrix is evaluated to check the overall consistency of the model where the following equations are used to determine the largest Eigen value, consistency index and consistency ratio respectively.

$$Aw = \lambda_{max}w \tag{1}$$

Where principle Eigen vector of the pairwise comparison matrix is denoted by w.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2}$$

Where n is the matrix size.

$$CR = \frac{CI}{RI} \tag{3}$$

Where RI is random index number determined from Table-2.

The pairwise comparison matrix will be accepted only if  $CR < 0.1$ , otherwise it will have to go through further revise.

Table2. Random index for different matrix size

Size (n)	1	2	3	4	5	6	7	8
RI	0	0	0.52	0.9	1.12	1.25	1.35	1.40

**Step 6: Calculation of priority weights at different level of hierarchy**

The allocated triangular fuzzy numbers into the pairwise comparison matrix can be expressed as  $M_{gi}^j$  ( $i = 1,2,3, \dots, n; j = 1,2,3, \dots, m$ ) with the parameter a, b and c. So, the value of fuzzy synthetic extent can be determined using equation (1).

$$S_i = \sum_{j=1}^m M_{gi}^j \times \left[ \sum_{i=1}^n \sum_{j=1}^m M_{gi}^j \right]^{-1} \tag{4}$$

Fuzzy addition is adopted to determine the value of  $\sum_{j=1}^m M_{gi}^j$  which has been shown in equation (2).

$$\sum_{j=1}^m M_{gi}^j = \left( \sum_{j=1}^m a_j, \sum_{j=1}^m b_j, \sum_{j=1}^m c_j \right), \quad (i = 1, 2, 3, \dots, n) \quad (5)$$

Using equation 4 and 5, fuzzy relative weights for each criteria can be determined.

**Step 7: Synthetic extent analysis of the fuzzy relative weights**

The degree of possibility of  $M_2 \geq M_1$  can be defined as,

$$V(M_2 \geq M_1) = \sup \left[ \min \left( \mu_{M_1}(x), \mu_{M_2}(x) \right) \right] \quad (6)$$

where,  $M_2 = (a_2, b_2, c_2)$  and  $M_1 = (a_1, b_1, c_1)$ .

This can be expressed as,

$$V(\widetilde{M}_2 \geq \widetilde{M}_1) = \text{hgt}(\widetilde{M}_1 \cap \widetilde{M}_2) = \begin{cases} 1, & b_2 > b_1 \\ 0, & a_1 > c_2 \\ \frac{a_1 - c_2}{(b_2 - c_2) - (b_1 - a_1)}, & \text{otherwise} \end{cases} \quad (7)$$

From equation 6 it can be inferred that the highest intersection point between the criteria is necessary to compare  $M_1$  and  $M_2$ . Later, the degree of possibility of a convex fuzzy number greater than all the other numbers compared with can be evaluated by the following equation.

$$\begin{aligned} V(M \geq M_1, M_2, M_3, \dots, M_k) \\ = V[(M \geq M_1) \text{ and } (M \geq M_2) \text{ and } (M \geq M_3) \dots \text{ and } (M \geq M_k)] \\ = \min V(M \geq M_i) \end{aligned} \quad (8)$$

where,  $i = 1, 2, 3, \dots, k$

**Step8: Normalization of weight**

In this step, the relative weight of each matrix is normalized and also, the global weight can be evaluated simply multiplying the relative weights of major criteria with the corresponding relative weights of sub criteria.

**4. Case Study**

**4.1 Identifying the barriers and structuring a hierarchy model**

After identifying all possible barriers of cleaner production, only 20 among them have been selected through survey which align with the perspective of textile industry in Bangladesh. Using this data, a tree hierarchy has been built up where all these barriers fall under four major criteria (shown in figure 1).

**4.2 Developing questionnaire and collecting expert opinion**

Linguistic scale has been used to collect data about the priority in the comparison matrix from three expert (one academic, and two practitioners). Later, these responses has been converted to triangular fuzzy scale using table 2. If the criteria in row is more important, it is replaced by triangular fuzzy scale, otherwise the reciprocal scale is used.

**4.3 Fuzzy evaluation of criteria**

In this step, fuzzy comparison matrix for each criteria is constructed among its sub category. Fuzzy pairwise comparison matrix of major criteria and their subcategories has been shown in Tables 3-7.

Table 3. Pairwise comparison matrix of the major criteria

Attributes	A1	A2	A3	A4
A1	(1,1,1)	(1,5/3,11/3)	(5/3,11/3,17/3)	(1/7,1/5,1/3)
A2	(3/11,3/5,1)	(1,1,1)	(3/7,3/5,1)	(1/5,1/3,1)
A3	(3/17,3/11,3/5)	(1,5/3,7/3)	(1,1,1)	(3/23,3/17,3/11)
A4	(3,5,7)	(1,3,5)	(11/3,17/3,23/3)	(1,1,1)

Table 4. Pairwise comparison matrix of technologic and information barrier

Attributes	TB1	TB2	TB3	TB4	TB5
TB1	(1,1,1)	(3/17,3/11,3/5)	(1,7/3,13/3)	(1/7,1/5,1/3)	(1,7/3,13/3)
TB2	(5/3,11/3,17/3)	(1,1,1)	(11/3,17/3,23/3)	(3/7,3/13,1)	(13/3,19/3,25/3)
TB3	(3/13,3/7,1)	(3/23,3/17,3/11)	(1,1,1)	(1/5,1/3,1)	(1/3,1,1)
TB4	(3,5,7)	(1,13/3,7/3)	(1,3,5)	(1,1,1)	(3,5,7)
TB5	(3/13,3/7,1)	(3/25,3/19,3/13)	(1,1,3)	(1/7,1/5,1/3)	(1,1,1)

Table 5. Pairwise comparison matrix of economic and financial barrier

Attributes	EFB1	EFB2	EFB3	EFB4	EFB5
EFB1	(1,1,1)	(1/5,1/3,1)	(3/11,3/5,1)	(3/11,3/17,3/25)	(3/11,3/17,3/25)
EFB2	(5/3,11/3,17/3)	(1,1,1)	(1,7/3,13/3)	(1/5,1/3,1)	(1/5,1/3,1)
EFB3	(3/13,3/7,1)	(3/25,3/19,3/13)	(1,1,1)	(1/5,1/3,1)	(1/7,1/5,1/3)
EFB4	(3,5,7)	(1,13/3,7/3)	(1,3,5)	(1,1,1)	(1/5,1/3,1)
EFB5	(3/13,3/7,1)	(3/25,3/19,3/13)	(1,1,3)	(1/7,1/5,1/3)	(1,1,1)

Table 6. Pairwise comparison matrix of market barrier

Attributes	MB1	MB2	MB3	MB4	MB5
MB1	(1,1,1)	(1/5,1/3,1)	(1,7/3,13/3)	(13/3,19/3,25/3)	(1,5/3,11/3)
MB2	(1,3,5)	(1,1,1)	(5/3,11/3,17/3)	(7/3,13/3,19/3)	(5/3,11/3,17/3)
MB3	(3/13,3/7,1)	(3/5,3/11,3/17)	(1,1,1)	(1,7/3,13/3)	(1,5/3,11/3)
MB4	(3/25,3/19,3/13)	(3/19,3/13,3/7)	(3/13,3/7,1)	(1,1,1)	(1/7,1/5,1/3)
MB5	(3/11,3/5,1)	(3/17,3/11,3/5)	(3/11,3/5,1)	(3,5,7)	(1,1,1)

Table 7. Pairwise comparison matrix of managerial barrier

Attributes	ManB1	ManB2	ManB3	ManB4	ManB5
ManB1	(1,1,1)	(1/5,1/3,1)	(3/13,3/7,1)	(1/7,1/5,1/3)	(1,5/3,11/3)
ManB2	(1,3,5)	(1,1,1)	(1/5,3/5,1)	(1/7,1/5,1/3)	(1,7/3,13/3)
ManB3	(1,7/3,13/3)	(1,5/3,5)	(1,1,1)	(1/5,1/3,1)	(5/3,11/3,17/3)
ManB4	(3,5,7)	(3,5,7)	(1,3,5)	(1,1,1)	(3,5,7)
ManB5	(3/11,3/5,1)	(3/13,3/7,1)	(3/17,3/11,3/5)	(1/7,1/5,1/3)	(1,1,1)

Consistency ratio of each matrix has been determined using the equation 1, 2 and 3 and the value below 0.1 proved the consistency of the matrix.(shown in Table 8).Later, using equation 4 and 5, the value of fuzzy synthetic extent of each criteria and sub criteria has been determined and a sample has been shown in Table 9.

Table 8. CR of the pairwise comparison matrix

Matrix	Major Criteria	Technologic and Information Barriers	Economic and Financial Barrier	Market Barrier	Managerial Barrier
<b>CR</b>	0.0036	0.0874	0.0810	0.0826	0.0727

Table 9. Determination of the value of fuzzy synthetic extent of market barrier

Attributes	MB1	MB2	MB3	MB4	MB5	$\sum_{j=1}^m M_{gi}^j$	$S_i$
<b>MB1</b>	(1,1,1)	(1/5,1/3,1)	(1,7/3,13/3)	(13/3,19/3,25/3)	(1,5/3,11/3)	(7.53,11.67,18.33)	(0.11,0.27,0.73)
<b>MB2</b>	(1,3,5)	(1,1,1)	(5/3,11/3,17/3)	(7/3,13/3,19/3)	(5/3,11/3,17/3)	(7.67,15.67,23.67)	(0.12,0.37,0.95)
<b>MB3</b>	(3/13,3/7,1)	(3/5,3/11,3/17)	(1,1,1)	(1,7/3,13/3)	(1,5/3,11/3)	(3.41,5.70,10.60)	(0.05,0.13,0.42)
<b>MB4</b>	(3/25,3/19,3/13)	(3/19,3/13,3/7)	(3/13,3/7,1)	(1,1,1)	(1/7,1/5,1/3)	(1.65,2.02,2.99)	(0.02,0.05,0.12)
<b>MB5</b>	(3/11,3/5,1)	(3/17,3/11,3/5)	(3/11,3/5,1)	(3,5,7)	(1,1,1)	(4.72,7.47,10.60)	(0.07,0.18,0.42)

#### 4.4 Applying synthetic extent evaluation

From the data shown in Table 8, the degree of possibility of superiority of  $S_{MB1}$  can be calculated and denoted by  $V(S_{MB1} \geq S_{MB2})$  using equation 6 and 7. So, the degree of possibility of superiority for the first requirement-

$$V(S_{MB1} \geq S_{MB2}) = 0.88, \quad V(S_{MB1} \geq S_{MB4}) = 1,$$

$$V(S_{MB1} \geq S_{MB3}) = 1, \quad V(S_{MB1} \geq S_{MB5}) = 1,$$

Similarly, the degree of possibility of superiority for the second requirement-

$$V(S_{MB2} \geq S_{MB1}) = 1, \quad V(S_{MB2} \geq S_{MB4}) = 1,$$

$$V(S_{MB2} \geq S_{MB3}) = 1, \quad V(S_{MB2} \geq S_{MB5}) = 1,$$

The degree of possibility of superiority for the third requirement-

$$V(S_{MB3} \geq S_{MB1}) = 0.69, \quad V(S_{MB3} \geq S_{MB4}) = 1,$$

$$V(S_{MB3} \geq S_{MB2}) = 0.57, \quad V(S_{MB3} \geq S_{MB5}) = 0.89,$$

The degree of possibility of superiority for the fourth requirement-

$$V(S_{MB4} \geq S_{MB1}) = 0.03, \quad V(S_{MB4} \geq S_{MB3}) = 0.44,$$

$$V(S_{MB4} \geq S_{MB2}) = 0.01, \quad V(S_{MB4} \geq S_{MB5}) = 0.27,$$

The degree of possibility of superiority for the fifth requirement-

$$V(S_{MB5} \geq S_{MB1}) = 0.76, \quad V(S_{MB5} \geq S_{MB3}) = 1,$$

$$V(S_{MB5} \geq S_{MB2}) = 0.62, \quad V(S_{MB5} \geq S_{MB4}) = 1,$$

The minimum degree of possibility of superiority of each criterion over another is taken as the weight of that criterion and further normalized to get the final weight (equation 8). The weight vector and normalized weight vector of market barriers are respectively shown below.

$$W = (0.88, 1, 0.57, 0.01, 0.62)$$

$$W' = (0.283, 0.326, 0.186, 0.004, 0.201)$$

#### 4.5 Determining global weight

After calculating the relative weight for each criterion, global weight has been determined by multiplying each relative weight of sub category with its respective relative weight of major criteria, to compare the priority of the barriers all together (Table-10).

Table 10. Weights and ranking of major criteria and sub-categories

Major Criterion	Relative Weights	Relative Rank	Sub-category	Relative weight	Relative Rank	Global Weight	Global rank
<b>Technologic and Information barrier (A1)</b>	0.3427	2	TB1	0.1898	3	0.06506	6
			TB2	0.3806	1	0.13043	3
			TB3	0.0049	5	0.00167	17
			TB4	0.3493	2	0.11970	5
			TB5	0.0754	4	0.02582	8
<b>Economic and Financial barrier (A2)</b>	0.0257	4	EFB1	0.0073	5	0.00019	19
			EFB2	0.2144	3	0.00550	15
			EFB3	0.1132	4	0.00290	16
			EFB4	0.3089	2	0.00793	13
			EFB5	0.3561	1	0.00914	11
<b>Market barrier (A3)</b>	0.0419	3	MB1	0.2833	2	0.01187	10
			MB2	0.3264	1	0.01368	9
			MB3	0.1855	4	0.00777	14
			MB4	0.0040	5	0.00017	20
			MB5	0.2009	3	0.00842	12
<b>Managerial barrier (A4)</b>	0.5898	1	ManB1	0.1045	4	0.06165	7
			ManB2	0.2140	3	0.12619	4
			ManB3	0.2791	2	0.16460	2
			ManB4	0.4010	1	0.23647	1
			ManB5	0.0015	5	0.00086	18

### 5. Result Analysis

In this research, both relative and global weight of each barriers identified to impede the cleaner production have been determined. From the final ranking of major criteria, managerial barriers has been observed to gain the highest weight since this study has been done on the textile industry of Bangladesh. From the perspective of developing countries, most of the organizations focus more on improving the bottom line rather than the social responsibility. Also, the myopic decision makers are unable to foresee the future boost in profit section by adopting cleaner production. The second most critical major criteria is technologic and information barrier. As a developing country, Bangladesh is also lagging in technologic advancement even though the government has undertaken manifold projects regarding this issue recently. Still, this criteria is considered as one of the major barrier to implement cleaner production. Market barrier comes as third in the priority list as the environmental rules and regulations in the developing countries are overlooked most of the times even by the government authority. As a result, industries as textile and leather, which are more likely to produce toxic industrial waste, take the advantage of these loophole to earn the short term profit neglecting the social responsibility. Economic and financial barrier come as the last one in priority list as the cleaner production is the major leap the organization has to take, and financial aid will be the last thing they will need to bring the changes.

According to the global rank, top 5 barriers can be marked as the most critical ones among the 20 barriers. Even though managerial barrier criteria tops in the major criteria priority list, it would be imprudent decision to focus on that branch which includes 5 sub categories. Rather, the top 5 barriers of the global rank, which are the subcategories of different major criteria should be focused to make the best utilization of allocated resource and effort. Lack of awareness of CP (ManB4) has been identified as the most critical barrier among all as it has the largest weight. This fall under the branch of managerial barrier which can be inferred as the lack of awareness among the decision makers about implementing CP. Textile industries in the developing countries like Bangladesh are more dependent on export



earnings and they can hardly presentiment the long term benefits of implementing CP. Also, the professional in this sector of Bangladesh are more likely to emphasize on profit margin rather than funding the research and development department. So, this is the most critical impediment as it would not be hard to realize how this barrier is impeding the initiation of adopting CP measures.

Management resistance to change (ManB3), technological awareness and expertise (TB2), concern about competitiveness (ManB2) and difficulty to access information on CP (TB4) took the second, third, fourth and fifth position respectively in the global rank. Management which shows resistance to change as it may include risks and does not encourage flexibility and innovation, also shows indifference to social responsibilities are greatly impeding the CP implementation across the country. Since, most of the textile factories are using age old technologies and process in conventional way, implementing the CP tools will require the flexibility to changes and new adoption. Technological awareness and expertise is a big issue for developing countries though the government has started to invest for technological advancement, but this barrier becomes redundant from the developed countries perspective. Also, the managers and the decision makers are more concerned about competitiveness in price setting and unaware of the economic and environmental benefits of implementing CP. Also, most of the company in textile industry of Bangladesh are small and medium sized enterprise which face difficulty to access information on CP. Using the aforementioned global rank list obtained from the research, critical managerial decisions regarding CP implementation can be made to be proactive about the impeding factors and overall process improvement.

## **6. Conclusion**

This research outcome can help the organization to set focus on pivotal area to align strategies with the sustainable goals and strategies. In most of the developing country, organizations deal with scant resource, goes along with the conventional process and hardly thinks about bringing any changes. While applying cleaner production in such organization, a manifold barriers can come across to impede even the initiation. However, it is not possible to allocate same amount of resource and attention to each one of them. So, the outcome of this research can help the decision makers narrow down the list. Fuzzy AHP method has helped to identify the most critical to least critical factor among the selected 20 and also allowed both local and global improvement according to necessity. Also, practitioners and experts are more comfortable to give their opinion in linguistic approach rather than sharp numbers and to deal with this uncertain and ambiguous data, fuzzy approach has been adopted.

Since this paper focused on the implementation of CP in textile industries of Bangladesh, government legislation has not been taken into consideration as the government has taken steps to encourage the organizations including SME to adopt greener approach and tightened up the environmental regulations. But the organizations which are adopting CP because of the government legislation have myopic view of possible obstruction that are impeding the whole process severely. So, this paper aims to contribute in this process through helping the managers being proactive about the potential critical barriers and allocate resource and effort to them to get the maximum output.

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## Biographies

**Farzana Islam** completed her Bachelor in Science (BSc) in Industrial & Production Engineering (IPE) from Bangladesh University of Engineering & Technology (BUET). She is currently doing Masters in science (MSc) in Industrial and Production Engineering in the same university. She has published conference papers. Farzana Islam is a Certified Supply Chain Analyst and has won Ptak Prize Scholarship through a global supply chain case competition organized by International Supply Chain Education Alliance (ISCEA) Bangladesh. Her major research interests include lean six sigma, supply chain and logistics management, operation management, operations research and cleaner production.

**Ahmed Shoyeb Raihan** has received his Bachelor in Science (BSc) degree from the Department of Industrial & Production Engineering of Bangladesh University of Engineering & Technology (BUET). At present, he is completing Masters in Science (MSc) in IPE from the same university. He has already worked on two journals which are currently being reviewed. He is also a Certified Supply Chain Analyst (CSCA). Currently, he is working on another project on the sustainability of plastic manufacturing and distribution. His field of research encompasses supply chain risk management, application of multi criteria decision making (MCDM) tools, green supply chain management and supply chain sustainability.