Investigation of best available technique for energy and environmental performance in textile industry: A combined SWOT and ARAS-G approach

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Highlights

- This study includes the new approach for ranking BAT for energy and environmental performance in the textile industry
- Integrated SWOT analysis and MCDM method for effective decision-making in making major inefficient operations in the textile industry sustainable.
- Results help in future policymaking for evaluating the energy and environmental performance of the industry.

ABSTRACT

This study includes connecting the Best Available Technique (BAT) for energy evaluations and environmental performance criteria in the textile industry, mainly employing fiber preparation, cotton fabric dying, printing and, other textile finishing operations. After careful investigation, 9 different techniques are identified in this study from three distinct categories of overall environmental performance, water consumption and wastewater generation, and energy efficiency. The SWOT analysis using the fuzzy analytical hierarchical process of this study revealed "Weakness" as the most influential factor, followed by "Opportunities", "Strengths" and then "Threats". Subsequently, a multi-criteria decision-making approach, employing the grey additive ratio assessment (ARAS-G) was used to rank the BAT in this study.

Keywords (3-6): SWOT Analysis, MCDM, ARAS-G method, Energy Management, Sustainability, Textile Industry

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1. Introduction

With the rapid industrialization and growing population that also resulted in urbanization in modern cities, the energy demand has increased significantly. According to the Energy Information Administration (EIA) the global electricity demand to double by 2050 ((IEA 2022), n.d.). Currently, more than 70% of the primary energy supply is coming from fossil fuel resources also resulting in 52 billion tons of greenhouse gas (GHG) emissions each year (Fareed, Khoja, et al., 2023), and continuous energy supply from these resources poses significant challenges for sustainable operations in major industries, many of these industries are already struggling with energy management and reducing waste resources from inefficient processes. Addressing GHG emissions from the manufacturing sector, one cannot sideline the textile industry, the involvement of pre-treating, textile ennoblement, dyeing, and other processes, this industry is regarded not only as one of the highly energy-intensive industries but also one of the most polluting industries in the manufacturing sector (EURATEX 2022rev, n.d.). The global share of the textile industry in GHG emissions is more than the combined total of global maritime transports and air transport (TEXTILES ECONOMY: n.d.). In addition to this, the global supply chain is also one of the major issues in this industry, where a high volume of waste disposal poses a significant threat to the environment and global community. Therefore, the problem of finding clean sources of energy and efficient operational technology remains urgent, in this regard, there is a growing need to develop innovative strategies to implement the best available techniques (BAT) with its various applications in the textile industry operations. Implementation of BATs in different units of the textile industry can reduce energy consumption, reduce water, and energy wastewater discharge, limit flue gas emissions in the industry, and address sustainability issues in the form of sustainable supply chain management (SSCM) that provides a competitive advantage in long term business viability.

The objective of this study is to assess the various BATs for cleaner production practices in the textile industry. In this study, the Strengths, Weakness, Opportunities, and Threats (SWOT) analysis has been used to identify the main overall internal and external factors in implementing BAT in the textile industry. Then in this study, we employed the (ARAS-G), which is the MCDM approach to evaluate and rank different BATs for implementation in the industry.

The rest of the paper is structured as follows, Section 2 represents the literature review and related studies. Section 3 discusses the research methodology of this study; Section 4 presents the results and discussion. Finally, Section 5 presents the conclusion of the study.

2. Literature Review

The finishing product in the textile industry goes through a long chain of processes, that also include backward and forward processes. This industry is also considered to have many stages of production processes in the whole manufacturing industry (Farhana et al., 2022). The major processes include agriculture process, shearing, fiber synthesis, knitting, dyeing, finishing, etc., it is a well-known fact that all these complex processes require vast amounts of energy, water, and chemical resources, where energy consumption is the major factor in not only implementing cleaner production practices in the manufacturing of textile product but also in defining the cost of the final product. Energy in the textile manufacturing industry is used in two categories, one in the form of electricity used for machinery, air conditioning, lighting, driving motors, etc., and another category where energy used in the form of natural gas, oil, LPG, coal to produce steam for dyeing, washing and other finishing processes (Lutz et al., 2015). Figure 1 illustrates the schematic diagram of the main processes of textile manufacturing with energy consumption.

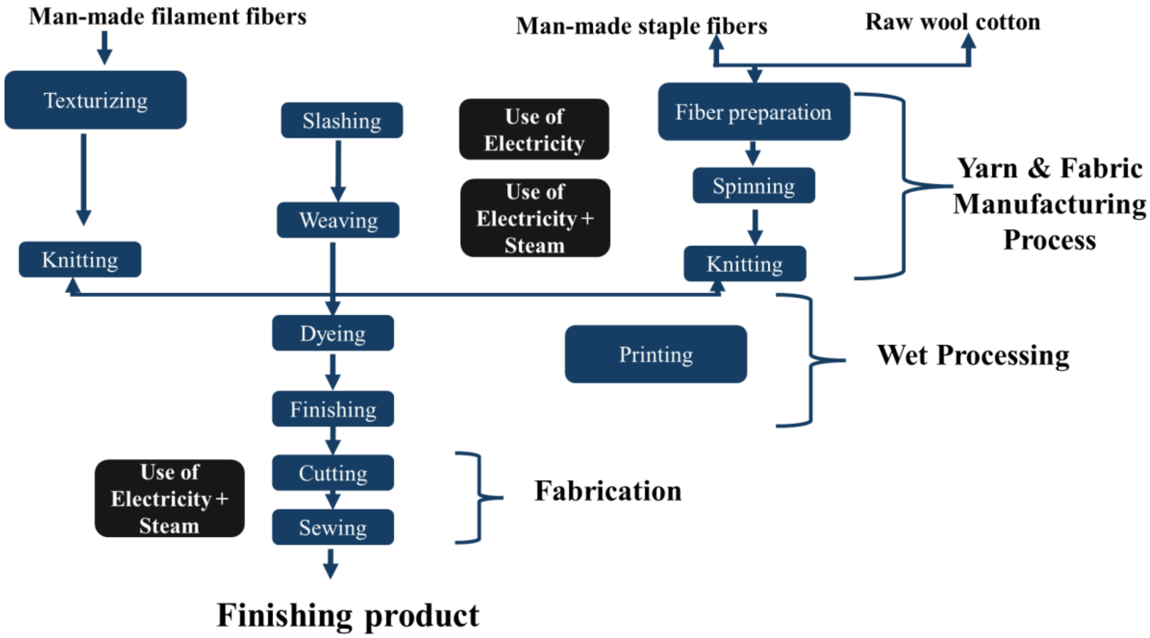


Figure 1. Flow processing of textile fabric manufacturing with the indication of the mode of energy use

In general, 30-40% of the energy in the textile industry is consumed in yarn and fabric manufacturing, while 40-60% of the energy is used in the wet processing unit. Mainly this energy comes from the burning of fossil fuels resulting in increased GHG emissions, in addition to this, the textile sector has also been condemned strongly for their participation in other anthropogenic activities that include deforestation, affecting ground for industrial activities, and environmental pollution (Farhana et al., 2022). Renewable energy resources have improved significantly in the past many decades and now their use in the industrial sector is considered a more reasonable option in combination with fossil fuels. As we have mentioned energy in the textile industry is used in two categories, for electricity production there are many alternate energy resources available on a commercial basis i.e., (solar, wind, geothermal, hydro, etc.,). Many studies are available on using various sources of renewable energy to produce electricity and their application in the textile industry (Dehshiri et al., 2023; Durru et al., 2021), for thermal requirements, industrial solar technologies such as parabolic solar collectors and solar industrial process heat are the good options (Fareed, Petrillo, et al., 2023). In context to the whole scenario of climate change and GHG emissions, implementation of the Best Available Techniques (BAT) has been mandated by the Integrated Pollution Prevention and Control (IPCC) and the directives of the Industrial Emissions Directive (IED) for less chemical pollution and for also sharing and identifying cleaner production opportunities with the public to strengthen the monitoring program (EEA, 2024). As per directives of the European Parliament and the Council on Industrial Emissions for the textile industry, the implementation decision includes more than 50 BAT for overall activities and different operations in the textile industry ((EU) BAT Textile 2022, n.d.). In this study, we have included only major BATs that need to be implemented in the textile industry for overall better energy-efficient operations and better environmental performance. Table 01 represents the BATs included in this study (Farhana et al., 2022).

Table 01 Major Best Available Techniques (BAT) Establishing in the textile industry

BAT	Technique	Brief Description
Overall environmental performance	Use of textile materials containing a minimized content of contaminants	Criteria that are based on certification of schemes and standards. These controls address wool fibers, cotton fibers, chemical sizing, etc.,
	Use of textile materials with reduced processing needs	The use of materials that require inherently low processing needs. These materials may include man-made fibers, polyester fibers, synthetic fibers, etc.,
Water consumption and wastewater generation	Water management plant and water audits	A management technique where water management plans and water audits are carried out at least once per year.
	Production optimization	Also, a management technique, where optimization production processes are optimized, in some operations it is done in the same dying equipment.
	Processes using little or no water	Using the processes of plasma, laser treatment, or ozone treatment using a low amount of water.
	Water reuse and/or recycling	Reuse of water in cleaning, rinsing, and cooling during processing of the textile materials. Where careful consideration should be given reuse/recycling of water is limited by the content of impurities.
Energy efficiency	Energy efficiency plan and audits	Implementing actions of energy efficiency plan that include energy flow diagrams, setting objectives in terms of energy efficiency, also carrying out audits at least once a year.
	Use of general energy saving techniques	Includes use of energy efficiency motors, efficient lighting system, efficient variable speed drives, optimizing air conditioning, and building heating.
	Use of heat recovery techniques	That includes recycling of warm cooling water, recovery of heat from wastewater, heat recovery from steam use, etc.,

3. Materials and Methods

3.1. SWOT Analysis

To address the gap in sustainable operations in the textile industry, this study adapts the comprehensive methodology of SWOT analysis and MCDM techniques, that provide a robust framework for strategic decision-making in the context of the textile industry.

SWOT analysis is a strategic technique that is very useful in evaluating the internal factors "strengths and weaknesses" and external factors "threats and opportunities". It is a two-step process, in 1st step, it forms the SWOT matrix, while in 2nd step it formulates the SWOT strategies using the SWOT matrix (Longsheng et al., 2022). The analysis leads to the development of four combinations SO "strength opportunities", ST "strengths threats", WO "weakness opportunities" and WT "weakness threats".

3.2. ARAS-G Method

ARAS-G Method is the application of the grey numbers theory, developed by Turskis and Zavadkas (Turskis & Zavadskas, 2010), it is also an MCDM technique, this process is used to rank alternatives, and optimal decisions can be taken based on a set of criteria. This method follows the structured process and involves the formation of a decision matrix. This ARAS-G method is recognized for its simplicity and flexibility. The major steps of the ARAS-G method explained in (Longsheng et al., 2022) are as follows.

i. Creation of initial grey matrix

$$X_{ij} = \begin{bmatrix} \otimes x_{01} & \cdots & \otimes x_{0n} \\ \otimes x_{21} \vdots & \ddots & \vdots \\ \otimes x_{m1} & \cdots & \otimes x_{mn} \end{bmatrix}, \; i = \overline{0, m}; \; j = \overline{1, n}$$

(2)

ii. Computation of normalized matrix

$$\otimes \overline{X}_{ij} = \begin{bmatrix} \otimes \overline{x}_{01} & \cdots & \otimes \overline{x}_{0n} \\ \vdots \otimes \overline{x}_{021} & \ddots & \vdots \otimes \overline{x}_{2n} \\ \otimes \overline{x}_{m1} & \cdots & \otimes \overline{x}_{mn} \end{bmatrix}, i = \overline{0, m}; j = \overline{1, n}$$

(3)

Also

$$\otimes \overline{x_{ij}} = \frac{\oplus x_{ij}}{\sum_{kj=1}^{n} \otimes x_{ij}} \; Benefit \; criteria,$$

(4)

$$\otimes x_{ij} = \frac{1}{\widehat{x_{ij}}} \text{ x } \overline{x}_{ij} = \frac{\oplus x_{ij}}{\sum_{i=0}^{m} \otimes x_{ij}} \; Cost \; criteria$$

(5)

iii. The next step is computing a weighted normalized matrix

$$\otimes \hat{x}_{ij} = \otimes \overline{x_{ij}} \; X \otimes w_{ij}; i = \overline{0, m}$$

(6)

iv. Then compute the function`s value.

$$\otimes S_i = \sum_{j=1}^{n} \otimes \hat{x}_{ij} \; ; \; i = \overline{0, m}$$

(7)

v. Following this convert grey numbers into crisp values.

$$S_i = \frac{1}{2}(S_{i\propto} + S_{i\gamma})$$

(8)

vi. And finally computing the utility value of each alternative.

$$K_i = \frac{S_i}{S_0}; i = i = \overline{0, m} \quad (9)$$

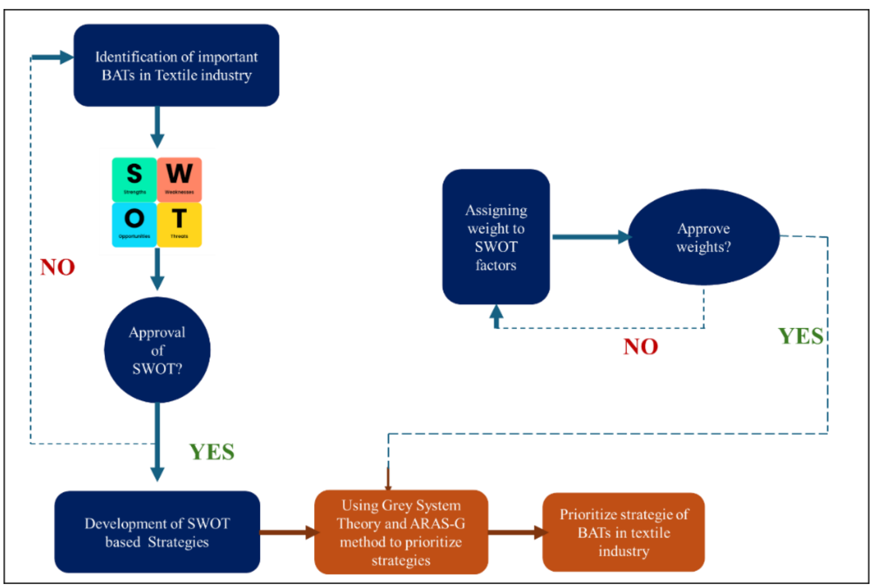
The integrated SWOT and ARAS-G methodology for the selection criteria of BAT in the textile industry is given in the following steps for this study.

- Listing out the hierarchical structure, where it is possible to transform the problems into criteria, sub-criteria, goals, and alternatives.
- Computes weights for SWOT main criteria and sub-criteria and provides scores for alternatives using the fuzzy AHP method.
- Finally computing relative closeness and ranking of BATs using ARAS-G method.

The schematic diagram of the research framework of this study is given in Figure 02.

Figure 02: Schematic diagram of the research framework using SWOT analysis and ARAS-G method

4. Results and Discussions



The SWOT analysis identifies the SWOT factors related to the implementation of BATs in the textile industry for sustainable development. These SWOT factors were identified using an extensive literature survey. A total of 12 factors were identified four factors under each category and weights were assigned to these factors using the fuzzy-AHP process. A brief description of SWOT factors is given in Table 02.

Table 02: SWOT overall weights and subfactors criteria description

	Main Criteria Weight	Sub Factors	Factor Code	Description
Strengths	0.218	Environmental Policies	S1	Almost all countries and big unions like the European Union in their environmental policies restrict big industries including the textile industry to limit their GHG emissions. Some countries also impose heavy fines on industries that restrain from following these laws.
		Development of structure for mitigation of waste	S2	Technologies like circular economy and other processes are helping mitigate waste generated in the textile industry.
		Better technology in fiber preparation	S3	Developed countries having technological resources are putting their efforts into making the fiber preparation process a more efficient and sustainable system, and so far results are very promising.
Weakness	0.314	Lack of integrated waste management policy	W1	Policymakers are not able to design an impactful waste management policy for the textile industry.
		High energy consumed practices	W2	The textile sector consumes abundant amounts of fossil fuel resources, and this high amount of energy consumption also has many adverse environmental impacts.

		Inefficient logistics	W3	Lack of priorities and collaboration in the logistics performance management performance.
Opportunities	0.298	Manufactured textile goods	O1	Development of the synthetic fibers and alternative fibers has the potential to reduce environmental impacts.
		Renewable energy generation	O2	Tactical and strategic decision models are implemented to integrate renewable energy systems in the textile industry.
		Expansion of new fashion trends	O3	The emergence of new fashion trends in textile manufacturing improved the overall design process of the industry.
Threats	0.17	Rapid change in the fashion market	T1	Complex market structure and united business patterns affecting the textile industry.
		Lack of corporate response	T2	Lack of public awareness and corporate response regarding green and sustainable issues in the textile industry.
		Release of hazardous substances	T3	In some cases, the textile industry releases more hazardous chemicals and substances than power plants.

The following result is the ranking prioritization of strategies for the implementation of BAT in the textile sector, the rankings obtained after the ARAS-G method operations as shown in Table 03.

Table 02 BAT ranking calculated by ARAS-G method

BAT Technique	Ki (%)	Rank
Water reuse and recycling	97	1
Use of heat recovery technique	96	2
Energy efficiency plan and audits	93	3
Use of textile material with reduced processing needs	92	4
Processes using little or no water	89	5
Production optimization	85	6
Water management plan and water audits	82	7
Use of general savings techniques	77	8
Use of textile materials containing the minimum number of contaminants	73	9

5. Conclusions

The overall results indicated that water and energy consumption can be reduced by applying BAT in the textile industry facilities. The BAT prioritization strategies in the industry are given in this study, which follows that any BAT selected for implementation should be coupled with energy and water evaluations, as all major operations of this industry link with these two sources. The methodology of this work may contribute to forming a policy or making decisions for stakeholders and policymakers in the industry.

6. Acknowledgement

We acknowledge financial support under the National Recovery and Resilience Plan (NRRP), Mission 4, Component 2, Investment 1.1, Call for tender No. 1409 published on 14.9.2022 by the Italian Ministry of University and Research (MUR), funded by the European Union – NextGenerationEU – Project Title “GENIUS - A GrEen Network for an Integrated bUsiness Strategy to monitor sustainability measures” CUP E53D2301682 0001 Grant Assignment Decree No. 1385 adopted on 01 September 2023 by the Italian Ministry of Ministry of University and Research (MUR).

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