

Paper Type: Original Article

Design of a Comprehensive Technology Sustainability Assessment Model in the Textile Industry Using Bayesian Networks

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Citation:

Received: 27 May 2026

Revised: 19 August 2026

Accepted: 12 November 2026

Mazinani, E., & Nahavandi, N. (2026). Design of a comprehensive technology sustainability assessment model in the textile industry using Bayesian networks. *Supply Chain and Operations Decision Making*, 3(4), 277-288.

Abstract

This study focuses on designing a comprehensive model for assessing technology sustainability in the textile industry using Bayesian networks. Given that the textile and apparel industry is recognized as one of the most polluting industries, it requires particular attention to sustainability issues. Accordingly, the proposed model seeks to identify the factors and risks affecting technology sustainability and provide a tool for assessing and analyzing these factors. The research adopts a developmental approach and is based on the collection of qualitative data through interviews with experts in the textile industry. The results indicate that economic and social sustainability have a significant impact on technology sustainability. This model can assist managers and policymakers in focusing on key factors to improve technology sustainability and promote the sustainable development of the textile industry.

Keywords: Technology sustainability, Textile industry, Bayesian networks, Sustainable development.

1 | Introduction

The textile and apparel industry, as one of the most polluting industries worldwide, has attracted considerable attention to sustainability-related issues. This industry, which is considered the second-largest polluter after the oil industry, has significant negative impacts on the three dimensions of sustainability, namely environmental, social, and economic sustainability. From an environmental perspective, activities in this industry contribute to air pollution, extensive greenhouse gas emissions, and serious damage to the environment and human life [1]. Sustainability challenges in this industry mainly arise from low environmental standards and inadequate social conditions for the workforce. This situation contrasts with the relatively high

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 <https://doi.org/10.48313/scodm.v3i4.68>



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level of sustainability of resources and processes in industrial regions. Therefore, companies operating in the textile and apparel sector are striving to improve sustainability through effective measures, including reducing their carbon footprint and enhancing working conditions [2]. From an economic perspective, the textile industry is considered one of the largest industries worldwide after agriculture and contributes significantly to employment generation. The industry is of great importance to many countries, as it not only contributes financially to national economies but also provides numerous employment opportunities. At the same time, companies operating in the textile and apparel sector face requirements to reduce costs and project completion times, as well as challenges associated with geographical complexities [3]. Government policies and regulations also have a broad impact on the textile industry. For example, due to monetization policies, this sector has been affected to a greater extent than other sectors. In the present era, sustainable development has become an essential necessity [4]. Among the various challenges facing the textile industry, the assessment of the technologies employed is one of the key factors influencing the stagnation or development of the industry. The main focus of sustainable technology assessment is on the functions associated with the use of technology in the textile industry. This assessment requires strategies such as strategic and forward-looking planning in the textile industry, evaluating the economic feasibility of sustainable technology and the possibility of securing the necessary investment based on a resilient economy approach, and assessing the qualitative, functional, and technical considerations of technology in the textile industry. Accordingly, various countries around the world, particularly those with a long-standing presence in the textile industry, have shifted their production programs toward modern and advanced products. The continuation of production, updating of existing products, and development of new products are essential; therefore, various countries have incorporated these issues into their research agendas. In this context, risk management plays an important role in addressing the uncertainties and challenges associated with technology and sustainability. Risk management is a formal process that enables an organization to identify risks, analyze them, and respond to them in an appropriate and effective manner. In one of the most comprehensive definitions, the risk management process is defined as a systematic and logical process that includes the identification, analysis, and measurement of risks (collectively referred to as risk assessment), as well as addressing risk exposure by taking into account the context, or, in other words, the organization's internal and external environment [5]. Risk measurement and management, along with performance measurement, are essential for sustainable supply chain management, as violations of social and environmental sustainability practices pose risks to the brand image of the apparel and textile industry [6]. Therefore, identifying and evaluating the factors and risks affecting technology sustainability is of particular importance. Accordingly, the objective of the present study is to identify the factors and risks that have a significant impact on technology sustainability in the textile industry and to develop a comprehensive model for assessing and analyzing these factors through the use of Bayesian networks. The proposed model seeks to provide an appropriate tool for forecasting and assessing sustainable technology in the textile industry while taking into account existing uncertainties and complexities. The use of Bayesian networks, owing to their ability to analyze probabilistic relationships among various factors and evaluate different scenarios, constitutes one of the key aspects of this study and can provide valuable insights for improving technology management and supporting the sustainable development of the textile industry.

2 | Research Methodology

The present study is developmental in terms of its objective, as the proposed model contributes to the development of sustainable technology, the advancement of the textile industry, and technology assessment in the textile industry. In terms of data collection, the research method is descriptive, while in terms of the nature of the data, the study is qualitative [7], [8].

2.1 | Research Population and Sample

The statistical population of the study comprises all experts in the textile industry in the country. In the qualitative phase, professional and academic experts in the fields of textile and technology were selected, and semi-structured interviews were conducted with them.

2.2 | Sampling Method

Given the lack of a structural framework for developing and assessing sustainable technology in the textile industry, interviews were conducted with textile industry experts based on theoretical perspectives, previous studies, and the identified indicators. To extract and identify the factors related to technology assessment, data were collected using theoretical sampling. Considering the criterion of theoretical saturation, 10 semi-structured interviews were conducted with textile industry experts, six of whom were interviewed electronically and online. The statistical sampling was conducted using a non-probability sampling method, with participants selected from four groups of individuals active in the fields of marketing, industry, operations, and management. The criteria for selecting experts for the interviews included their experience, knowledge, willingness to participate, and sufficient time to take part in the interviews. Based on library studies related to technology assessment and the findings obtained from the reviewed articles, the interview protocol was prepared, and the experts were interviewed using open-ended and semi-structured questions [9].

2.3 | Data Collection Method

Based on the library studies, the questions for the semi-structured interviews were developed, and the information obtained from the interviews was collected. Through individual semi-structured interviews lasting 90–180 minutes, the most important criteria for assessing sustainable technology in the textile industry were identified. Subsequently, a questionnaire based on the identified criteria was developed and provided to the experts. The basic information was collected based on the data available from textile industries in the country and research centers related to the textile industry, including the Customs Administration, active industries, and textile factories [10].

2.4 | Expert Interviews

Table 1. The characteristics of the expert sample.

Organizational Position	Educational Level	Work Experience (Years)
Manager	M.Sc.	21
CEO	Ph.D.	17
Textile expert	M.Sc.	11
Executive and managerial staff	M.Sc.	13
Academic expert	Ph.D.	6
Maintenance and repair expert	M.Sc.	10
Planning expert	M.Sc.	18
Industry manager	Ph.D.	10
Financial manager	M.Sc.	8
Production expert	M.Sc.	14

3 | Questionnaire

By examining the current situation, conducting library studies, and interviewing various experts, the most important strengths, weaknesses, opportunities, and threats affecting technology assessment in the country were identified. The identified factors were then presented to the experts. The items were designed based on a Likert-scale questionnaire, and the experts were asked to review the questionnaire and determine the importance of each factor in the field of technology assessment. *Table 2* summarizes the interview questions.

Table 2. Summary of the interview questions.

Components	Questions
Economic	1. What economic barriers exist to sustainable technology and its assessment in the textile industry? 2. To what extent does the lack of government support for providing funding and equipment to factories contribute to technological decline and bankruptcy? 3. How can the government influence the modernization of factory technologies?
Political	1. What are the political barriers to sustainable technology and its assessment in the textile industry? 2. How can textile factories maintain up-to-date technology and conduct effective technology assessment despite sanctions, economic considerations, and barriers to imports and exports?
Socio-cultural	1. What social and cultural barriers exist to the assessment of sustainable technology? 2. How can social and cultural factors contribute to forecasting and sustaining sustainable technology?
Research and development	1. What factors should be considered in the development of technological knowledge? 2. What are the reasons for deficiencies in knowledge, technology updates, and the training of specialized personnel? 3. How can the research and development problems of the textile industry be addressed? 4. How can up-to-date technological knowledge from around the world be utilized?
Marketing	1. What barriers exist to marketing the products of textile factories? 2. What factors affect the marketing and sales of products?
Organizational	1. What organizational barriers exist to technology assessment and its sustainability? 2. What organizational factors affect technology assessment and its sustainability? 1. What managerial barriers exist to technology assessment and its sustainability? 2. What managerial factors affect technology assessment and its sustainability? 3. What factors should managers consider when selecting technology and making informed decisions?
Environmental	1. What environmental barriers exist to technology assessment and sustainability? 2. How should pollutants generated by textile factories be addressed? 3. How can industrial pollutants be reduced?
Legal	1. What legal barriers exist to technology assessment and sustainability? 2. What solutions can be proposed to reduce legal barriers? 3. Which organization has the greatest influence on reforming customs and tax regulations? 4. How can the alignment of textile factory activities with the development of the textile industry be implemented?
Technical and engineering	1. What technical and engineering barriers exist to technology assessment and sustainability? 2. What technical factors affect technology assessment and sustainability? 3. What are the advantages of technological knowledge and the cost of implementing it in the country? 4. How should technology be aligned with market demand? 5. Is monthly maintenance of machinery necessary?

3.1| Questionnaire Validity and Reliability

After developing the preliminary version of the questionnaire, efforts were made to determine its validity and reliability. Validity refers to the extent to which a measurement instrument measures the intended construct. Without knowledge of the validity of a measurement instrument, it is not possible to ensure the accuracy of the data obtained from it. There are several methods for determining questionnaire validity; in this study, content validity was used. To determine the validity of the questionnaire for technology assessment in the textile industry, a number of questionnaires were distributed among experts, and the validity and reliability of the questionnaire were confirmed based on the experts' opinions.

3.1.1 | Content validity

The Content Validity Ratio (CVR) is a method for assessing the content validity of a questionnaire. This ratio was developed by Lawshe. To calculate the CVR, the opinions of experts specialized in the content area of the test under consideration are used. First, the test objectives are explained to the experts, and the operational definitions related to the content of the questions are provided. They are then asked to classify each question according to the following three-point Likert scale:

- I. The item is essential.
- II. The item is useful but not essential.
- III. The item is not necessary.

After collecting the experts' opinions, the CVR can be calculated using the following equation:

$$\text{CVR} = (n_e - N/2) / N/2,$$

where:

CVR: Content validity ratio.

N: Total number of experts.

n_e : Number of experts who considered the respective item in the questionnaire appropriate.

Minimum Acceptable CVR Based on the Number of Experts

Based on the number of experts who evaluated the questions, the minimum acceptable CVR value is determined according to the following table. Questions for which the calculated CVR value is lower than the required threshold corresponding to the number of experts evaluating the question should be excluded from the test, as they do not have acceptable validity based on the calculated CVR.

Table 3. Minimum acceptable CVR values based on the number of experts.

Number of Experts	CVR Value	Number of Experts	CVR Value
5	99%	11	59
6	99%	12	56
7	99%	13	54
8	78%	14	51
9	75%	15	49
10	62%	20	42

Accordingly, after preparing the questionnaire, the researcher distributed it among 20 experts, university professors, textile industry managers, and engineers. The degree and frequency of each respondent's agreement with the questionnaire items were determined, after which the CVR was calculated. The results obtained are presented in *Table 4*.

Table 4. Results obtained and number of experts for content validity.

Number of Experts	CVR
11	75%
12	72%
14	64%
15	58%
20	52%

3.1.2 | Reliability of the research instrument

Reliability is one of the technical characteristics of a measurement instrument. This concept concerns the extent to which a measurement instrument produces consistent results under different conditions. To determine the reliability of the research instrument, Cronbach's alpha coefficient was calculated. As shown in *Table 5*, the Cronbach's alpha coefficient for each component is above 70%; therefore, the instrument has an acceptable level of reliability.

Table 5. Cronbach's Alpha.

Variable	Cronbach's Alpha
Weaknesses	0.92
Strengths	0.89
Threats	0.78
Opportunities	0.80

4 | Bayesian Networks

Bayes' theorem is the foundation of Bayesian inference and Bayesian networks. Bayes' theorem was initially developed in the 1970s to update probabilities based on new information.

The following section examines Bayes' theorem:

$$P(B|A) = \frac{P(A|B)P(B)}{P(A)},$$

where $P(A)$ denotes the probability of occurrence of event A , $P(B)$ denotes the probability of occurrence of event B , $P(B|A)$ denotes the conditional probability of occurrence of event (B) , given the occurrence of event (A) , and $P(A|B)$ denotes the conditional probability of occurrence of event (A) , given the occurrence of event (B) . For event (B) , $P(B)$ represents the prior probability and $P(B|A)$ represents the posterior probability, each of which is associated with evidence. Therefore, Bayesian analysis describes the relationship between the prior and posterior probabilities using Bayes' theorem.

A Bayesian network is a probabilistic graphical model that represents the relationships among a set of random variables and their conditional dependencies through a Directed Acyclic Graph (DAG). Bayesian networks consist of two components. The first component is the DAG, in which each node represents a random variable and the arcs represent conditional dependencies. For example, if there is an arc from node (A) to node (B) , then (A) is the parent variable of (B) . The second component is the conditional probability distribution associated with each node. If the variables are discrete, this distribution can be represented by a table that lists the probability that the child node takes each of its possible values for each combination of values of its parent nodes. It should be noted that strong conditional dependencies exist within a Bayesian network. Based on the chain rule, when the conditional dependencies are taken into account, the joint probability of all nodes in the graph can be expressed as follows:

$$P(C, S, R, W) = P(C)P(S|C)P(R|S, C)P(W|C, S, R).$$

Using conditional independence relationships, the above equation can be simplified as follows:

$$P(C, S, R, W) = P(C)P(S|C)P(R|C)P(W|S, R).$$

For a generalized model with (n) components $X_1, X_2, \dots, X_i, \dots, X_n$, when the parent node $pa(X_i)$ of node X_i is given, (X_i) is conditionally independent of all other nodes except its descendants. Based on conditional independence, the joint probability can be expressed as follows:

$$P(X_1, X_2, \dots, X_n) = \prod_{i=1}^n P(X_i | \text{pa}(X_i)).$$

In this equation, $(\text{pa}(X_i))$ denotes the set of all parent nodes of (X_i) .

However, if there is no conditional independence among the nodes, the joint probability is given by the following equation:

$$\begin{aligned} P(X_1, X_2, \dots, X_n) &= P(X_1)P(X_2|X_1)P(X_3|X_1, X_2) \dots P(X_n|X_1, X_2, \dots, X_{n-1}) \\ &= \prod_{i=1}^n P(X_i | X_1, X_2, \dots, X_{n-1}). \end{aligned}$$

The number of independent parameters required in the above chain rule is $2^n - 1$. When it is assumed that there are (m) parameters in the parent set of $\text{pa}(X_i)$, the maximum number of independent parameters required for the joint probability of a Bayesian network is 2^m . In most normal systems, (m) is much smaller than (n) ; therefore, the computational complexity of Bayesian networks is significantly reduced.

4 | Research Model Description

The information required for modeling was obtained through an overall understanding of the textile industry, observations, a review of the literature, an examination of available analytical reports, interviews with managers and experts in the textile industry, and the opinions of experts at various technical and managerial levels. It should be noted that, among the factors introduced in the conceptual framework, some were incorporated into the model. In addition, different states were defined for nodes with multiple states based on the nature and characteristics of the variables. For example, “government programs and policies” was defined as a ranking-type node with three states: “efficient,” “acceptable,” and “inefficient.” Furthermore, for ranking-type nodes, a range from the lowest to the highest possible level was defined, with each level assigned a score ranging from the worst to the best condition. *Table 6* presents the nodes used in the model.

Table 6. Variables used in the research model.

Variable	Node Type and States
Budget available	Qualitative, with three states (low–medium–high)
Cost of production	Qualitative, with three states (high–medium–low)
Stability of profitability	Qualitative, with three states (low–medium–high)
Economic stability	Qualitative, with three states (low–medium–high), with a T-Normal distribution
Water waste management	Qualitative, with three states (low–medium–high)
Waste management	Qualitative, with three states (low–medium–high)
Supplying suitable raw materials	Qualitative, with three states (Unsuitable–Acceptable–Suitable)
Environmental sustainability	Qualitative, with three states (low–medium–high), with a T-Normal distribution
Safety culture	Qualitative, with three states (low–medium–high)
Managing relationships with suppliers	Qualitative, with three states (weak–average–excellent)
Fight against smuggling and corruption	Qualitative, with three states (weak–average–excellent)
Social stability	Qualitative, with three states (low–medium–high), with a T-Normal distribution
Compatibility of technology with market demand	Qualitative, with three states (low–medium–high)
Maintenance strategy	Qualitative, with three states (preventive–periodic–corrective)
Government programs and policies	Qualitative, with three states (inefficient–acceptable–efficient)
Sustainability of technology	Qualitative, with three states (low–medium–high), with a T-Normal distribution

To complete the Bayesian network, it is necessary to determine the relationships among the identified and defined variables. The relationships among the variables were examined through a review of the literature and previous research in the field of sustainability. In addition, the knowledge of experts in this field was used to verify and validate the identified relationships. Several face-to-face interviews were also conducted with experts in the textile industry. The AgenaRisk software was used for modeling. *Fig. 1* presents the proposed Bayesian network.

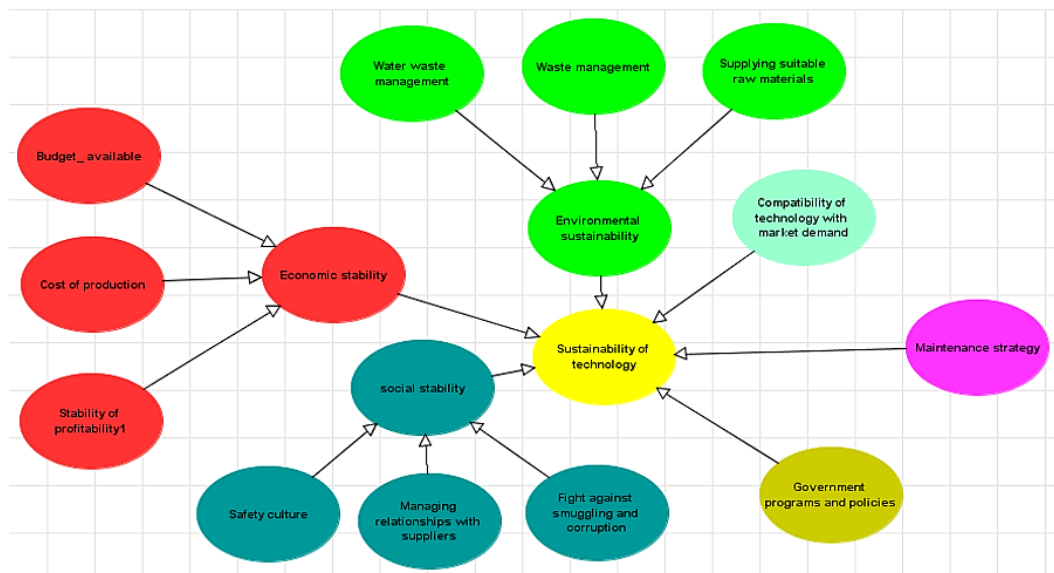


Fig. 1. Proposed Bayesian network for sustainable technology assessment.

The implementation of the model using AgenaRisk software with the initial data is presented in *Fig. 2*.

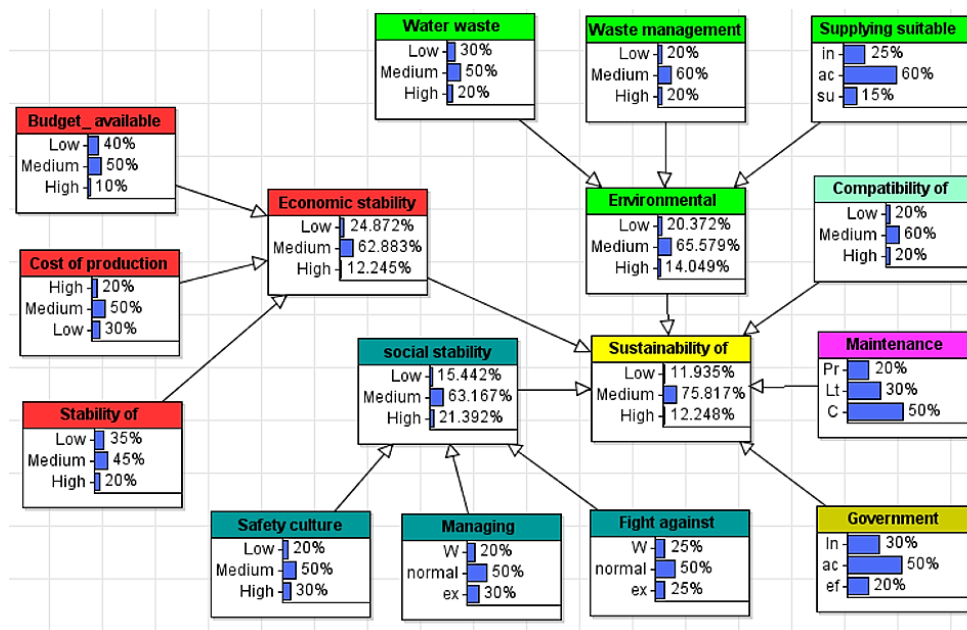


Fig. 2. Implementation of the proposed model with initial data using AgenaRisk software.

5 | Different Scenarios for Model Evaluation

In this section, two scenarios are considered to evaluate the model. The results obtained from the scenarios after implementing the model are reported below.

5.1| Considering the Economic Stability Node at a High Level and Its Effect on the Target Node (Technology Sustainability)

After setting the economic stability node to the high state, it was observed that technology sustainability increased by approximately 14%. Fig. 3 presents the implementation of this scenario in the model.

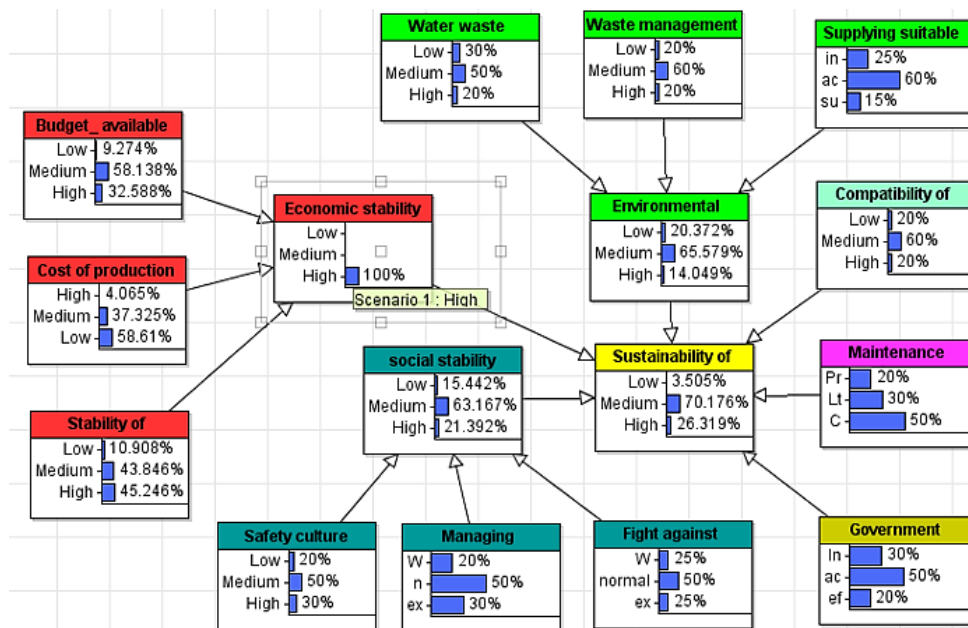


Fig. 3. Model implementation under high economic stability.

5.2| Considering the Social Stability Node at a High Level and Its Effect on the Target Node (Technology Sustainability)

After setting the social stability node to the high state, it was observed that technology sustainability increased by approximately 8%. Fig. 4 presents the implementation of this scenario in the model.

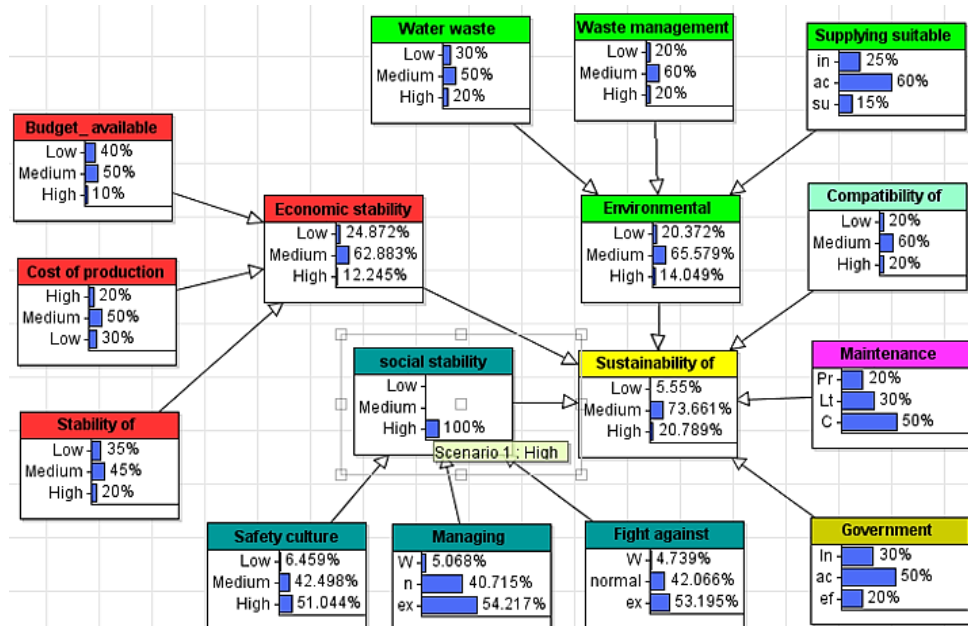
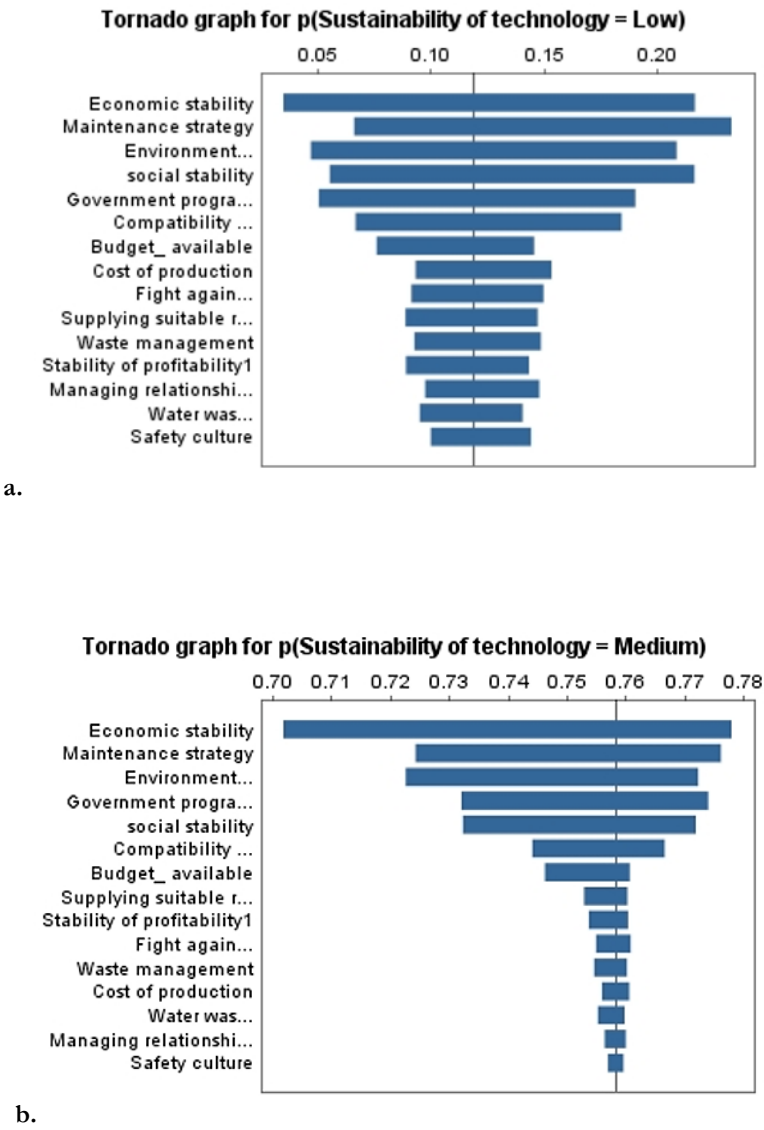
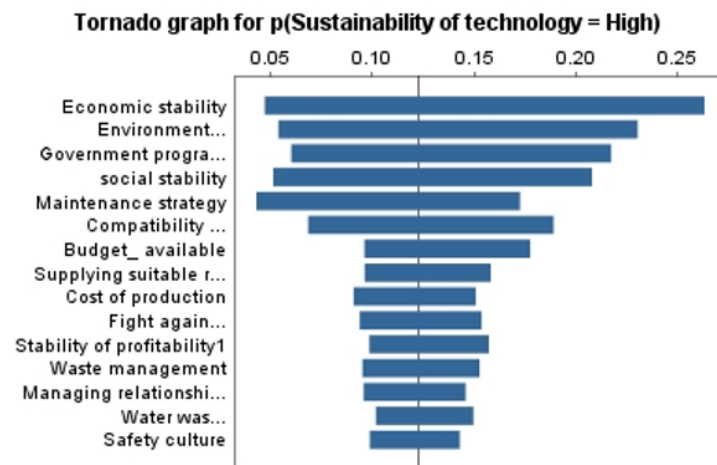


Fig. 4. Model implementation under high social stability.

6 | Sensitivity Analysis

Sensitivity analysis can highlight the factors that significantly influence the output of the model. If the validation result is positive, it means that none of the possible causes for rejecting the validity of the model have been identified, and the validation procedure is considered complete. However, if the result of this process is not positive, it is necessary to conduct a verification process to identify the sources and reasons for the model’s lack of validity. For the research model, the results of the sensitivity analysis are reported as an example for the target variable.





c.

Fig. 5. Tornado diagram for the target node.

7 | Conclusion

The present study aimed to identify the factors and risks affecting technology sustainability in the textile industry and to develop a comprehensive model for assessing and analyzing these factors using Bayesian networks. By considering the uncertainty and complexities inherent in this industry, the proposed model provides an appropriate tool for forecasting and assessing sustainable technology. The use of Bayesian networks, owing to their ability to analyze probabilistic relationships among various factors and evaluate different scenarios, enables the provision of valuable insights for improving technology management in the textile industry. The results of this study showed that economic and social sustainability have a significant impact on technology sustainability in the textile industry. As economic sustainability increases, technology sustainability increases considerably.

Furthermore, improving social sustainability also has a positive effect on technology sustainability. The sensitivity analysis also indicated that certain factors have a substantial influence on the model output. These findings can help managers and policymakers in the textile industry focus on key factors and manage related risks to improve technology sustainability and ultimately contribute to the sustainable development of the industry.

Acknowledgments

The authors are grateful to all individuals who contributed to the completion of this study through their assistance and constructive input.

Funding

The authors declare that this study was conducted without financial support from any external organization.

Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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