Journal of Engineering and Technology for Industrial Applications

ISSN ONLINE: 2447-0228

ITEGAM-JETIA

Manaus, v.11 n.56, p.119-135. November/December., 2025.

DOI: https://doi.org/10.5935/jetia. v11i56.2721

RESEARCH ARTICLE OPEN ACCESS

APPLYING THE BAYESIAN NETWORK MODEL FOR SUSTAINABLE SUPPLY CHAIN MANAGEMENT IN THE PALM OIL INDUSTRY: IMPLICATIONS FOR OPEN INNOVATION

Rabiatul Adwiyah[1], Yusman Syaukat[2], Heti Mulyati[3], Diky Indrawan[4] and Nizar Fauzan[5]

[1] Faculty of Economic and Business, Universitas Islam Bandung, Bandung, Indonesia
[2,3] Faculty of Economics and Management, IPB University, Bogor, Indonesia
[4] School of Business, IPB University, Bogor, Indonesia
[5] Faculty of Business Administration and Accountancy, Khon Kaen University, Khon Kaen, Thailand

[1]https://orcid.org/0000-0002-7627-0088, [2]http://orcid.org/0000-0002-6473-3647, [3]https://orcid.org/0000-0001-9466-3785
[4]https://orcid.org/0000-0003-1291-5729, [5]https://orcid.org/0000-0002-0876-1491,

Email: rabiatuladwiyah@unisba.ac.id, ysyaukat@apps.ipb.ac.id, heti@apps.ipb.ac.id, rdiky@apps.ipb.ac.id

ARTICLE INFO

Article History
Received: September 21, 2025.
Revised: October 20, 2025.
Accepted: November 1, 2025.
Published: November 30, 2025.

Keywords:
Bayesian network model,
Open innovation,
Palm oil industry,
SSCM.

ABSTRACT

The palm oil industry is known for its social and environmental challenges that require innovative solutions. This study investigated the Bayesian network model designed to provide better sustainable supply chain transparency by considering social responsibility and ecological effects. The data was collected using questionnaires from 16 respondents responsible for the company's supply chain operations. The application of the Bayesian Network Model in sustainable supply chain management (SSCM) in the palm oil industry contributed to breakthroughs, especially in sustainability practices and efficient decision-making action to countermeasure and resolve complex interactions and uncertainties. The output presented the interaction between factors on sustainable supply chain management in the palm oil sector, demonstrating the mechanism for stakeholders' decision in open innovation to prioritize environmental sustainability and behavioral transparency in their supply chain operation. As a result, the company can exhibit an advanced and clean palm oil supply chain.

Copyright ©2025 by authors and Galileo Institute of Technology and Education of the Amazon (ITEGAM). This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

I. INTRODUCTION

Palm oil plantations are a strategic sub-sector that economically, ecologically, and socio-culturally play a vital role in many developing countries, including Indonesia, one of the leading exporters. Indonesia has a high potential for palm oil because the climate optimizes its growth. Palm oil is a tropical plant from West Africa that can reach 24 m in height. Their flowers and fruits are attached in bunches and have many trunks. The fruit is small, blackish-red when it ripens, and the flesh is firm [1]. The high growth of the palm oil industry in Indonesia positively affects employment and additional foreign exchange [2]. Index Mundi [3] reported that Indonesia secured its first position as a crude palm oil producer in 2023, producing 46,500 million tons or 58.7% of the global output (Figure 1). Furthermore, Indonesia's palm oil plantation area is the largest in the world (14.5 million ha). Therefore, palm oil commodities are at the forefront compared to other plantation commodities in Indonesia.

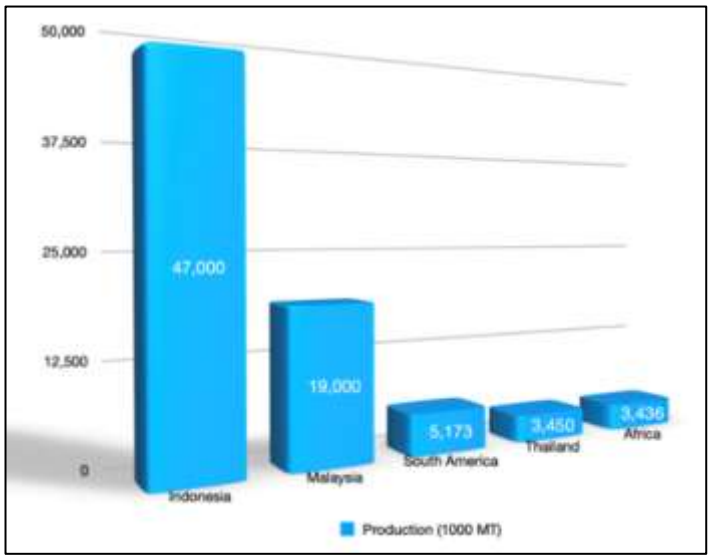

Figure 1: World palm oil producers (million tons) in 2023.
Source: [3].

Palm oil plantations are a large-scale, complex, and capital-intensive agricultural economic system. In their operations, palm oil plantations use large parcels of land, have a large labor organization with detailed divisions, use modern technology, and are equipped with a specialized administrative system. Palm oil plants are one of the leading vegetable oil-producing crops and significantly influence economic growth. Following Republic of Indonesia Law Number 39 of 2014 concerning Plantations [4], plantations are all activities for managing natural resources, human resources, production facilities, tools and machines, cultivation, harvesting, processing, and marketing related to plantation crops. As a result, many palm oil plantations export and significantly contribute to the country's foreign exchange earnings [5].

The palm oil industry is considered an industry that damages the environment and has been unfriendly to social welfare [6]–[8]. Pacheco et al. [9] found that improving the performance of the palm oil industry can be done through the Roundtable on Sustainable Palm Oil (RSPO) with a primary focus on nature conservation. Their findings found that the RSPO needs to expand fundamental control and take a more decisive role in fighting forest destruction because the expansion of palm oil plantations is affecting the climate and destroying many forests. The expansion of palm oil plantations must be balanced with reforestation policies that favour environmental aspects to achieve sustainable development goals. Carlson et al.

[10] found that sustainable certification for palm oil companies can be implemented to eliminate deforestation and wildfire. Furthermore, companies with sustainable certification activities are better than plantations without accreditation. These difficulties can be addressed by focusing on the rules for company sustainability. Elkington [11] defined the triple bottom line as profits, people, and the environment, which has become the standard guideline for business sustainability. These features represent an effort to incorporate economic, environmental, and social factors into company decision-making that necessitates operational innovation [12]. A sustainable supply chain is one example of a multifaceted method that can be applied.

This strategy is critical in the industry and can be implemented by combining economic, social, technological, and environmental factors to innovate firm supply chain operations [13]. Brandenburg et al. [14] defined a sustainable supply chain as representing economic, social, environmental, and political policies related to the improvement and innovation in the consumer fulfillment process phases of design, procurement, manufacturing, packaging, and distribution. In addition, sustainable supply chains can maximize profitability, minimize environmental impacts, and recover social welfare [15]. This indicates that sustainable supply chain management requires innovation based on the triple bottom line idea, which includes economic, social, and environmental factors.

I.1 ORIGINALITY

The palm oil business relies heavily on the supply chain management performance of palm oil companies that employ product sustainability practices. It takes time to reach optimal settings for the performance of palm oil's supply chain management. Sustainable palm oil supply chain management, also known as the Green Supply Chain (GSC), is now in its early phases of development. However, many GSC applications address ecologically sustainable development strategies. As a result, many proposals for adopting sustainable palm oil supply chain management, such as triple-bottom-line effectiveness indicators, need to be made more explicit.

Furthermore, the factors that influence the performance of sustainable supply chain management in the palm oil industry have yet to be well identified. Suroso et al. [16] found that the palm oil industry can have negative domestic implications, such as land access conflicts and differences in crop yields. These issues intersect with sustainable development aspects. Improving palm oil's supply chain management so that the palm oil industry can operate optimally in the long term requires innovation for the palm oil industry to work in an integrated and systematic manner. This reason supports this study, which aims to reveal how sustainability works in the present palm oil business model innovation trend.

The demands of the sustainable palm oil industry were resolved by implementing the Roundtable on Sustainable Palm Oil and the Indonesian Sustainable Palm Oil. However, many unsustainable palm oil industries still exist, such as fog due to wildfire, child labor, land conflicts, and underpaid workers [17]. These challenges may arise due to a need for more information on variables and determinants in supply chain performance that aid corporate decision-making in improving its sustainability strategies. According to a literature review,

there still needs to be more research on palm oil companies' strategies for meeting market sustainability requirements and enhancing supply chain performance by employing dynamic assessments to measure overall sustainability challenges. The majority of research in supply chain focuses on the use of analytical tools such as Supply Chain Operations Reference [18], [19], Six Sigma [20], and Structural Equation Modelin [21]. Apart from that, some studies use Fuzzy AHP [22], Analytic Network Process [23], and Balanced Scorecard [24]. Companies in Indonesia require a strategy to restore the social and environmental issues harmed by the palm oil sector while increasing its economic contribution. The plan includes supply chain innovation and using Bayesian networks as indicators in a probabilistic graphical model for measuring sustainable supply chain performance.

This novel research strategy addresses the sustainability challenges confronting Indonesia's palm oil industry. Bayesian network consists of two main parts: the Directed Acyclic Graph structure and the Conditional Probability Table [25], [26]. In addition, methods for building Bayesian network structures directly from databases, such as search and scoring methods and constraint-based analysis, have been widely developed. Search and scoring methods are used to obtain a structure that suits the data. The construction process is carried out iteratively to find better structures than the previous ones. Meanwhile, in the dependency analysis method, the Bayesian network is seen as a structure representing the conditional independence of groups between variables [26]. The Bayesian network model can consider sustainable supply chain integration, allowing businesses to improve work procedures and the net economy [27]–[29].

I.2 RESEARCH AIMS AND QUESTION

This research aimed to develop a model to assist the palm oil business improve supply chain profitability, reduce environmental impacts, and increase social welfare in complex scenarios. The Bayesian network model was used to create and evaluate a sustainable supply chain model for the palm oil business in PTPN III Indonesia. The analysis outcomes should contribute to increased competitiveness and efficiency while considering the implications for open innovation.

II. THEORETICAL BACKGROUND AND HYPOTHESES

II.1 SUSTAINABLE SUPPLY CHAIN MANAGEMENT

According to Dyllick and Hockerts [30], sustainable supply chain management integrates sustainable development and environmental, social, and economic issues. Although sustainable supply chain management is considered relatively new, interest in this knowledge has proliferated over the years. Seuring and Müller [31] reviewed 191 scientific journals on supplier management's risks and performance and supply chain management's sustainable products from 1994 to 2007. They found that economic and environmental aspects in the supply chain were the most studied dimensions. Sikdar [32] defined sustainability as a melting point between economic development, environmental management, and social justice.

A review of various elements related to a sustainable supply chain shows that sustainable supply chain management can be linked to environmentally friendly aspects, inventory management, production planning and control, product recovery, reverse logistics, waste management, energy consumption, and emission reduction [33]. Furthermore, Carter and Rogers [34] defined sustainable supply chain management as a transparency-work process to achieve strategic social goals and economic objectives in an organization with an environmental-based scheme. Improving long-term sustainable economic performance can be achieved through coordinated and systematic business processes between organizations within the company.

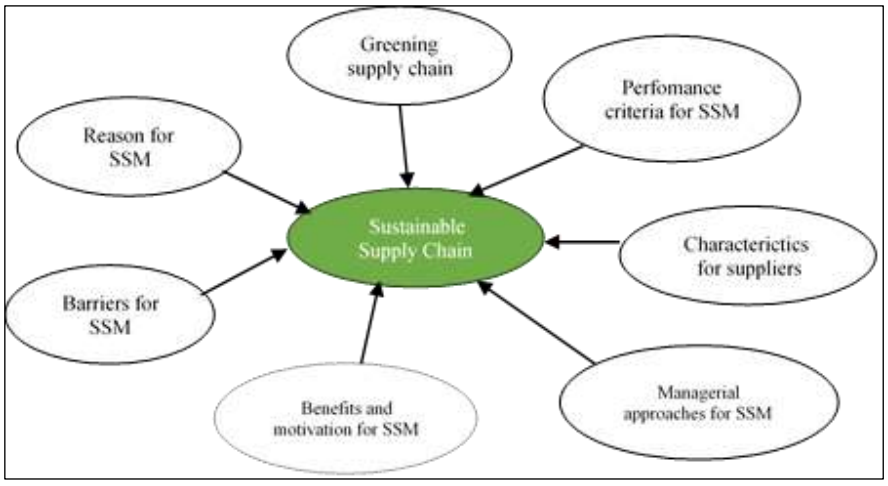

Figure 2: Sustainable supply chain management conceptual model.
Source: [35].

According to Ageron et al. [35], sustainable supply chain management includes seven branches (Figure 2). In addition, Carter and Rogers [34] argued that the sustainable supply chain framework intersects with resource aspects, transaction cost economics, population ecology, and the resource-based view of the company. Furthermore, Ageron et al. [35] divided corporate supply chain sustainability into five dimensions: business-level application and communication, organizational focus scope, innovation-oriented sustainability, economic/ ecological-environmental/ social-justice emphasis, and compliance attitude. They also added that companies can perform well in these five dimensions only if they have an excellent public image, achieve zero pollutant emissions, have comprehensive supply chain information, and prioritize a willingness to share.

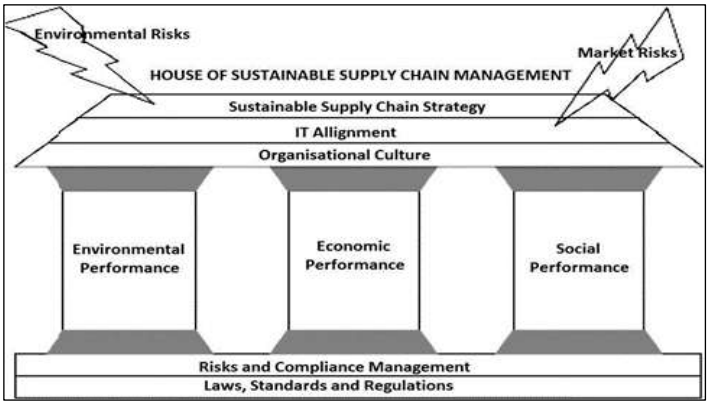

Figure 3: Sustainable supply chain house.
Source: [36].

Wittstruck and Teuteberg [36] proposed a Sustainable Supply Chain House (Figure 3) based on three triple bottom line dimensions: building balance, risk management, and compliance from the building foundation. Sustainable supply chain management requires establishing values and ethics throughout the organization, such as an efficient green technology information environment and a company strategy focusing on harmonizing development. By taking these steps, sustainable corporate networks will be effectively protected from environmental and social menaces.

II.2 SUSTAINABLE SUPPLY CHAIN MANAGEMENT PERFORMANCE

In recent years, sustainable supply chain management has become a well-known topic among researchers and practitioners [14], [37]. Many researchers acknowledge that sustainable supply chain management is vital for companies because it is related to market demands, the overall economy, company strategies in achieving goals, market competition, and overall company performance [38], [39]. Therefore, companies must be innovative in sustainably managing supply chains in three dimensions: social, environmental, and economic [40].

Figure 4: Process of attaining sustainable development through sustainable supply chain management.
Source: [41].

Sustainable development is characterized by the participation of every member of society in economic activities. Pham et al. [42] found that traditional agricultural systems integrating humans with nature can achieve better results in financial and environmental dimensions. Supply chain management's sustainability indicators from previous studies with various objectives are presented in Table 1.

Table 1: Indicators for assessing sustainable supply chain performance.

Aspects	Criteria	Sources
Economic Dimension (E)	1. Productivity of the palm oil industry	[43]
	2. Financial performance and financial competitiveness of the palm oil industry	[22], [40], [44]
	3. Business transparency Commitment to transparency and traceability	[20], [43]
	4. Ease of access to price information	[40]
	5. Logistics Optimization	[45]
Social Dimension (S)	1. The educational level of industrial employees	[39]
	2. Availability of infrastructure for agricultural activities	[38]
	3. Ethics and awareness of entrepreneurs regarding palm oil businesses	[22], [44]
	4. Working conditions, employee rights, and welfare of palm oil industry employees	[22]
Environmental Dimensions (L)	1. Area of managed palm oil plantations	[46]
	2. Implementation of ISO 14000 standards	[47]
	3. Environmental pollution	[47]
	4. Environmental Management System	[48]

Source: Authors, (2025).

II.3 BAYESIAN NETWORK

Bayesian network/probabilistic network is a model for representing interactions between variables depicted by graphs and consisting of nodes and arcs. The node will display the variable (p) and its p(x) probability value. Meanwhile, arcs will show the relationships between nodes. If there is a connection from X to Y, variable X influences variable Y. This influence is expressed by the conditional probability P(Y|X). Naïve Bayes ignores the correlation between variables, while the Bayesian network assumes input variables can depend on each other [44]. Bayesian networks are based on Bayes' theorem, where conditional probability is denoted by P(A|B) (the probability that A exists if state B has occurred.) Bayes' theorem formula:

$$P(A|B) = P(B|A)\, x\, P(A)/\, P(B) \quad (1)$$

Where P(A|B) is the posterior probability (the chance of A will occur after B has occurred), P(B∩A) is the probability that B and A occur together, P(B|A) is the likelihood (the chance that B will occur after A has happened), P(A) = prior (the probability of event A), and P(B) = probability of event B. According to [45], Bayesian Networks (BN) offer several benefits, including a) effective treatment of missing value problems; b) good prediction due to the knowledge of causal relationships between variables; c) easy application of prior knowledge; d) the ability to use probability propagation "backward," when the goal is to determine the most likely scenario explaining the set of evidence.

II.4 HYPOTHESES

This research develops hypotheses as follows:
H0: There are no opportunities for implementing indicators to assess sustainable supply chain performance in the palm oil industry.
H1: There are opportunities for implementing indicators to assess sustainable supply chain performance in the palm oil industry.

III. METODOLOGY

III.1 RESEARCH STAGES

The Bayesian Network (BN) is a probabilistic graphical model that illustrates a set of variables along with their interrelationships. The probability of a relationship between related or unrelated events can be displayed using a Bayesian network. A Bayesian network is represented by graphs with nodes that serve as variables or hypotheses for a given assertion. Two primary components comprise the Bayesian Network [46]:

A. Graph structure

A directed acyclic graph (DAG) is a directed graph that lacks directed cycles, and it is the type of graph structure found in Bayesian networks. A DAG is made up of edges and nodes. Nodes represent random variables, and direct dependency links—causal relationships between connected variables—are represented by edges. There is a conditional independent relationship between the variables if there are no edges.

B. A group of parameters

The conditional probability distribution is defined by the parameter set for every variable. Bayesian Network is built using a statistical approach called Bayes' Theorem, namely conditional probability. Conditional Probability is denoted by the chance of a condition A if it is known that condition B has occurred. The flow diagram for building a Bayesian network model in studying sustainable supply chain management in the palm oil industry and its implications for open innovation consists of several stages: (1) Identity and formulation problem, (2) Gathering information/ Data Collection, (3) Data testing, (4) Modeling Bayesian Network and (5) Data Analysis (Figure 5).

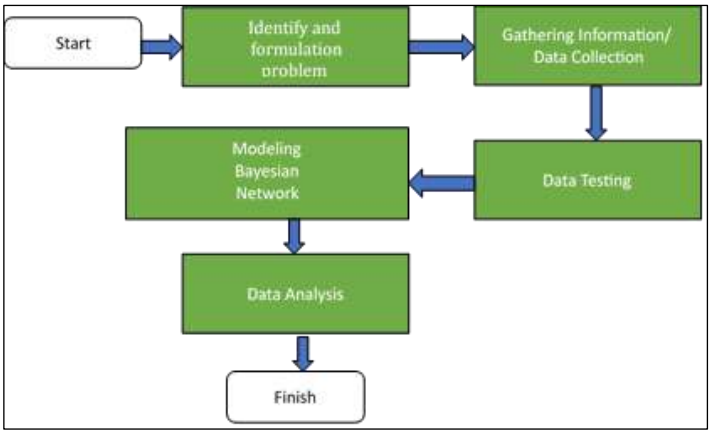

Figure 5: Research flowchart.
Source: Authors, (2025).

III.2 IDENTIFY AND FORMULATION PROBLEM

Start by learning everything there is to know about PTPN III Indonesia's palm oil sector. This entails researching the industry's operating environment and social, economic, and geographic contexts. Determine the unique opportunities and problems facing the region's palm oil industry. This could involve supply chain effectiveness, market dynamics, regulatory compliance, socioeconomic

development, and environmental sustainability. Determine the critical elements and variables that affect the supply chain for palm oil's sustainability. Consider both quantitative and qualitative variables that may impact the sustainability of the supply chain and their interrelationships. Formulate a Bayesian network model to represent the probabilistic relationships between the critical variables identified in the previous steps.

III. 3 DATA COLLECTION

The data used in this research was collected by distributing questionnaires to respondents at PT Industri Nabati Lestari (PT.INL) KEK Sei Mangkei, PT PTPN III, North Sumatra, Indonesia. Sixteen respondents consisted of operational managers (Two Respondent), supply chain managers (Two Respondent), financial managers (One Respondent), human resources managers (One Respondent), and parties supervising crude palm oil products and other derivative products (Ten Respondent). These respondents were selected because daily operations in the palm oil supply chain, such as planting, harvesting, processing, and distribution, are under the purview of operational managers. Comprehending the consequences of a sustainable supply chain model is essential for maximizing operational effectiveness, cutting expenses, and guaranteeing adherence to social and environmental norms. From the procurement of raw materials to the delivery of completed goods, supply chain managers manage the complete flow of commodities and information.

They must guarantee that the supply chain is robust, sustainable, and adaptable to the shifting needs of the market. The Bayesian network model offers insights that can be used to manage inventories better, find bottlenecks, and strengthen ties with suppliers. Data extracted from the questionnaire were responses related to Productivity of the palm oil industry, Financial performance and financial competitiveness of the palm oil industry, Business transparency Commitment to transparency and traceability, Ease of access to price information, Logistics Optimization, The educational level of industrial employees, Availability of infrastructure for agricultural activities, Ethics and awareness of entrepreneurs regarding palm oil businesses, Working conditions, employee rights, and welfare of palm oil industry employees, Area of managed palm oil plantations, Implementation of ISO 14000 standards, Environmental pollution and Environmental Management System.

III.4 MODELLING BAYESIAN NETWORK AND DATA ANALYSIS

The research used 13 triple-bottom-line economic, social, and environmental variables (Table 1). The relationship between 13 variables was modeled using the structural Bayesian model on R-Studio version 0.98.1014. The resulting model was used to implement sustainable supply chain management in the palm oil industry. The data obtained was processed using the following stages: 1. Collecting data on economic, social, and environmental dimensions at the research location. The data obtained was neatly organized into Microsoft Excel software; 2. Data pre-processing: (a) data cleaning by deleting data with missing or empty attribute values; (b) data transformation; (c) grouping the attribute or variable values; and 3. System testing is done by measuring the system's classification performance based on accuracy, which is how much data was predicted correctly and the time the system takes to process data. The Bayesian network model workflow consists of six stages: 1) Data pre-processing: data accuracy and data correctness are very important because poor-quality data will produce useless output.

Therefore, this research cleaned data and corrected inconsistencies; 2) The study used a scoring-based approach/search method to build and evaluate models based on score values. The score calculation stops if the value of a model does not have a more significant difference than the previous model; 3) The scoring-based method was equipped with a hill-climbing algorithm. Hill climbing is a heuristic search method that works by giving a score to each parameter to determine the level of connectedness of each parameter using the Bayesian information criterion score function; 4) After obtaining a score for each connected node, the node was visualized in the form of a Directed Acyclic Graph; 5) After the Bayesian network structure was formed, parameter calculations were carried out to obtain the conditional values for the Probability Table; and 6) The final stage is inference. This stage was carried out to see the model's accuracy using the approximate inference approach.

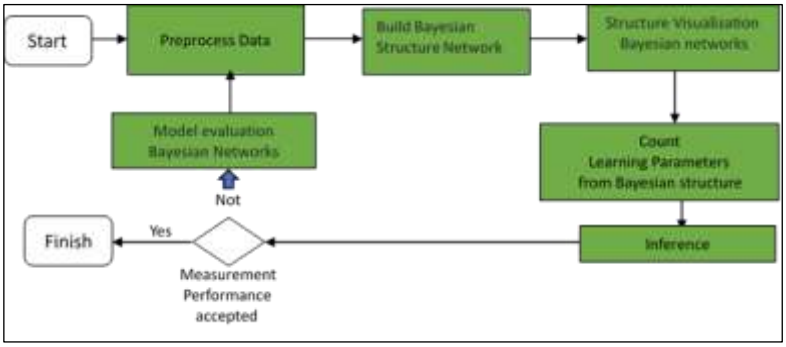

Figure 6: Application of the bayesian network method.
Source: Authors, (2025).

IV. RESULTS AND DISCUSSIONS

IV.1 BAYESIAN NETWORK STRUCTURE

The Bayesian network structure for triple-bottom-line variables in sustainable supply chain management studies began with formulating the problems to be studied. Structures formed using the Hill-Climbing method are popular for obtaining high-quality Bayesian network structures. Instructions used to form structure learning in the Bayesian network structure:

> library (bnlearn)
> network=hc(data, score="BIC", max.iter=1000)

Iteration through a scoring-based algorithm assumes the nodes are in an ordered state and starts from a structure that does not have a network. The network formation process will stop if the number of iterations is met. Data processing in this study is presented in Table 2 below:

Table 2: Data adjustment results.

No	Q3	Q4	Q5	Q6	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17
1	Manager	Male	s1	> 40 year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2	Manager	Female	s1	> 40 year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3	Manager	Male	s2	< 40 year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4	Other	Female	s1	< 40 year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5	Manager	Male	s2	> 40 year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
6	Other	Female	s1	< 40 year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7	Other	Male	s2	> 40 year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
8	Manager	Male	s2	> 40 year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
9	Other	Female	s2	> 40 year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
10	Manager	Male	s2	> 40 year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
11	Manager	Male	s2	> 40 year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
12	Other	Male	s2	> 40 year	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No
13	Other	Male	s1	< 40 year	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No
14	Other	Male	s2	< 40 year	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	No
15	Other	Male	s2	< 40 year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
16	Other	Male	s1	< 40 year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Source: Authors, (2025).

Note: S1 = Bachelor; S2 = Master's; Yes = 1; No = 0

Table 3: Conditional probability table (CPT) bayesian optimal results bayesian network parameters.

Occupation (Q3)	Age (Q3)	Sex (Q4)	Education (Q3)
Manager (0.1666667)	< 40 (0.6578947)	Male (0.7352941)	S2 (0.4411765)
Other (0,8333333)	>40 (0.3421053)	Female (0.2647059)	S1 (0.5588235)

Source: Authors, (2025).

The questionnaire produces respondent profiles according to occupation, gender, highest level of education, and age.

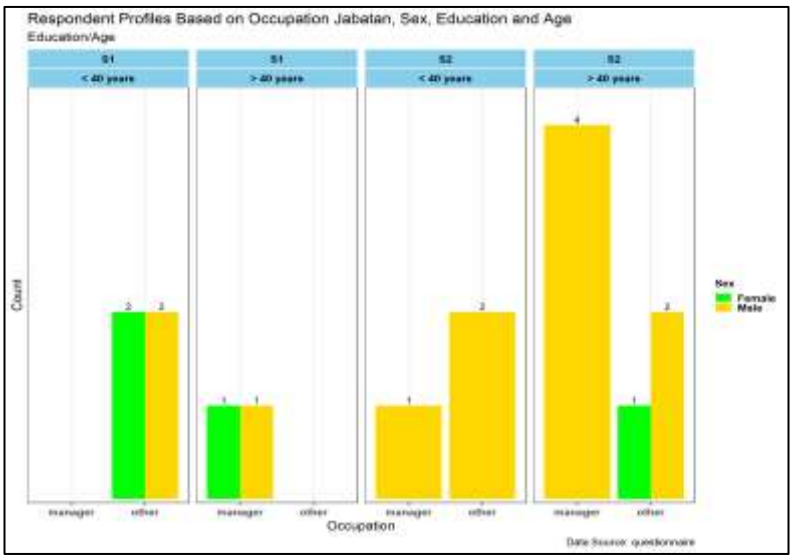

Figure 7: Respondent's profiles.
Source: Authors, (2025).

The average respondent profile is that of a man aged >40 years with a master's degree who is working as a manager. In addition, other respondents were managers and other occupations aged >40 years and <40 years with a bachelor's degree. Globalization makes

company competition increasingly fierce. This situation requires every company to improve their activities to maintain their existence in the long run.

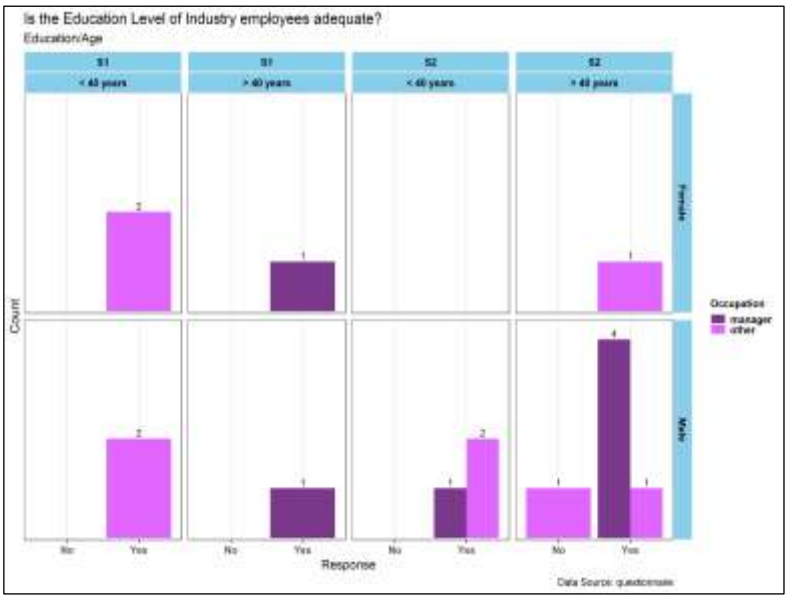

Figure 8: The educational level of industry employees.
Source: Authors, (2025).

Unquestionably, globalization has increased the level of corporate rivalry. Because of the fierce competition, every business must enhance every facet of the organization to stay in business and grow. Human resources (HR) are one illustration of the most crucial component of an organization's success. Since HR is the primary factor influencing every aspect of business success, HR is the organization's central figure. Any firm that wants to succeed must have credible human resources because they make all actions and objectives real. The research revealed that 93.8% of industrial employees felt their education level needed to be improved, while 7.2% felt insufficient.

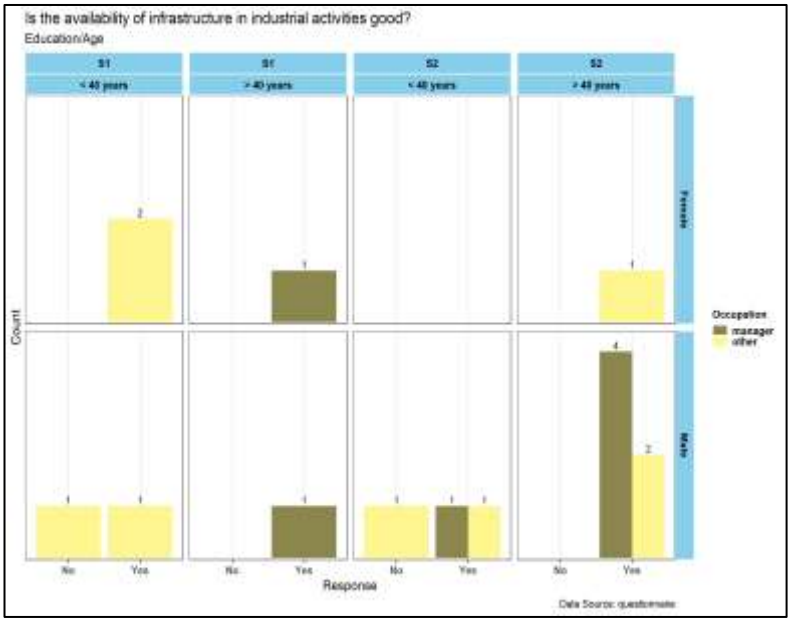

Figure 9: Infrastructure variable.
Source: Authors, (2025).

Figure 9 shows respondents working as managers aged >40 with a master's degree background (S2) who responded that the availability of infrastructure in their palm oil company was considered satisfactory. The seamless operation of industrial zones is significantly dependent on the availability of infrastructure. According to the answers to a survey on infrastructure availability, 87.5% of participants claimed that industrial operations had good infrastructure, while 12.5% said that it did not. One of the components in the engine of economic expansion is infrastructure. Increasing productivity and accessibility for people in their activities is one of the functions of infrastructure.

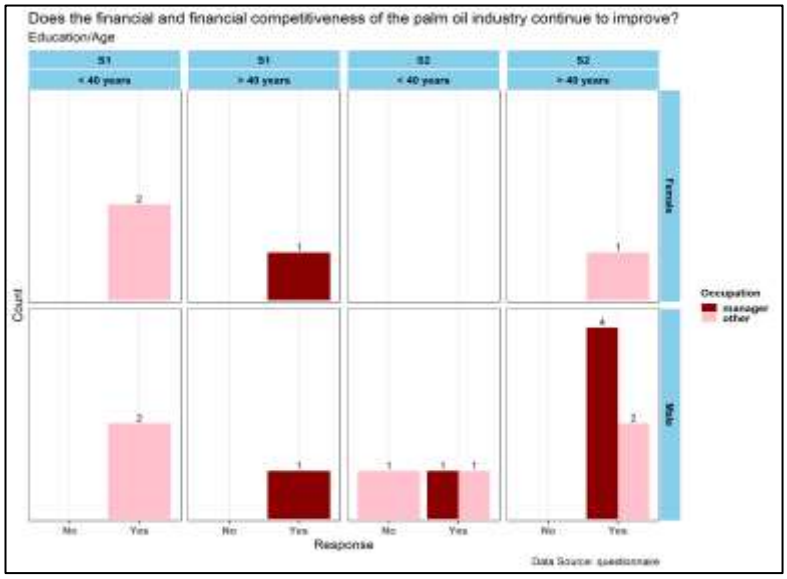

Figure 10: Financial competitiveness variable.
Source: Authors, (2025).

Figure 10 shows that respondents working as managers aged >40 with a master's degree level (S2) responded that their palm oil industry's financial performance and competitiveness are rising. Economic performance is one parameter for evaluating financial reports and determining if a business is performing well or not, as well as for observing and forecasting a company's future. According to the survey results, 93.8% of respondents said their financial competitiveness had increased, while 6.2% said it had not.

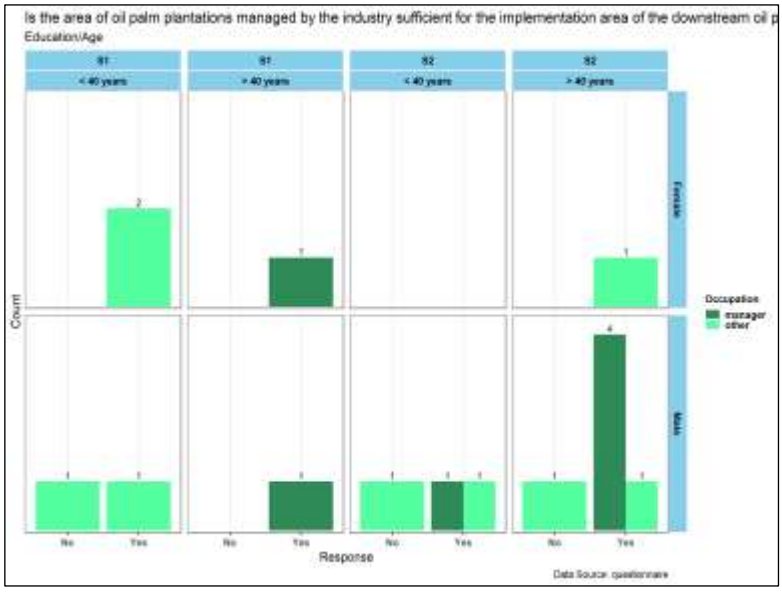

Figure 11: Area plantations variable.
Source: Authors, (2025).

Based on Figure 11, respondents working as managers aged >40 with a master's degree background (S2) responded that their palm oil plantation area managed by their industry is sufficient for the downstream business implementation. Six respondents said the oil palm plantation land managed by their industry already encompasses the downstream implementation. The land in Indonesia has the potential to be used as an oil palm plantation, estimated to be around 47 million hectares; high potential of around 25 hectares, medium potential of around 3.4 hectares, and low potential of about 18.6 hectares, according to data from the Agricultural Research and Development Agency, Ministry of Agriculture. With approximately 15 million hectares of plantation land currently in use, over 68% is still usable.

IV.2 BAYESI=AN NETWORK STRUCTURE VISUALIZATION

The visual representation of the probabilistic interactions between variables in a graphical manner is known as Bayesian network structure visualization. Nodes represent variables, and dependencies—which show causal or conditional relationships—are demonstrated by edges. Understanding intricate interdependencies and the spread of uncertainty within a network is made easier with the help of visualization. It makes scenario analysis, variable identification, and model interpretation easier. Probabilistic graphical models (PGMs), which represent joint probability distributions, and directed acyclic graphs (DAGs), in which nodes are ordered hierarchically based on causal interactions, are two popular visualization techniques. These visual aids improve communication by helping stakeholders understand the dynamics and structure of Bayesian networks so they can make well-informed decisions across various industries.

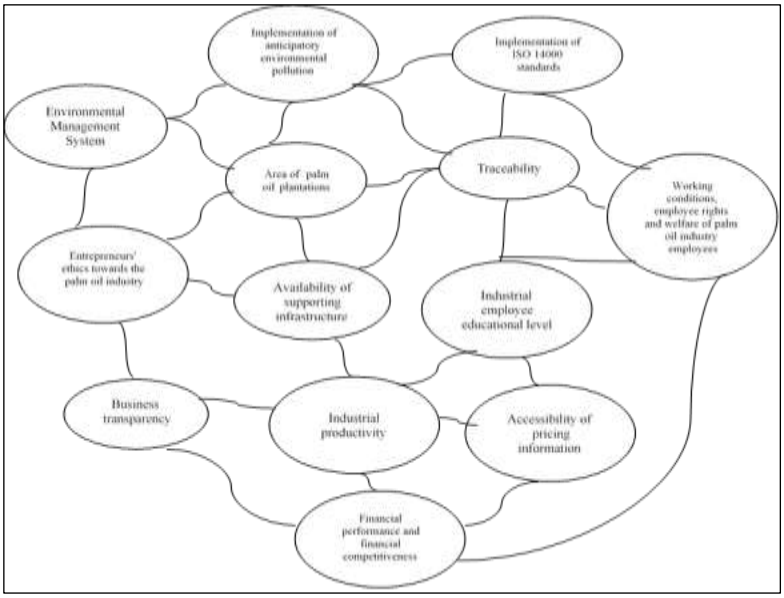

Figure 12: Structure of Bayesian network in sustainable supply chain management.
Source: Authors, (2025).

The assessment was done heuristically using the Hill-Climbing algorithm by studying the data network structure and estimating the local discovery model. Based on the Bayesian network plot, the results of the Hill-Climbing algorithm identified an illogical relationship (occupation influences age). Thus, modifications to the network structure were carried out.

IV.3 CALCULATING LEARNING PARAMETERS

Once the Bayesian network structure was formed, each node was calculated to produce parameter values indicating each variable's probability value. This learning parameter calculation used Bayesian Estimation to obtain CPT values (Conditional Probability Figures 13 and 14).

Q13: Company financial performance
Q12: Availability of supporting infrastructure for the palm oil industry
Q10: Educational level of palm oil industry employees
Q17: Area of palm oil industrial land

The structure in Figure 13 shows the relationship between variables Q10 (educational level of palm oil industry employees) and Q13 (company financial performance). The probability of employee education accomplishing sustainable performance in palm oil's supply chain is 91.2%. In addition, the probabilities for financial performance and infrastructure availability in supporting the sustainable performance of palm oil's supply chain are 85.3% and 91.2%, respectively.

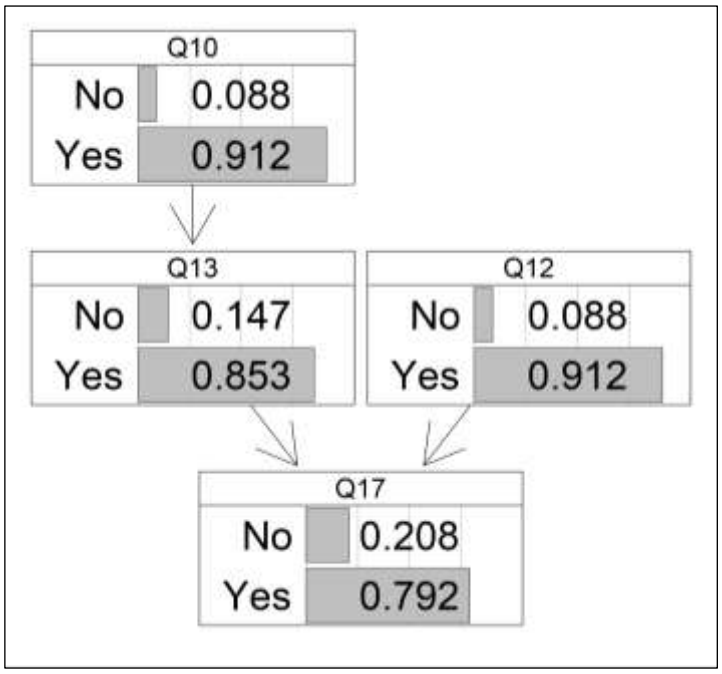

Figure 13: Result of Bayesian network-Hill Climbing.
Source: Authors, (2025).

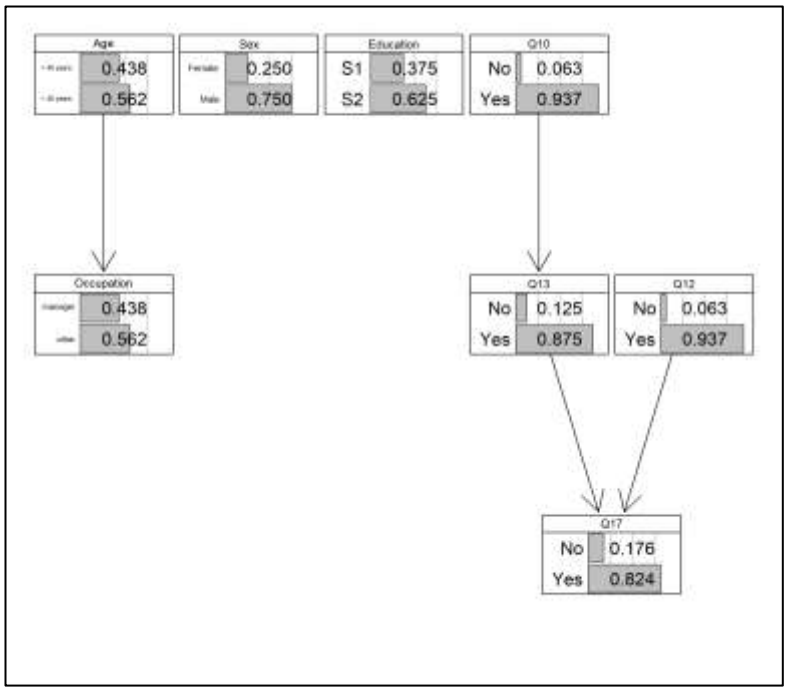

Figure 14: Modification results of Bayesian network-Hill Climbing.
Source: Authors, (2025).

Modifications to the Bayesian network on the Hill-Climbing network found the relationship between age and occupation variables. Besides, the relationship between the level of education on the company's financial performance and the area of land used was also found. The educational level of palm oil industry employees influences the company's financial performance, while company financial performance influences the location of palm oil industrial land. This is consistent with the assertion that a business operates effectively with satisfactory economic performance.

According to [47], while firm profit findings are significant, additional information from financial reports that still needs to be integrated must be carefully examined. According to [48], an analysis of a financial report can provide information about sustainable palm oil's performance and financial situation in Indonesia. Company financial performance influences the area of palm oil industrial land; this is consistent with the ability of a business to invest in land for the production of palm oil based on its financial standing. Financial solid performance gives firms more accessible access to finance, which enables them to buy additional land for farming. This growth potential may immediately affect the area used for palm oil production [49].

IV.4 MODEL TESTING

Model testing on Bayesian network SSCM analysis for the palm oil industry at PT PTPN III using triple bottom line indicators and dimensions was carried out using approximate inference, hoping that the results obtained are comparable to the actual probability. Approximate inference is used to evaluate the results obtained in structure learning and parameter learning. The results of assessing the strength of edges/arcs/arrows (relationships) using the Pearson $\chi 2$ test (Pearson Chi-Square) are presented in Table 3 below:

Table 4: Strength of the variable's relationship Bayesian network SSCM analysis for the palm oil industry at PT PTPN III.

From	To	Strength
Q13	Q17	0.00055*
Q12	Q17	0.00091*
Q10	Q13	0.00629*
Occupation	Age	0.03924*
Q17	Occupation	**0.09014**
Education Level	Age	**0.1309**

Source: Authors, (2025).

Note: (*) The lower the value, the stronger the relationship; Bold text: not significant/weak/ inconsistent with the data (> 0.05)

Bayesian network calculation found economic, social, and environmental dimensions that strongly influence sustainable supply chain performance in the palm oil industry: company financial performance (0.00055). Companies that exhibit solid financial performance have the means to allocate resources toward sustainability projects. This could involve reducing environmental influence, such as planting new trees, protecting biodiversity, or implementing sustainable land management techniques. The amount of palm oil industrial land and its management techniques may change as a result of these initiatives [50], availability of supporting infrastructure (0.00091) To convert fresh fruit bunches (FFBs) into crude palm oil (CPO) and then further refine it into a variety of derivative products, infrastructure such as mills and refineries is necessary. It is ensured that gathered palm fruits are processed effectively, minimizing waste and environmental

impact, by having access to well-maintained processing facilities [51], and employee education (0.00629) The findings of the field visit indicate that knowledgeable staff members are more likely to understand the significance of sustainable practices in the production of palm oil. Their knowledge of their work's effects on the environment and society makes them more capable of implementing sustainable practices at every stage of the supply chain, from agriculture to harvesting to processing.

Occupation has a more substantial relationship with age (0.03924). Elderly workers must adjust to changing environmental norms, technology, and market demands even though their experience is valued. There is growing pressure on the palm oil sector to embrace more environmentally friendly methods, like lessening deforestation, preserving biodiversity, and upholding human rights. Older workers must be willing to learn and adopt new strategies to tackle these obstacles. According to [9] Putting money into training and development initiatives can enable employees of all ages to support the palm oil industry's sustainable objectives. These programmers can offer chances for lifelong learning, skill development, and career advancement, guaranteeing that the labor force is flexible and can effect constructive change.

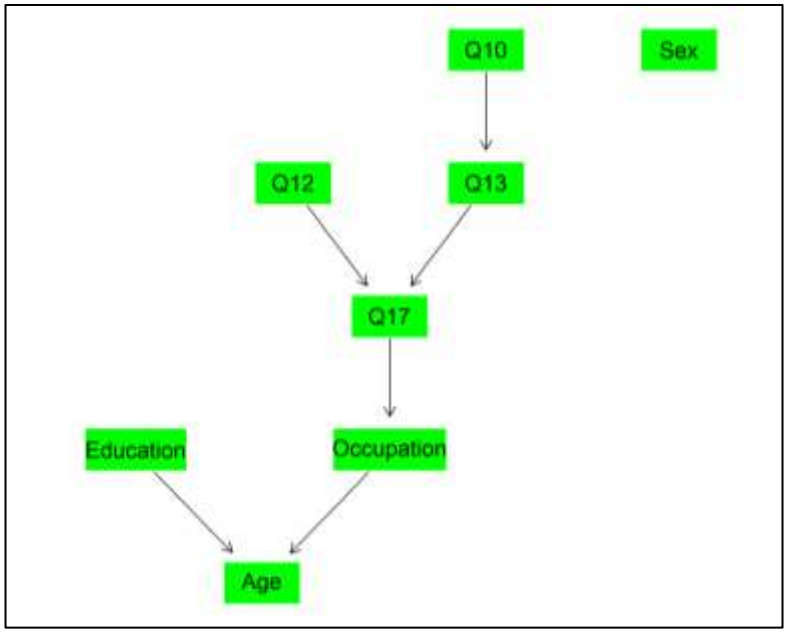

Figure 15: Variable's relationship.
Source: Authors, (2025).

The Bayesian network model in sustainable supply chain management in Indonesia's palm oil sector can encourage transparent innovation. The palm oil industry in Indonesia often intersects with sensitive characteristics such as social responsibility, environmental sustainability, and economic prosperity. Therefore, using Bayesian network models in sustainable supply chain management can encourage open innovation. Bayesian networks in sustainable supply chain performance provide five benefits. The first advantage is that it helps in resolving complex decisions. In dealing with complex uncertainty scenarios in a system, the Bayesian network model can simulate and simplify various variables/factors appropriately to find good choices in sustainable supply chain studies. In sustainable supply chain operations, Bayesian networks detect prospective risks and their likelihood of occurrence, enabling probabilistic risk assessment. Decision-makers can use the models to set priorities for risk mitigation techniques, distribute resources wisely, and create backup plans in case of uncertainties and vulnerabilities.

Bayesian networks facilitate proactive risk management and resilience-building in supply chain sustainability by measuring hazards and their possible effects. These advantages enable stakeholders to construct more sustainable decisions while comprehensively analyzing environmental, social, and economic aspects. Aguilera et al. [52] studied using Bayesian networks for modeling environmental system management in the ISI Web of Knowledge. Later, McDonald et al. [53] explored using Bayesian networks for ecological risk assessment in freshwater and estuarine ecosystems. Still related to environmental issues, Sperotto et al. [54] investigated the use of Bayesian networks for the evaluation of climate change in environmental management, and Phan et al. [55] reviewed the application of Bayesian networks for water resources management in various water management domains and geographic locations. However, studies have yet to evaluate the application of Bayesian networks as a decision-support tool to identify appropriate options for sustainable supply chain performance. Creating a measuring system that facilitates coordination for collaborative decision-making is crucial to supply chain management [56].

This mechanism can help independent members align their goals and coordinate their actions to maximize the chain's performance [12]. Furthermore, optimal supply chain design and practice are centered on a seamless and well-managed material flow [57]. A key component of supply chain management is developing a measuring system that makes coordination easier for group decision-making [56]. To maximize the performance of the chain, this mechanism can assist independent members in coordinating their actions and aligning their goals [58]. Moreover, a smooth and well-managed material flow is at the core of ideal supply chain design and practice [57]. Managers must use data mining technology to support their organization's decision-making process and monitor behavior in the complex and demanding business environment. Because of this, BN is widely accepted as an artificial intelligence technique for dealing with ambiguous problems [59].

Table 5: Focus of research on application of BN in supply chain-related areas (selected publications).

Field of Focus	Source
Analyze the performance of the supply chain by combining Monte Carlo simulation and data envelopment analysis.	[60]
Reverse supply chain and product failure rate	[58]
Application of imprecise probability for system reliability assessment	[61]
Decision support under uncertainty in collaborative networks	[62]
Risk assessment of new product development	[63], [64]

Source: Authors, (2025).

Application of BN in supply chain-related areas is Given the observation of complementary subset variables; the BN statistical model can calculate the posterior probability distribution of any unobserved stochastic variable [65], [66]. This methodology provides a comprehensive approach to identifying the relationships and impacts among variables. Additionally, this strategy has been effectively applied to other supply chain-related subjects (Table 4). Supervised learning algorithms are typically employed to construct the network's architecture. The second advantage is risk management and scenario analysis. Bayesian networks make scenario analysis and risk assessment uncomplicated. This ability makes it easier for scholars to predict future difficulties and consider aspects of various options. Risk management in the palm oil sector requires careful consideration of multiple factors while creating a sustainable supply chain. These factors include: The findings of the observations in PT PTPN III Kek Sei Mangkei show that a large number of palm oil farmers prioritize the production process over marketing, placing more emphasis on the quality of their products than on marketing, even though this is one of the issues that palm oil Farmers frequently deal with ineffective distribution and marketing. Setting priority for issues that need to be fixed and projecting the worst-case scenario are crucial components of risk management.

Every business process has a risk management procedure associated with it. Then, to handle risk management, it is necessary to recommend new production techniques, business risk planning, and increased focus and action from palm oil producers and farmers. Sustainable development aims to promote the concept that environmental impacts due to industrial operations can be satisfactorily mitigated through appropriate waste processing systems. In a rapidly ever-changing world, leaders in the supply chain can identify possible sustainability risks and create creative solutions to minimize negative impacts. Example: Understanding the value of working together, PT INL Kek Sei Mangkei addresses social and environmental issues and promotes sustainable practices by directly conversing with palm oil suppliers. The organization offers training and capacity-building support to assist suppliers in meeting certification criteria like RSPO standards and enhancing their sustainable performance. To increase the sustainability of palm oil production, PT INL Kek Sei Mangkei investigates cutting-edge farming methods like agroforestry and precision agriculture in partnership with academic institutions and agricultural specialists (IPB University and Faculty of Agriculture, University of North Sumatra). These strategies increase yields and resilience to climate change while improving soil health, conserving water, and protecting biodiversity. Therefore, proactive risk management will create a culture focusing on appropriate improvements and adaptations, ultimately strengthening supply chain resilience. In the mercury mining industry, Jimenez-Oyola et al.

[67] assessed the dangers of mercury mining on human health using Bayesian networks. In addition, Bayesian network models in the occupational safety aspect enable environmental risk assessment in dams [68], risk investigation of pipeline failure [69], risk assessment of company activities exposed to landslides [70], evaluation of insurability risks and the risk level of refineries against fire and explosion [71], and assessment of the relationship between disease and air pollution at industrial sites and their risks to environmental health [72]. The third benefit is data-driven insights, as organizations can use historical and real-time data to make decisions that support sustainability goals. Organizations can identify areas that need improvement, simplify ineffective work procedures, and use creative approaches to improve sustainability performance in a specific manner or holistically. Requejo Castro [73] explored the benefits of a Bayesian networks approach that can be adopted to integrate expert knowledge and accurately replicate a composite indicator-based conceptual framework. Such integration increases the inference capacity of the model and reduces/quantifies the key variables that explain the predefined objective variables. Additionally, interrelationships between variables that promote better integration can be identified. This approach helps analyze complex problems and provide comprehensive interpretation because the available data drive the identification of variables' relationships. Thus, knowledge about the validity, reliability, and accuracy of using Bayesian network modeling can be further deepened.

The fourth benefit is the availability of collaborative decision-making. The cooperative character of Bayesian networks encourages stakeholders to exchange knowledge, skills, and insights to develop creative solutions in supply chain sustainability. This activity forms a knowledge-sharing culture and cooperation among stakeholders, distributors, producers, and suppliers. The final benefit is the formation of adaptive learning and continuous concept improvement. These activities enable organizations to respond to information, new insights, creative ideas, and constant improvement. A continuous process of innovation in maximizing a company's supply chain performance can be achieved when stakeholders learn from the decisions they made in the past and are also willing to modify their models according to the learning outcomes. Open innovation is needed to drive positive change in the palm oil business in Indonesia. The Bayesian network model has implications for simplifying the relationship of complex variables. Open innovation can potentially be a potent tool in Indonesia's palm oil sector for addressing sustainability, environmental preservation, social responsibility, and economic growth. Working together to co-create solutions and exchange information, resources, and skills with outside partners—research institutes, non-governmental organizations, government agencies, and local communities—is known as open innovation.

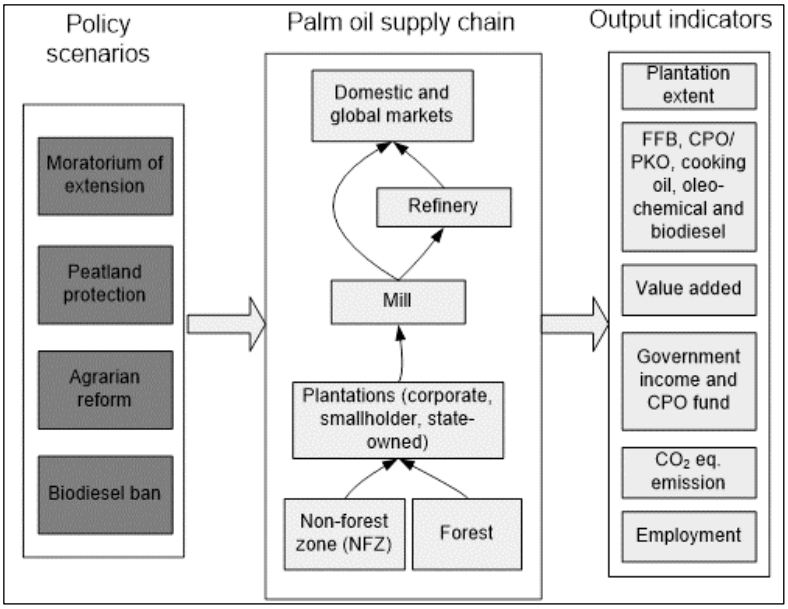

Figure 16: Architecture of the Indonesian Palm Oil Simulation (IPOS) model Source: Center for International Forestry Research (CIFOR), 2020.
Source: Authors, (2025).

There are a few critical factors to consider when utilizing open innovation in the palm oil sector: Transparency and Trust Establishing trust between stakeholders is essential to the success of cooperative open innovation projects. Building trust and ensuring all parties feel appreciated and respected is achieved through transparency in communication, decision-making procedures, and data exchange. A defined method for information sharing, resolving disputes, and making decisions can help reduce the likelihood of miscommunications or confrontations during the innovation process. Through such a course, uncertainty can be resolved, and decision-makers can understand the dynamics in their company's supply chain, including further integration of the supply chain with social, environmental, and economic elements. A thorough understanding is essential in creating creative solutions and balancing profit goals, social issues, and ecological interests.

The collaborative nature of Bayesian network models in assessing frameworks, risks, and scenarios enables stakeholders to estimate possible obstacles and find creative solutions to resolve problems. This proactive approach emphasizes that adaptive, collaborative, and sustainable learning can answer complex issues and deliver the objectives of open innovation across all industries, specifically the palm oil industry. Implementing the Bayesian network model in sustainable supply chain management through this research maximizes sustainability in decision-making that prioritizes transparency and cooperation. Stakeholders can share insights, encourage implementing sustainable practices, ignite innovations, and promote collaboration in creating a more thorough and environmentally friendly palm oil supply chain. A collaborative ecosystem through applying the Bayesian network model in the Indonesian palm oil industry can overcome the conflicting sustainability concepts inherent in this sector through creative problem-solving and knowledge interaction.

V. CONCLUSIONS

This Bayesian network structure was built using the scoring-based method with a Hill-Climbing algorithm approach and the BIC score function. The three variables found by the present study represent a solid relationship based on Pearson's $\chi 2$ (Pearson Chi-Square) calculations. Such a method has been proven to produce a Bayesian network representing the palm oil industry in Indonesia. There are opportunities for implementing indicators for assessing sustainable supply chain performance in Indonesia's palm oil industry: company financial performance (0.00055), availability of supporting infrastructure (0.00091), and employee education (0.00629).

VI. REFERENCES

[1] T. M. I. Mahlia, N. Ismail, N. Hossain, A. S. Silitonga, and A. H. Shamsuddin, ‘Palm oil and its wastes as bioenergy sources: a comprehensive review’, Environ. Sci. Pollut. Res., vol. 26, pp. 14849–14866, 2019.

[2] A. Syahza and B. Asmit, ‘Development of palm oil sector and future challenge in Riau Province, Indonesia’, J. Sci. Technol. Policy Manag., vol. 11, no. 2, pp. 149–170, 2020.

[3] I. Mundi, ‘Indonesia palm oil production by year’. 2023.

[4] ‘Republic of Indonesia Law No. 39 of 2014 on Plantations’. 2014.

[5] C. D. T. Siregar and E. D. Sihaloho, ‘Could palm oil plantation increase individual expenditure? The Dutch disease implication in Indonesia’, Signifikan J. Ilmu Ekon., vol. 10, no. 1, pp. 77–92, 2021.

[6] P. Oosterveer, ‘Promoting sustainable palm oil: viewed from a global networks and flows perspective’, J. Clean. Prod., vol. 107, pp. 146–153, 2015.

[7] L. Rist, L. Feintrenie, and P. Levang, ‘The livelihood impacts of oil palm: smallholders in Indonesia’, Biodivers. Conserv., vol. 19, pp. 1009–1024, 2010.

[8] K. Saswattecha, C. Kroeze, W. Jawjit, and L. Hein, ‘Assessing the environmental impact of palm oil produced in Thailand’, J. Clean. Prod., vol. 100, pp. 150–169, 2015.

[9] P. Pacheco, G. Schoneveld, A. Dermawan, H. Komarudin, and M. Djama, ‘Governing sustainable palm oil supply: Disconnects, complementarities, and antagonisms between state regulations and private standards’, Regul. Gov., vol. 14, no. 3, pp. 568–598, 2020.

[10] K. M. Carlson et al., ‘Effect of oil palm sustainability certification on deforestation and fire in Indonesia’, Proc. Natl. Acad. Sci., vol. 115, no. 1, pp. 121–126, 2018.

[11] J. Elkington, ‘Partnerships from cannibals with forks: The triple bottom line of 21st-century business’, Environ. Qual. Manag., vol. 8, no. 1, pp. 37–51, 1998.

[12] L. Wang and L. Lin, ‘A methodological framework for the triple bottom line accounting and management of industry enterprises’, Int. J. Prod. Res., vol. 45, no. 5, pp. 1063–1088, 2007.

[13] B. Beamon, ‘Sustainability and the future of supply chain management’, Oper. Supply Chain Manag. An Int. J., vol. 1, no. 1, p. 15, 2014.

[14] M. Brandenburg, K. Govindan, J. Sarkis, and S. Seuring, ‘Quantitative models for sustainable supply chain management: Developments and directions’, Eur. J. Oper. Res., vol. 233, no. 2, pp. 299–312, 2014.

[15] E. Hassini, C. Surti, and C. Searcy, ‘A literature review and a case study of sustainable supply chains with a focus on metrics’, Int. J. Prod. Econ., vol. 140, no. 1, pp. 69–82, 2012.

[16] A. I. Suroso, H. Tandra, M. Najib, and Y. Syaukat, ‘Firm performance factors and efficiency of Indonesian palm oil companies’, J. Manaj. Agribisnis, vol. 17, no. 3, p. 227, 2020.

[17] L. Naidu and R. Moorthy, ‘A review of key sustainability issues in Malaysian palm oil industry’, Sustainability, vol. 13, no. 19, p. 10839, 2021.

[18] R. S. Kaplan and D. P. Norton, ‘Having trouble with your strategy? Then map it. Focusing Your Organization on Strategy—with the Balanced Scorecard’, Harv. Bus. Rev., vol. 49, no. 5, pp. 167–176, 2000.

[19] R. I. D. Pooe and K. Mhelembe, ‘Exploring the challenges associated with the greening of supply chains in the South African manganese and phosphate mining industry’, J. Transp. Supply Chain Manag., vol. 8, no. 1, pp. 1–9, 2014.

[20] A. Jafarnejad, A. S. Rokhi, A. K. S. Abad, S. Khoury, and K. Jenab, ‘The effects of supply chain strategies on supply chain performance of Malaysian manufacturing companies with moderation of six sigma and lean production’, Bus. Manag. Dyn., vol. 6, no. 11, pp. 16–30, 2017.

[21] K. Emamisaleh, K. Rahmani, and S. Iranzadeh, ‘Sustainable supply chain management practices and sustainability performance in the food industry’, South East Asian J. Manag., vol. 12, no. 1, pp. 1–19, 2018.

[22] R. J. Lin, R. H. Chen, and T. H. Nguyen, ‘Green supply chain management performance in automobile manufacturing industry under uncertainty’, Procedia-Social Behav. Sci., vol. 25, pp. 233–245, 2011.

[23] T. A. Chin, H. H. Tat, and Z. Sulaiman, ‘Green supply chain management, environmental collaboration and sustainability performance’, Procedia CIRP, vol. 26, pp. 695–699, 2015.

[24] H. Reefke and M. Trocchi, ‘Balanced scorecard for sustainable supply chains: design and development guidelines’, Int. J. Product. Perform. Manag., vol. 62, no. 8, pp. 805–826, 2013.

[25] D. Heckerman, ‘A Bayesian approach to learning causal networks’, ArXiv Prepr. ArXiv1302.4958, 2013.

[26] D. E. Holmes and L. C. Jain, ‘Introduction to Bayesian networks’, in Innovations in Bayesian networks: Theory and applications, Springer, 2008, pp. 1–5.

[27] K. Jermsittiparsert, P. Siriattakul, and S. Wattanapongphasuk, ‘Determining the environmental performance of Indonesian SMEs influence by green supply chain practices with moderating role of green HR practices’, Int. J. Supply Chain Manag., vol. 8, no. 3, pp. 59–70, 2019.

[28] M. S. Lasaki and S. Gilaninia, ‘PARTICIPATION AND INVESTMENT OF PRIVATE SECTOR ON GREEN SUPPLY CHAIN PERFORMANCE OF TOURISM INDUSTRY’, Kuwait Chapter Arab. J. Bus. Manag. Rev., vol. 5, no. 11, p. 38, 2016.

[29] C. Purnama, ‘Improved performance through empowerment of small industry’, J. Soc. Econ. Res., vol. 1, no. 4, pp. 72–86, 2014.

[30] T. Dyllick and K. Hockerts, ‘Beyond the business case for corporate sustainability’, Bus. Strateg. Environ., vol. 11, no. 2, pp. 130–141, 2002.

[31] S. Seuring and M. Müller, ‘From a literature review to a conceptual framework for sustainable supply chain management’, J. Clean. Prod., vol. 16, no. 15, pp. 1699–1710, 2008.

[32] S. K. Sikdar, ‘Sustainable development and sustainability metrics’, AIChE J., vol. 49, no. 8, pp. 1928–1932, 2003.

[33] I. Masudin and M. G. F. Ayni, ‘Pengambilan keputusan multi kriteria: Kajian teoritis metode dan pendekatan dalam pemilihan pemasok’, J. Ilm. Tek. Ind., vol. 17, no. 1, pp. 1–12, 2018.

[34] C. R. Carter and D. S. Rogers, ‘A framework of sustainable supply chain management: moving toward new theory’, Int. J. Phys. Distrib. Logist. Manag., vol. 38, no. 5, pp. 360–387, 2008.

[35] B. Ageron, A. Gunasekaran, and A. Spalanzani, ‘Sustainable supply management: An empirical study’, Int. J. Prod. Econ., vol. 140, no. 1, pp. 168–182, 2012.

[36] D. Wittstruck and F. Teuteberg, ‘A reference model for sustainable supply chain management’, Zeitschrift Für Manag., vol. 5, pp. 141–164, 2010.

[37] A. Genovese, A. A. Acquaye, A. Figueroa, and S. C. L. Koh, ‘Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications’, Omega, vol. 66, pp. 344–357, 2017.

[38] N. Kobza and A. Schuster, 'Building a responsible Europe-the value of circular economy', IFAC-PapersOnLine, vol. 49, no. 29, pp. 111–116, 2016.

[39] A. Sutawidjaya, L. Nawangsari, and N. Nor, 'Life cycle assessment: Study linkage between environment supply chain management and sustainability of supply chain', Uncertain Supply Chain Manag., vol. 9, no. 1, pp. 179–186, 2021.

[40] R. D. Raut, B. Narkhede, and B. B. Gardas, 'To identify the critical success factors of sustainable supply chain management practices in the context of oil and gas industries: ISM approach', Renew. Sustain. Energy Rev., vol. 68, pp. 33–47, 2017.

[41] A. Kumar, S. K. Shrivastav, A. K. Shrivastava, R. R. Panigrahi, A. Mardani, and F. Cavallaro, 'Sustainable Supply Chain Management, Performance Measurement, and Management: A Review', Sustainability, vol. 15, no. 6, p. 5290, 2023.

[42] H. V Pham, A. Sperotto, E. Furlan, S. Torresan, A. Marcomini, and A. Critto, 'Integrating Bayesian Networks into ecosystem services assessment to support water management at the river basin scale', Ecosyst. Serv., vol. 50, p. 101300, 2021.

[43] W. Zhou and S. Piramuthu, 'Information relevance model of customized privacy for IoT', J. Bus. Ethics, vol. 131, no. 1, pp. 19–30, 2015, doi: 10.1007/s10551-014-2248-y.

[44] N. Friedman and M. Goldszmidt, 'Building classifiers using Bayesian networks', in Proceedings of the National Conference on Artificial Intelligence, 1996, pp. 1277–1284.

[45] R. E. Neapolitan, Learning Bayesian Networks. Upper Saddle River: Prentice Hall, 2003.

[46] Tinaliah, 'Aplikasi sistem pakar untuk diagnosa penyakit hewan ternak sapi dengan Bayesian Network', SISFOTENIKA J. Ilm. Sist. Inf. dan Tek. Inform., vol. 5, no. 1, 2015, doi: 10.30700/jst.v5i1.19.

[47] T. A. Gumanti, 'Earnings management: Suatu telaah pustaka', J. Akunt. dan Keuang., vol. 2, no. 2, pp. 104–115, 2004, doi: 10.9744/jak.2.2.pp.104-115.

[48] T. Rinawati, A. Niati, and Y. Suhardjo, 'Analisis penilaian kinerja keuangan perusahaan berbasis Du Pont System', J. Din. Sos. Budaya, vol. 22, no. 2, pp. 174–183, 2020, doi: 10.26623/jdsb.v22i2.2794.

[49] M. S. Elfian, H. Harianto, and N. Zulbainarni, 'Financial Performance of The Main Palm Oil Companies in Indonesia and The Influencing Factors', Bus. Rev. Case Stud., vol. 4, no. 1, pp. 62–72, 2023, doi: 10.17358/brcs.4.1.62.

[50] Y. S. Tey, M. Brindal, M. Djama, A. H. I. A. Hadi, and S. Darham, 'A review of the financial costs and benefits of the Roundtable on Sustainable Palm Oil certification: Implications for future research', Sustain. Prod. Consum., vol. 26, pp. 824–837, 2021.

[51] J. A. Garcia-Nunez, S. Van Passel, I. Muñoz, and I. Aldana, 'Evaluation of alternatives for the evolution of palm oil mills: Six alternatives for the conversion of an average Colombian palm oil mill (30 t h−1 of fresh fruit bunches (FFB)) into biorefineries', J. Clean. Prod., vol. 129, pp. 127–142, 2016, doi: 10.1016/j.jclepro.2016.04.084.

[52] P. A. Aguilera, A. Fernández, R. Fernández, R. Rumí, and A. Salmerón, 'Bayesian networks in environmental modelling', Environ. Model. Softw., vol. 26, no. 12, pp. 1376–1388, 2011.

[53] K. S. McDonald, M. Tighe, and D. S. Ryder, 'An ecological risk assessment for managing and predicting trophic shifts in estuarine ecosystems using a Bayesian network', Environ. Model. Softw., vol. 85, pp. 202–216, 2016.

[54] A. Sperotto, J. L. Molina, S. Torresan, A. Critto, and A. Marcomini, 'Reviewing Bayesian Networks potentials for climate change impacts assessment and management: A multi-risk perspective', J. Environ. Manage., vol. 202, pp. 320–331, 2017.

[55] T. D. Phan, J. C. R. Smart, S. J. Capon, W. L. Hadwen, and O. Sahin, 'Applications of Bayesian belief networks in water resource management: A systematic review', Environ. Model. Softw., vol. 85, pp. 98–111, 2016.

[56] B. Kim and H. Oh, 'The impact of decision-making sharing between supplier and manufacturer on their collaboration performance', Supply Chain Manag., vol. 10, no. 3, pp. 223–236, 2005, doi: 10.1108/13598540510606287.

[57] S. Geary, S. M. Disney, and D. R. Towill, 'On bullwhip in supply chains - historical review, present practice and expected future impact', Int. J. Prod. Econ., vol. 101, no. 1 pp. 2–18, 2006, doi: 10.1016/j.ijpe.2005.05.012.

[58] M. Wang, 'Reverse logistics optimization: A research to the uncertainties in the third party reverse logistics — case of New Zealand Couriers Ltd', Massey University, New Zealand, 2011.

[59] S. Nadkarni and P. P. Shenoy, 'A Bayesian Network approach to making inferences in causal maps', Eur. J. Oper. Res., vol. 128, no. 2, pp. 479–498, 2001, doi: 10.1016/S0377-2217(99)00368-9.

[60] W. P. Wong, 'Performance evaluation of supply chain in stochastic environment: Using a simulation based DEA framework', Int. J. Bus. Perform. Supply Chain Model., vol. 1, no. 2, pp. 203–228, 2009, doi: 10.1504/IJBPSCM.2009.030642.

[61] Z. Xing, J. Pei, and E. Keogh, 'A brief survey on sequence classification', SIGKDD Explor., vol. 12, no. 1, pp. 40–48, 2010, doi: 10.1145/1882471.1882478.

[62] E. Shevtshenko and Y. Wang, 'Decision support under uncertainties based on robust Bayesian networks in reverse logistics management', Int. J. Comput. Appl. Technol., vol. 36, no. 3–4, pp. 247–258, 2009, doi: 10.1504/IJCAT.2009.028047.

[63] K. S. Chin, R. Kay, and Y. Yuan, 'Assessing new product development project risk by Bayesian network with a systematic probability generation methodology', Expert Syst. Appl., vol. 36, no. 3, pp. 6469–6479, 2009, doi: 10.1016/j.eswa.2009.02.029.

[64] M. Maleki and V. Cruz-Machado, 'Supply chain performance monitoring using Bayesian network', Int. J. Bus. Perform. Supply Chain Model., vol. 5, no. 2, pp. 177–197, 2013.

[65] D. Gambelli and V. Bruschi, 'A Bayesian network to predict the probability of organic farms' exit from the sector: A case study from Marche, Italy', Comput. Electron. Agric., vol. 71, pp. 22–31, 2010.

[66] J. V. Queiroz, F. C. B. P. Queiroz, H. R. Hékis, A. F. da S. Queiroz, and M. G. de Araujo, Um instrumental de auxílio à tomada de decisão no financiamento para Instituições de Ensino Superior. 2011.

[67] S. Jimenez-Oyola et al., 'Multi-pathway human exposure risk assessment using Bayesian modeling at the historically largest mercury mining district', Ecotoxicol. Environ. Saf., vol. 201, p. 110833, 2020.

[68] B. Malekmohammadi and N. Tayebzadeh Moghadam, 'Application of Bayesian networks in a hierarchical structure for environmental risk assessment: a case study of the Gabric Dam, Iran', Environ. Monit. Assess., vol. 190, pp. 1–17, 2018.

[69] Y. Cui, N. Quddus, and C. V Mashuga, 'Bayesian network and game theory risk assessment model for third-party damage to oil and gas pipelines', Process Saf. Environ. Prot., vol. 134, pp. 178–188, 2020.

[70] M. Lan, J. Zhu, and S. Lo, 'Hybrid Bayesian network-based landslide risk assessment method for modeling risk for industrial facilities subjected to landslides', Reliab. Eng. Syst. Saf., vol. 215, p. 107851, 2021.

[71] L. Mkrtchyan, U. Straub, M. Giachino, T. Kocher, and G. Sansavini, 'Insurability risk assessment of oil refineries using Bayesian Belief Networks', J. Loss Prev. Process Ind., vol. 74, p. 104673, 2022.

[72] S. Pérez, C. German-Labaume, S. Mathiot, S. Goix, and P. Chamaret, 'Using Bayesian networks for environmental health risk assessment', Environ. Res., vol. 204, p. 112059, 2022.

[73] D. Requejo Castro, 'Data–driven Bayesian networks modelling to support decision–making: application to the context of Sustainable Development Goal 6 on water and sanitation', 2021.