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A decision support system for selection and risk management of sustainability governance approaches in multi-tier supply chain

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A R T I C L E I N F O

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A B S T R A C T

Lower-tier suppliers' sustainability noncompliance and focal company's failure at meeting the expectations of the stakeholders to extend sustainability towards lower-tier suppliers carry multiple risks, tangible and intangible, to the focal company. It is expected that extending sustainability to suppliers at lower tiers through effective sustainability governance approaches (SGAs) can reduce these risks for focal companies. The existing literature lacks research on decision support tools using management science techniques to help decision makers choose the most suitable SGA/SGAs in a given situation and the risk management of SGAs in multi-tier supply chain. The present study develops a model-driven decision support system (DSS) using Bayesian network (BN) that can assist operations managers in selecting the most effective SGA/SGAs in multi-tier supply chain considering each situation. The developed DSS includes contingency factors and risk variables and their relationships which are identified through a systematic literature review and is applied to the multi-tier, sustainable supply chain of a multinational company operating in China to demonstrate its practical applicability. The DSS is then used in the risk management of the SGAs in multi-tier supply chain, which includes core steps such as identification of the contingency factors and risk variables, the prioritisation of the contingency factors and risk treatment. By Prioritising the basic contingency factors, "Focal company's sustainability knowledge" and "The specific nature of the materials sourced from lower-tier supplier", and "First-tier supplier's possession of internal resources" and "First-tier supplier's sustainability training" were identified as the two most important factors regarding their impact on the effectiveness of the direct and indirect approaches respectively. Detailed managerial implications related to the development and implementation of the DSS and the risk management process are also provided.

1. Introduction

Traditionally, the research about sustainable supply chain management has been studying first-tier suppliers' sustainability-related misconducts (Grimm et al., 2014; Wilhelm et al., 2016a). However, the research has recently been gradually shifting towards studying how focal companies can extend sustainability to suppliers at lower tiers besides the first-tier suppliers in the context of multi-tier supply chain (Tachizawa and Wong, 2014; Wilhelm et al., 2016b; Gong et al. 2018a, 2021; Kannan, 2021). This is particularly important because the most severe environmental and social misconducts are expected to happen at lower-tier supplier sites (Wilhelm et al., 2016b; Wilhelm and Villena,

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2021), and unlike the downstream, close to end-consumer members of the supply chain that take the sustainability issues more seriously (Ghadge et al., 2018), the lower-tier suppliers generally have a passive approach to social and environmental issues and can pose serious risks to the focal companies (Villena and Gioia, 2018).

Internal and external stakeholder sustainability-driven pressures enhance the sustainability awareness of the firms and drive them towards adopting and implementing sustainability in their supply chains (Tachizawa et al., 2015; Meixell and Luoma, 2015; Roy et al., 2020; Sauer and Seuring, 2019; Nath and Eweje, 2021; Sharma et al., 2022). Focal company's neglecting of lower-tier suppliers' non-adherence to sustainability standards, despite pressures from stakeholders for establishment of sustainability compliance at lower-tier supplier stage, can inflict significant reputational and financial risks on the focal company (Foerstl et al., 2010; Hofmann et al., 2014), such as corporate reputation damage, boycotting the focal company's products/services by consumer organisations and fines as a result of legal action against the focal company (Foerstl et al., 2010; Hofmann et al., 2014; Sajjad et al., 2015; Kumar and Rahman, 2016; Meixell and Luoma, 2015; Nath and Eweje, 2021). Different sustainability governance approaches (SGAs) have been suggested in the literature for dissemination of sustainability towards the suppliers of lower tiers in multi-tier supply chain in order to manage the risks related to lower-tier suppliers' sustainability noncompliance for focal companies (Tachizawa and Wong, 2014; Meinlschmidt et al., 2018).

Although, over the past few years, academics and practitioners have been increasingly showing interest in general supply chain risk management (Yoon et al., 2017), yet very limited amount of research has been conducted on examining the impact of sustainability-related practices on supply chain risks, especially with a focus on the suppliers of lower tiers (Gouda and Saranga, 2018). Furthermore, despite the fact that both quantitative and qualitative methods have been applied to supply chain risk management (Pournader et al., 2020; Baryannis et al., 2019), still there is a dearth of literature on the risk management of SGAs in multi-tier supply chain utilising quantitative, analytical techniques. This is especially important considering the abovementioned risk variables, related to sustainability noncompliance by the suppliers of lower tiers, for focal company and how applying suitable SGA/SGAs can reduce these risks.

As the success of activities related to sustainable supply chain management is basically contingent upon the circumstance/context in which they are applied, the effectiveness of the SGAs in multi-tier supply chain may be dependent on specific contingency factors (Tachizawa and Wong, 2014; Wilhelm et al., 2016a). Identifying these contingency factors and determining how they impact the effectiveness of the SGAs would be useful in developing decision making tools that can help supply chain managers make better-informed decisions about which SGA to apply to establish supplier sustainability compliance at lower tiers.

Also, the extant literature in the area of multi-tier, sustainable supply chain management (MT-SSCM) lacks a decision support tool to assist operations managers in choosing the most effective SGA/SGAs in their multi-tier supply chain.

Model-driven decision support system (DSS) applies analytical management science/operations research tools, such as mathematical optimisation, simulation and Bayesian network (BN), to develop models that support decision making (Sauter, 2014; Power and Sharda, 2007). When risks are interrelated, the instances of the risks have not happened in the past, insufficient past data is available about the risks and the occurrence probability of one risk depends on the occurrence probability of another risk, BN can be an effective tool for the risk management (Fenton and Neil, 2011; Badurdeen et al., 2014; Lockamy III and McCormack, 2010).

The present study aims to respond to the above-described research gaps. First, a BN-based DSS is developed according to the causal relationships between the contingency factors and the effectiveness of the

Table 1
Concise descriptions of the SGAs in multi-tier supply chain.

	The SGAs	Description
Mena et al. (2013)	Open triad	Basically, open triad structure represents a traditional supply chain, in which only straight information and physical (product or material) flows exist between each stage in the supply chain, but a direct contact between focal company and lower-tier supplier does not exist. This gives the first-tier supplier a mediating role.
	Closed triad	In closed triad, contrary to the open triad, a direct, formal link exists between focal company and the supplier of lower tier. Focal company and the supplier of lower tier are in regular contact, share relevant information with each other and have mutual, formal or informal relationship.
	Transitional triad	This is an intermediate structure between closed and open triads, in which, focal company and lower-tier supplier start building a connection to communicate with each other, and initiate a transition from open triad to closed triad.
Tachizawa and Wong (2014)	Direct	Focal companies establish direct contact with lower-tier suppliers and can use both formal and informal communication methods to manage their mutual relationship with these suppliers. They can choose to bypass first-tier suppliers and through direct communication with suppliers at lower tiers monitor their compliance with sustainability standards, train them to incorporate sustainability into their operations and assist them in improving their sustainability performance in both social and environmental aspects.
	Indirect	The responsibility for evaluating, selecting and developing the suppliers of lower tiers with regard to sustainability requirements are delegated to first-tier suppliers. Focal companies may exert their power over tier-1 suppliers as a leverage to make them monitor the suppliers of lower tiers for possible violation of sustainability requirements or collaborate with these suppliers to enhance their sustainability performance.
	Work with third parties	Focal companies delegate their responsibilities for providing lower-tier suppliers with elaborations on sustainability standards, making lower-tier suppliers implement industry-wide voluntary sustainability standards and monitoring sustainability compliance at lower-tier suppliers level to third-party institutions such as governments, non-governmental organisations (NGOs), industrial alliances, standards institutions and competitors.
	Don't bother	Focal company does not engage in practices associated with the management of sustainability at lower-tier supplier level and only focuses on first-tier suppliers as it has neither the means nor the intention to disseminate sustainability towards lower-tier suppliers.
Meinlschmidt et al. (2018)	Direct-holistic	Under this strategy, focal company regularly manages the sustainability compliance of lower-tier suppliers,

(continued on next page)

Table 1 (*continued*)

	The SGAs	Description
		which requires allocation of the highest amount of resources. In order to provide the appropriate resources for this proactive sustainability governance strategy, focal companies evaluate the costs and potential benefits of cascading sustainability to their first-tier and lower-tier suppliers.
	Direct: product-specific	First-tier suppliers are mostly monitored by focal companies, but they assess and develop selected suppliers at lower-tiers whose products are a cause for concern as these products are manufactured by ingredients that were probably produced under environmentally and socially unsustainable conditions.
	Direct: region-specific	This SGA is employed by focal companies to monitor a certain group of lower-tier suppliers that are operating in regions that environmental and social sustainability violations are frequent.
	Direct: event-specific	This sustainability governance plan is in essence a reactive strategy. Focal companies use their resources to sort out particular, crucial environmental and social misconducts once they have occurred in the lower-tiers of their supply chain.
	Indirect: multiplier-based	First-tier suppliers are assessed, selected, trained and promoted by focal companies based on predefined sustainability standards, and in turn, they expect their first-tier suppliers to proactively manage suppliers at lower-tiers with equal sustainability standards.
	Indirect: alliance-based	Focal company joins the industry alliances/associations for the advancement of sustainability. These alliances can execute sustainability audits at lower-tier supplier level, award sustainability certifications of lower-tier suppliers and share the information about the sustainability assessment of lower-tier suppliers with members.
	Indirect: compliance-based	The supplier codes of conduct of focal companies require first-tier suppliers to implement the sustainability requirements of focal company to lower-tier suppliers.
	Neglect: tier-1-based	Focal company only manages compliance with sustainability requirements at first-tier supplier stage, and does not take part in lower-tier supplier assessment, training and selection plans with regard to sustainability criteria.
Alexander (2020)	Hierarchical	Suppliers of several tiers are vertically integrated by focal companies to make certain that they have proper control over upstream suppliers.
	Compliance	Sustainability standards are set by focal companies and they monitor the lower-tier suppliers' adherence to those standards by providing incentives or deterrents.
	Support services	By providing different types of assistance to suppliers at different tiers (the suppliers of first tier and lower tiers), such as sustainability training courses and workshops for workers and managers and monetary aid for upgrading the facilities and equipment, focal companies encourage them to create more sustainable operations.
	Partnership	This is a collaborative approach, where focal companies collaborate with suppliers at first tier and lower tiers to cooperatively address the sustainability issues in upstream segment of their supply chain while taking mutual priorities into account and emphasising shared values.
	Promotion of voluntary change	Advancement of sustainable business practices is encouraged by focal companies at multiple tiers of suppliers in various ways. This includes directly interacting with suppliers, having partners of focal companies promote new or modified sustainable practices and creating public campaigns. In order to achieve sustainable operations, suppliers of different tiers are given the freedom to choose how they want to implement these sustainable practices.

relevant SGA, which can help operations managers select the most effective SGA/SGAs considering the related contingency factors in a given situation. The contingency factors and how variations in their states impact the effectiveness of the relevant SGA, and the risks of lower-tier suppliers' sustainability noncompliance for focal company are determined through a systematic literature review. To show the applicability of the developed DSS, it is applied to the multi-tier, sustainable supply chain of a multinational firm operating in China. Then, the BN-based DSS is used as a tool to perform a complete risk management of SGAs in multi-tier supply chain, which includes the identification of the risk variables and the contingency factors that influence the risk variables through influencing the effectiveness of the relevant SGA, prioritising the contingency factors and risk treatment as the primary steps.

The rest of the paper is structured as follows. In Section 2, the relevant literature is reviewed and research gaps are identified. Section 3 presents the research method. The risk management process which includes identifying the contingency factors and risk variables from the literature, clustering the contingency factors, developing the DSS and its implementation, prioritising the basic contingency factors, risk treatment and managerial implications are presented in Section 4. Finally, Section 5 provides conclusions and recommendations for future research.

2. The relevant literature and research gaps

2.1. SGAs in multi-tier supply chain

MT-SSCM is not just focused on first-tier supplier sustainability compliance. Lower-tier suppliers frequently engage in unsustainable practices mostly because they are less famous and visible to the general public. This can have negative consequences for focal companies. Thus, focal companies need to devise strategies for disseminating sustainability towards their suppliers at lower tiers (Meinlschmidt et al., 2018; Wilhelm et al., 2016a; Gong et al., 2018a). In the MT-SSCM literature, several SGAs for extending sustainability towards the suppliers of lower tiers have been identified from MT-SSCM practice, which are presented in Table 1.

We found that the MT-SSCM literature has widely applied the four SGAs proposed in Tachizawa and Wong (2014), i.e., direct, indirect, work with third parties and don't bother, probably because these approaches were identified from a literature review. Thus, the SGAs identified by Tachizawa and Wong (2014) are considered in current study to represent the dominant trend in the literature of MT-SSCM.

2.2. BN to develop DSS for sustainability management

BN method has been applied to develop DSS for different social and environmental sustainability management problems in the literature as follows: planning the decarbonisation of urban areas (Mrówczyńska et al., 2022), assessing the drivers of climatic and anthropogenic processes that cause saltwater intrusion (Rachid et al., 2021), the ecological operation of a reservoir constructed across Heigh River in China (Zhou et al., 2021), sustainable maritime traffic safety (Khan et al., 2020), the management of coral reef ecosystem services (Carriger et al., 2019), military land conservation management (Fox et al., 2017), shipping safely with regard to environmental considerations (Gyftakis et al., 2018), selecting the optimal design of a building regarding the resilience and sustainability considerations (Alibrandi and Mosalam, 2017), dynamic safety analysis in metro-tunnel construction operations (Wu et al., 2015), assessing how different climate change scenarios may impact the intensively-used groundwater systems (Molina et al., 2013), the rehabilitation project of a river (Glendining and Pollino, 2012), deciding which product recovery option would be the best option based on the information supplied by sensor networks and radio frequency identification (RFID) tags (Parlikad and McFarlane, 2009), and management of nonpoint source pollution (Dorner et al., 2007).

2.3. Risk assessment/management in single-tier, sustainable supply chains using BN

To the best of our knowledge, neither quantitative nor qualitative risk management methods have been used in existing research to address the risk management of SGAs in multi-tier supply chains. Thus, we consider the existing research on risk assessment/management in single-tier, sustainable supply chains using BN as the relevant category of the literature.

From reviewing the literature, we found out that in comparison with the amount of research on risk assessment/management in supply chains using BN that does not take into account sustainability, risk analysis/management in supply chains using BN with regard to sustainability considerations is under-researched.

Kumari and Pandey (2022), Xu et al. (2022), Shafiee Neyestanak and Roozbahani (2021), Bozorgi et al. (2021) and Bertone et al. (2016) utilised BN for the sustainability risk assessment/management of water supply chain. Kumari and Pandey (2022) constructed a BN model to assess the sustainability of Jumar River in eastern India, where this river's sustainability was found to be highly influenced by extreme events such as drought and water shortage. Using BN method, Xu et al. (2022) quantitatively assessed the impact of climate change and a reservoir constructed in Yangtze River, China on this river's water temperature. BN-based assessment of the risk of using treated wastewater for agriculture, industry, groundwater artificial recharge and landscape irrigation is conducted by Shafiee Neyestanak and Roozbahani (2021), regarding the social, environmental, economic and technical criteria; while in Bozorgi et al. (2021) a risk assessment model that takes into account multiple hazards is constructed for water distribution and delivery systems in agriculture by applying a hybrid BN. Bertone et al. (2016) developed a participatory BN-driven risk assessment tool to estimate and rank health risks associated to water quality, originating from weather-related extreme events, for a dam that supplies water to a treatment plant.

Liu et al. (2022), Onakoya et al. (2022), Rezazade et al. (2022) and Bouzembrak and Marvin (2019) applied BN for risk analysis/assessment in food supply chain taking into account the sustainability criteria. BN is employed in Liu et al. (2022) for identifying food safety hazards in a dairy supply chain in Europe. Fuzzy rule-based system and BN are combined in Onakoya et al. (2022) in order to identify and evaluate the risk variables that influence food transport logistics in two main food supply chains in Vietnam. Rezazade et al. (2022) developed a holistic BN approach for analysing factors related to food fraud vulnerability using the incidents data recorded in Decernis food fraud database. Bouzembrak and Marvin (2019) applied BN for identifying relationships and interactions between climatic, economic and agronomic variables on one hand, and the food safety hazards for raw vegetables and fruits on the other, and quantifying the strength of the relationships.

Jayasinghe et al. (2022) identified risks in four reverse logistics sub-processes of demolition waste management, and assessed the interdependencies between these risks through BN to improve operations performance from quality perspective. Chhimwal et al. (2021) employed BN methodology for analysing the risk propagation in the circular supply chain of automobile industry. A dynamic BN model is applied in Sajid (2021) to investigate the COVID 19-associated risks over a ten-year period for the biomass supply chain of a biofuel company operating in the United States. A BN model was created in Sakib et al. (2021) for the prediction and assessment of disasters in supply chain of oil and gas industry with regard to seven key factors: *technical, environmental, social, safety, economic, political,* and *legal*.

Shakeri et al. (2020) analysed the performance of the green supply chain of a hospital with regard to different types of risks using BN. Thöni et al. (2018) developed a BN-based expert system for monitoring suppliers for possible social sustainability noncompliance especially with regard to child labour. Using a Bayesian hierarchical model, Eckle and Burgherr (2013) performed a risk analysis for major fatal accidents resulting in several fatalities and a group of different activities throughout the oil supply chain. The Bayesian data analysis in their study provides a framework for the risk allocation in sustainability assessments. Modelling and analysing risks in the biomass supply chain of a biorefinery using BN is studied by Amundson et al. (2012). BN is employed in Yen and Zeng (2010) to develop a hierarchical assessment method for guiding outsourcing decisions and detecting material risk in green supply chain.

Table 2
Comparing the relevant literature with each other and with the present study.

	Multi-tier/ single-tier supply chain	DSS for selecting the effective SGA/ SGAs	Risk management of SGAs in multi-tier supply chain
The literature on BN-based DSS for sustainability management	Single-tier/ Not within supply chain	Not developed	Not applicable
The literature on risk assessment/ management in single-tier, sustainable supply chains using BN	Single-tier	Not applicable	Not applicable
The present study	Multi-tier	Developed	Considered

2.4. Research gaps

Table 2 compares the relevant literature with each other and with the present research.

Reviewing the literature shows that there is no published research on developing a decision support tool using management science methods (whether BN or other management science methods) to assist operations managers in making decision about which SGA/SGAs to apply in a given situation.

Lack of the risk management of SGAs in multi-tier supply chain, whether using quantitative or qualitative risk management techniques, is another gap in the literature.

The above research gaps are of high significance to be addressed. Unlike first-tier suppliers, lower-tier suppliers more frequently violate the sustainability requirements of focal companies (Wilhelm and Villena, 2021; Wilhelm et al., 2016b). The unsustainable actions taken by

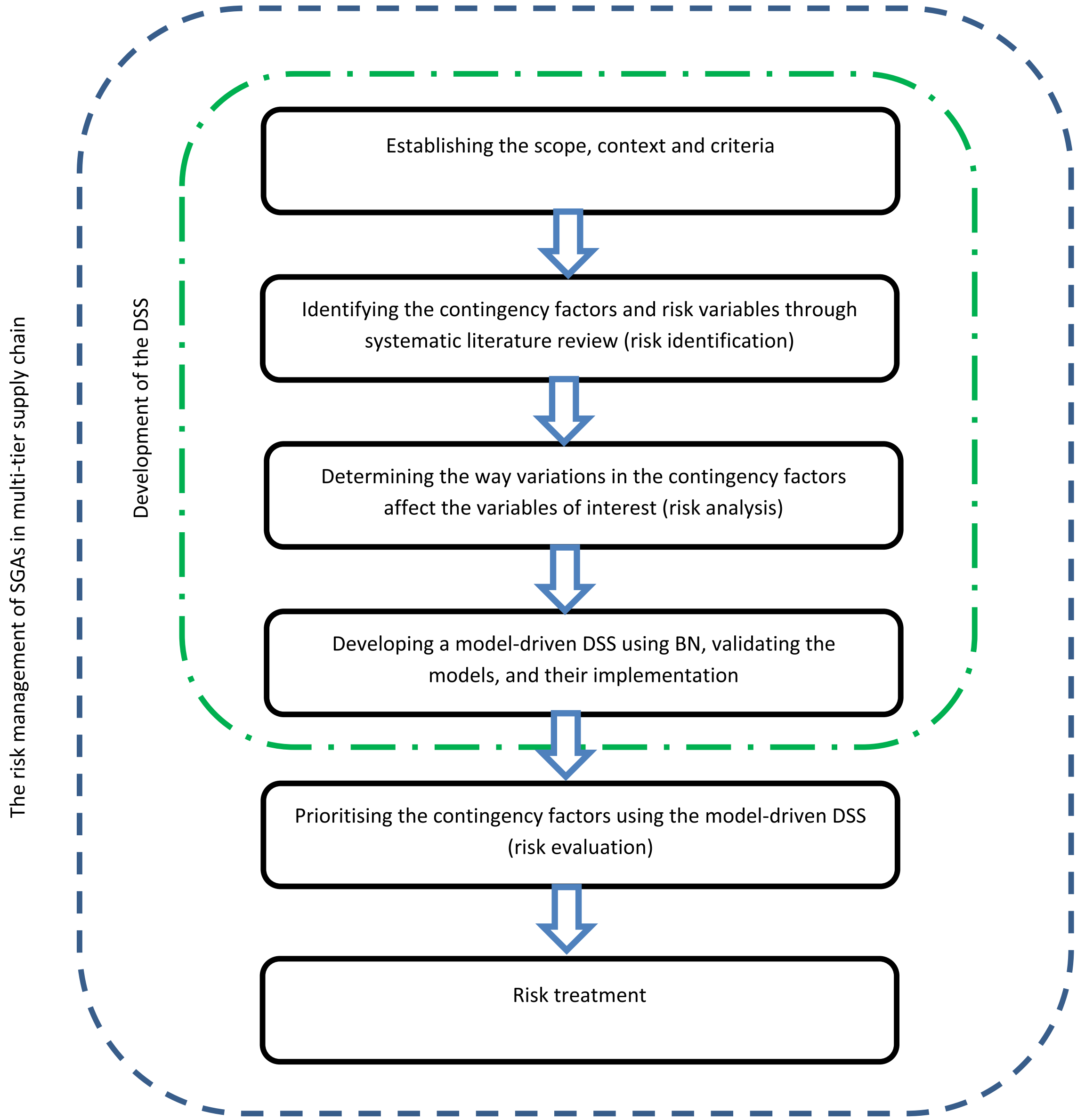

Fig. 1. Fundamental steps of the research method of the present study.

the suppliers at the lower tires of the supply chain and focal company's failure at meeting the internal and external stakeholders' demands to extend sustainability to these suppliers carry several risks, of tangible and intangible nature, to the focal company (Foerstl et al., 2010; Hofmann et al., 2014; Nath and Eweje, 2021). Applying effective SGA/SGAs to disseminate sustainability to suppliers at lower tiers is expected to reduce these risks for focal companies (Meinlschmidt et al., 2018; Tachizawa and Wong, 2014). A DSS can be helpful for the supply chain/operations managers in selecting the most suitable SGA/SGAs in a given condition. Additionally, this DSS can be embedded in the process for the risk management of SGAs in multi-tier supply chain. This is of particular importance considering the risks of sustainability violations by lower-tier suppliers for focal company if focal company takes no action to establish lower-tier suppliers' sustainability compliance or inappropriate SGA is applied.

3. Research method

Fig. 1 outlines the research method of this study for the risk management of SGAs in multi-tier supply chain, which includes development and implementation of a model-driven DSS that is used for determining the most effective SGA/SGAs in different situations, prioritising the basic contingency factors and risk treatment.

We follow the risk management process proposed by ISO, 31000:2018, which contains five core steps: (i) establishing the scope, context and criteria, (ii) risk identification, (iii) risk analysis, (iv) risk evaluation, and (v) risk treatment (ISO, 2018).

The scope and context of the risk management for the present research is extending sustainability to lower-tier suppliers in multi-tier supply chains, and the criteria are tangible and intangible losses a focal company would incur as a result of lower-tier suppliers' failure to comply with sustainability standards.

To reduce sustainability noncompliance by lower-tier suppliers and the resulting risks, focal company applies the SGAs to extend sustainability towards these suppliers and monitor them for possible sustainability noncompliance. Specific contingency factors can determine the effectiveness of these SGAs. Through a systematic literature review on the literature of MT-SSCM, these contingency factors are identified, and how variations in their states affect the effectiveness of each SGA and the risks of *sustainability noncompliance by lower-tier suppliers* for focal company are determined. The details about the systematic literature review, including its steps and the literature screening process, and the full references list for the reviewed literature, have respectively been presented in Parts A and B of Supplementary Materials, which can be found at the link provided in the footnote.[1] Identifying the risks related to lower-tier suppliers' unsustainable actions for focal company and the contingency factors impacting the likelihood of occurrence of these risks through influencing the effectiveness degree of SGAs corresponds to the risk identification step.

The way variations in the states of contingency factors determine the effectiveness of SGAs and therefore the risks of *sustainability noncompliance by lower-tier suppliers* for focal company are explained in the risk analysis step.

In the next stage of the research, a model-driven DSS is developed using BN and according to the identified contingency factors, risk variables and the causal relationships to help decision makers choose the most useful SGA/SGAs in each circumstance. To validate the BN models of SGAs, first, the causal relationships between the contingency factors are established according to the clustering pattern of the contingency factors. Then, eleven practitioners from different tiers of the supply chains of different industries approve the relevance of the contingency factors and their cause and effect relationships. The practitioners together with the four members of the authors team, as researchers researching primarily on MT-SSCM, subjectively provide the comparative weights of the parent nodes with regard to their impact on each child node in order to use the AgenaRisk 10 software capability to automatically generate the node probability tables based on the comparative weights (details are provided in Subsection 4.1.3.3). Finally, the developed BN models of SGAs are implemented in the multi-tier, sustainable supply chain of a multinational company that operates in China in cotton-textile industry to demonstrate the developed DSS is applicable to real-world cases.

The BN is applied in the present research for developing the DSS and the risk management of SGAs in multi-tier supply chain because when risks are new or insufficient past data is available, the statistical models of risk assessment based on historical data are inefficient. In addition, the data-driven and the risk register approaches are not capable of modelling dependencies between different risk variables. BN is able to capture the complex interrelationships that exist between risk variables, and can effectively combine expert opinions with historical data and provide a methodology for combining subjective beliefs with available evidence (Fenton and Neil, 2011, 2019).

In the risk evaluation step, the contingency factors are prioritised based on their impact on the effectiveness of SGAs and thus on the risks of *sustainability noncompliance by lower-tier suppliers* for focal company using the BN-based decision models developed in the previous step.

For the risk treatment purpose, the occurrence probability of the risks of *sustainability noncompliance by lower-tier suppliers* for focal company is reduced by increasing the probability of effectiveness of SGAs in two ways: (i) choosing the most effective SGA/SGAs regarding the pertinent contingency factors before applying a SGA, and (ii) regularly assessing the situation considering the states of the relevant contingency factors over time to confirm that the currently in use SGA/SGAs is/are still the most effective approach/approaches, since variations in contingency factors' states due to a new circumstance could make the currently in use SGA/SGAs less effective or not effective.

4. The risk management of SGAs in multi-tier supply chain

4.1. Development of the model-driven DSS

4.1.1. The assumptions

The model-driven DSS for selecting the most effective SGA/SGAs in multi-tier supply chain is developed and then used in the risk management process of SGAs according to the following assumptions:

First, it is assumed that only the contingency factors presented in the current study have an impact on the effectiveness of SGAs and hence on the risk variables related to lower-tier suppliers' noncompliance with sustainability standards, and no other unknown variable/factor play a role in this regard.

Second, the cause and effect relationships between the contingency factors are built according to the clustering pattern of each cluster of the contingency factors, which itself is influenced by the authors' understanding from the relevant literature about MT-SSCM.

Third, to measure the unique contribution of each basic contingency factor to making the pertinent SGA effective, which is used as a criterion to prioritise these factors in the risk management process, it is assumed that there is no interrelationships between these factors.

Fourth, since the don't bother approach, in essence, is not an active strategy, its usefulness in reducing the risks of *sustainability noncompliance by lower-tier suppliers* for focal company would be hard to determine. Therefore, the risk management is performed for the other three SGAs.

Fifth, from reviewing the MT-SSCM literature, we realised that how the contingency factors influence the effectiveness of the mixed approach (i.e., the simultaneous application of more than one SGA) is largely under-researched. Thus, in the current study, for the developed DSS to be grounded in the relevant MT-SSCM literature, BN-based models are developed only for the pure approach (i.e., the application of a single SGA at the same time), and a simple procedure is proposed in Subsection 4.1.3.4.3 on how to decide which combination of SGAs to apply (i.e., mixed approach).

4.1.2. The contingency factors and risk variables identification

Specific contingency factors can determine the effectiveness of the SGAs for spreading sustainable practices towards lower-tier suppliers. These contingency factors were identified through a systematic literature review. Significant overlap existed among some of the initially identified contingency factors from the relevant literature. However, to reduce the overlap among the factors as much as possible, evaluate the unique contribution of each contingency factor to the effectiveness of a given SGA and avoid excessive complexity, these factors were screened. Finally, 33 contingency factors were identified from the MT-SSCM literature, which are called "the basic contingency factors". The basic contingency factors and their concise descriptions are presented in Table 3.

Because of the relatively large set of the basic contingency factors and their high variety, and also for efficiently analysing the relationship between these factors and the effectiveness of the relevant SGA, these factors are clustered in two stages, called "the primary clusters of contingency factors" and "the secondary clusters of contingency factors". The clustering of the contingency factors which is done based on their similarity, interrelationships and how their variations affect the effectiveness of each SGA is presented in Table 4. For instance, there could be interrelationships between *the specific nature of the materials sourced from lower-tier supplier* and *the critical importance of the materials sourced from lower-tier supplier to focal company*, so that when the materials sourced from lower-tier supplier are specific, it can become hard or even impossible to switch the lower-tier supplier and this can increase *the critical importance of the materials sourced from lower-tier supplier to focal company* because of the great impact that it could have on the quality of the final product. These two contingency factors would make it difficult for the buyers to turn to other suppliers, and therefore they are clustered under the primary cluster "The difficulty of changing the lower-tier supplier because of the specificity and criticality of the sourced materials". *The difficulty of changing the lower-tier supplier because of the specificity and criticality of the sourced materials* and the *focal company's perceived sustainability risk* may convince the focal company that it is necessary to take direct action to promote sustainability among lower-

[1] https://figshare.com/articles/dataset/Supplementary_Materials/21890784.

Table 3
The concise descriptions of the basic contingency factors.

The relevant SGA	The basic contingency factors	Description	References
Direct	Focal company's sustainability knowledge	The knowledge of sustainability and the expertise that would enable focal company on training the suppliers of lower tiers in integrating sustainability into their business practices and more efficient monitoring of their sustainability compliance.	Villena and Gioia (2018); Wilhelm et al. (2016a); Wilhelm et al. (2016b); Tachizawa and Wong (2014)
	Focal company's supply knowhow	The robust understanding of the focal company of its supply base, mainly the upstream members of its supply chain and their specific attributes, core operational processes and procured materials.	Dou et al. (2018); Grimm et al. (2014); Reuter et al. (2010); Hall (2000)
	Willingness of first-tier supplier for disclosing lower-tier supplier to focal company	The readiness of first-tier supplier to reveal lower-tier suppliers' unsustainable actions to focal company, which is of great importance in situations that so many lower-tier suppliers exist and focal company lacks sufficient resources for directly searching and gathering the relevant information about the sustainability performance of these suppliers.	Dou et al. (2018); Grimm et al. (2014); Vachon and Klassen (2006)
	First-tier supplier's perceived risk that it can be disintermediated by focal company	The disintermediation risk, or the risk that focal firm bypasses first-tier supplier by terminating its business relationship with first-tier supplier and directly procuring materials and services from lower-tier supplier.	Dou et al. (2018); Grimm et al.(2014); Choi and Linton (2011)
	Involvement of first-tier supplier in cascading sustainability towards lower-tier supplier	Active intermediary role of tier-1 suppliers in focal company's initiatives to ensure sustainability compliance of lower-tier suppliers.	Grimm et al. (2014); Grimm (2013)
	Mutual trust in first-tier supplier-focal company relationship	This mutual trust is established if each party in the relationship believes that the other party is not behaving opportunistically and does not exploit vulnerabilities, even if such exploitations cannot be easily detected.	Dou et al. (2018); Sjoerdsma and Weele (2015); Grimm et al. (2014); Grimm (2013)
	First-tier supplier's buyer-power over lower-tier supplier	A key determinant of buyer-power of first-tier supplier over lower-tier supplier is the purchasing volume, i.e., higher purchasing volume means higher buyer-power.	Dou et al. (2018); Grimm et al. (2014); Grimm (2013)
	The critical importance of the materials sourced from lower-tier supplier to focal company	The quality of the products produced by focal company or their sustainability is significantly dependent upon the materials first-tier supplier sources from lower-tier supplier.	Yawar and Kauppi (2018); Sauer and Seuring (2018); Tachizawa and Wong (2014); Mena et al. (2013)
	The specific nature of the materials sourced from lower-tier supplier	The special features of the materials so that they can be sourced from a limited number of suppliers.	Meinlschmidt et al. (2018); Sauer and Seuring (2018)
	Stakeholder prominence	Supply chain managers perceive the importance of stakeholders as a function of stakeholders' power, the legitimacy of their sustainability demands and the urgency associated with those demands.	Meinlschmidt et al. (2018); Kannan (2018); Mitchell et al. (1997)
	The salience of the product and industry	The industries that manufacture products which are more easily visible to consumers, such as firms operating in pharmaceutical, apparel and chemical industries, and companies with famous brand names.	Meinlschmidt et al. (2018); Hajmohammad and Vachon (2016); Hartmann and Moeller (2014); Schneider and Wallenburg (2012); Simpson et al. (2012); Castka and Balzarova (2008)
	Sustainability misconducts in focal company's/competitors' supply chain in the past	Environmental and social incidents at supplier sites and the resulting disruptions in supply chain of the focal company or that of the competitors' occurred in the past.	Meinlschmidt et al. (2018); Grimm et al. (2016); Hajmohammad and Vachon (2016); Groetsch et al. (2013)
	Complex sustainability knowledge, which suppliers of different tiers need to learn	The level of complexity of the sustainability-knowledge material that first-tier supplier and suppliers of the lower tiers are required to learn.	Jia et al. (2019); Gong et al. (2018a)
	Lower-tier suppliers are monitored for adherence to the social dimension of sustainability	Monitoring lower-tier supplier's compliance regarding the social dimension of sustainability such as unequal payment for equal work, child labour and sexual abuse.	Wilhelm et al. (2016a)
	Public attention on the sustainability performance of first-tier supplier	Different groups of stakeholders, governments, media, NGOs and employees can have the capability to influence first-tier suppliers to taking into account the sustainability criteria in their supplier selection decisions.	Lechler et al. (2020); Grimm et al. (2016)
Indirect	Information asymmetry between focal company and lower-tier supplier	In case of significant *information asymmetry between focal company and lower-tier supplier*, the focal company has narrow information about the business processes at lower-tier suppliers' organisations and how those processes can become environmentally and socially sustainable.	Wilhelm et al. (2016b); Wilhelm et al. (2016a)
	Coordination between sustainability and purchasing departments at focal company	The close interaction between the purchasing function and sustainability function at focal company's organisation, so that the purchasing function shares the information regarding the sustainability performance of lower-tier suppliers with the sustainability function.	Villena (2019); Wilhelm et al. (2016b)
Indirect	Benefits for first-tier supplier for disseminating sustainability towards lower-tier supplier	The perceived value by first-tier supplier for engagement in activities related to cascading sustainability to suppliers at lower tiers. This perceived value, which can be of monetary and nonmonetary nature, is a trade-off between first-tier supplier's sacrifices and benefits it receives in return.	Villena and Gioia (2020); Villena (2019); Grimm et al. (2014); Grimm (2013)

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Table 3 (*continued*)

The relevant SGA	The basic contingency factors	Description	References
	Lower-tier suppliers are monitored for adherence to the environmental dimension of sustainability	Monitoring lower-tier supplier's compliance regarding the environmental dimension of sustainability, for example high emissions of CO2 or pesticides misuse.	Wilhelm et al. (2016a)
	Focal company's buyer-power over first-tier supplier	It is directly related to focal company's purchase volume from its first-tier supplier.	Wilhelm and Villena (2021); Dou et al. (2018); Wilhelm et al. (2016a); Grimm et al. (2014)
	Focal company size	Measures such as annual revenue or the total number of employees can be used to determine the company size.	Dou et al. (2018); Grimm et al. (2016); Bourlakis et al. (2014b); Bourlakis et al. (2014a); Hartmann and Moeller (2014); Mena et al. (2013); Melnyk et al. (2003)
	First-tier supplier's sustainability training	The sustainability-related trainings and knowledge that first-tier supplier can receive from focal company and/or third parties.	Alexander (2020); Villena and Gioia (2020); Gong et al. (2019); Jia et al. (2019); Villena (2019); Gong et al. (2018a); Gong et al. (2018b); Villena and Gioia (2018); Wilhelm et al. (2016a); Klassen and Vachon (2003)
	First-tier supplier's possession of internal resources	Financial resources and physical assets that enable first-tier supplier to cascade sustainability towards the suppliers of the lower tiers.	Wilhelm et al. (2016b)
	Power asymmetry in first-tier supplier-lower-tier supplier relationship, which favours first-tier supplier	When lower-tier supplier depends on first-tier supplier for resources (e.g. materials, expertise and information), there is power asymmetry in favour of first-tier supplier.	Wilhelm et al. (2016a); Wilhelm et al. (2016b)
	The capability of lower-tier supplier to comply with focal company's sustainability standards	Lower-tier supplier's capability, such as sustainability-related knowledge and financial resources for fulfilling focal company's sustainability requirements.	Dou et al. (2018); Grimm et al. (2014); Grimm (2013)
	Benefits for lower-tier supplier for meeting focal company's sustainability requirements	This is of great importance as lower-tier suppliers normally incur costs and have to make extra efforts in order to comply with focal company's sustainability standards. Therefore, increased sales volumes or price premiums are expected by lower-tier suppliers as rewards for compensating their sustainability compliance.	Villena (2019); Grimm et al. (2014); Grimm (2013)
	Geographical distance between focal company, and the suppliers of first tier and lower tiers	Increased geographical distance between focal company and its supply base would make sustainability training programmes, sustainability auditing, periodic monitoring of suppliers' sustainability performance, and collaboration costly and difficult tasks.	Dou et al. (2018); Busse et al. (2016); Grimm et al. (2014); Grimm (2013); Awaysheh and Klassen (2010); Simpson et al. (2007)
	Cultural distance between focal company, and the suppliers of first tier and lower tiers	It indicates the differences between the cultures, social standards, norms and values of the societies where the companies are located.	Busse et al. (2016); Wilhelm et al. (2016a); Grimm et al. (2014); Tachizawa and Wong (2014); Sarkis (2012); Awaysheh and Klassen (2010)
	Horizontal complexity level at first-tier supplier stage	The number of suppliers at first-tier supplier stage is used as the main criterion to measure the horizontal complexity at this stage.	Meinlschmidt et al. (2018); Wilhelm et al. (2016a); Choi and Hong (2002)
	Mutual trust in lower-tier supplier-first-tier supplier relationship	*Mutual trust in lower-tier supplier-first-tier supplier relationship* is established if each party in the relationship believes that the other party is not behaving opportunistically and does not exploit vulnerabilities, even if such exploitations cannot be easily detected.	Dou et al. (2018); Grimm et al. (2014); Grimm (2013)
	Committed, long-term lower-tier supplier-first-tier supplier relationship	It makes the implementation of the initiatives for management of lower-tier supplier's sustainability easier, and lower-tier suppliers generally give higher priority to sustainability compliance requests from first-tier supplier if they have established long-term relationship.	Dou et al. (2018); Grimm et al. (2014); Grimm (2013); Castka and Balzarova (2008); Walker et al.(2008); Carter and Dresner (2001)
Work with third parties	Partnership with external stakeholders for spreading sustainability towards suppliers at lower tiers	Collaboration with salient stakeholders, for example governments, NGOs, industrial alliances, sustainability auditors and suppliers, for sourcing the knowledge of sustainability, providing sustainability trainings to suppliers, assessing the sustainability performance of the suppliers and providing sustainability certifications.	Grimm et al. (2022); Alexander (2020); Villena and Gioia (2020); Gong et al. (2019); Hannibal and Kauppi (2019); Jia et al. (2019); Lechler et al. (2019); Gong et al. (2018a); Gong et al. (2018b); Formentini and Paolo (2016); Grimm et al. (2011); Peters et al. (2011)
	Horizontal complexity level at lower-tier supplier stage	The number of suppliers at lower-tier supplier stage is used as the main criterion to measure the horizontal complexity at this stage.	Wilhelm et al. (2016a); Choi and Hong (2002)

tier suppliers. So, these two contingency factors are clustered under the secondary cluster "The perceived necessity by focal company to directly adopt measures for managing sustainability at lower-tier supplier stage''.

The way variations in the contingency factors impact the effectiveness of each SGA, which is inferred from the reviewed literature, is indicated in Table 4. For example, (High, Low) in the row of the basic contingency factor "Focal company's sustainability knowledge'' in Table 4 means if *focal company's sustainability knowledge* is "High'', the direct approach is expected to be effective, and operations managers are recommended to apply this approach; if it is "Low'', this approach would not be effective.

Sustainability noncompliance by lower-tier suppliers motivates the external and internal stakeholder pressures on focal company to urge the focal company to cascade sustainability towards the suppliers of lower tiers (Nath and Eweje, 2021; Tachizawa et al., 2015; Meixell and Luoma, 2015; Roy et al., 2020; Sauer and Seuring, 2019). Focal company's negligence in meeting the expectations of the stakeholders to cascade sustainability towards the lower-tier supplier level could result in significant risks for the focal company. These risks include consumer boycott of focal company's products/services, decline in share values, reputational damage, fines associated with legal actions taken against the focal company, increased total expenses as a result of the additional costs incurred to achieve sustainability compliance with lower-tier suppliers, negative media coverage and the loss of customer credibility (Foerstl et al., 2010; Hofmann et al., 2014; Sajjad et al., 2015; Kumar

Table 4
The two-stage clustering of the basic contingency factors, and their variations impact on the effectiveness of the relevant SGAs.

The relevant SGA	The basic contingency factors	The relevant SGA effectiveness		The primary clusters of contingency factors	The relevant SGA effectiveness		The pivotal point connecting each cluster in the primary clusters of contingency factors	The secondary clusters of contingency factors	The relevant SGA effectiveness		The pivotal point connecting each cluster in the secondary clusters of contingency factors
		Effective	Not Effective		Effective	Not Effective			Effective	Not Effective	
The direct approach	A-1. Focal company's sustainability knowledge	High	Low	A. The knowledge-capability of focal company for managing sustainability at lower-tier supplier stage (A-1 and A-2 clustered)	High	Low	These two contingency factors represent the knowledge-related capability that a focal company should possess for directly extending sustainability to suppliers of the lower tiers.	Factors enabling the direct involvement of focal company in promoting sustainability among lower-tier suppliers (A and B clustered)	Exist	Do Not Exist	The contingency factors that can enable focal company to become directly engaged in plans for sustainability management at lower-tier supplier stage.
	A-2. Focal company's supply knowhow	High	Low								
	B-1. Willingness of first-tier supplier for disclosing lower-tier supplier to focal company	High	Low	B. Focal company's sustainability compliance monitoring at lower-tier supplier stage smoothed by first-tier supplier (B-1, B-2, B-3, B-4 and B-5 clustered)	True	False	The contingency factors under this cluster describe the ways through which first-tier suppliers can play a role in facilitating focal company's direct participation in monitoring sustainability compliance at lower-tier supplier stage.				
	B-2. First-tier supplier's perceived risk that it can be disintermediated by focal company	Low	High								
	B-3. Involvement of first-tier supplier in cascading sustainability towards lower-tier supplier	High	Low								
	B-4. Mutual trust in first-tier supplier-focal company relationship	High	Low								
	B-5. First-tier supplier's buyer-power over lower-tier supplier	High	Low								
	C-1. The critical importance of the materials sourced from lower-tier supplier to focal company	High	Low	C. The difficulty of changing the lower-tier supplier because of the specificity and criticality of the sourced materials (C-1 and C-2 clustered)	High	Low	According to these two contingency factors, if the materials sourced from lower-tier supplier are critical to focal company and the materials are specific (i.e., they are produced by few suppliers), this can make it difficult to switch the lower-tier supplier when needed.	The perceived necessity by focal company to directly adopt measures for managing sustainability at lower-tier supplier stage (C and D clustered)	High	Low	Focal company would consider direct engagement in plans for managing sustainability at the lower tiers to be highly necessary, if switching the lower-tier supplier is deemed a less practical option and focal company expects a high sustainability violation risk at lower-tier supplier stage.
	C-2. The specific nature of the materials sourced from lower-tier supplier	High	Low								
	D-1. Stakeholder prominence	High	Low	D. Focal company's perceived sustainability risk (D-1, D-2, D-3, D-4, D-5 and D-6 clustered)	High	Low	A situation in which focal company perceives a high degree of risks related to sustainability violations from lower-tier suppliers and embarks on taking direct action to bring lower-tier suppliers to sustainability compliance.				
	D-2. The salience of the product and industry	High	Low								
	D-3. Sustainability misconducts in focal company's/competitors' supply chain in the past	Frequent	Not Frequent								
	D-4. Complex sustainability knowledge, which suppliers of different tiers need to learn	True	Not True								
	D-5. Lower-tier suppliers are monitored for adherence to the	True	False								

(*continued on next page*)

Table 4 (*continued*)

The relevant SGA	The basic contingency factors	The relevant SGA effectiveness		The primary clusters of contingency factors	The relevant SGA effectiveness		The pivotal point connecting each cluster in the primary clusters of contingency factors	The secondary clusters of contingency factors	The relevant SGA effectiveness		The pivotal point connecting each cluster in the secondary clusters of contingency factors
		Effective	Not Effective		Effective	Not Effective			Effective	Not Effective	
	social dimension of sustainability										
	D-6. Public attention on the sustainability performance of first-tier supplier	Low	High								
The relevant SGA	The basic contingency factors	The relevant SGA effectiveness		The primary clusters of contingency factors	The relevant SGA effectiveness		The pivotal point connecting each cluster in the primary clusters of contingency factors	The secondary clusters of contingency factors	The relevant SGA effectiveness		The pivotal point connecting each cluster in the secondary clusters of contingency factors
		Effective	Not Effective		Effective	Not Effective			Effective	Not Effective	
The indirect approach	E−1. Information asymmetry between focal company and lower-tier supplier	Low	High	E. Ease of persuading first-tier supplier to take part in plans for cascading sustainability towards lower-tier supplier (E−1, E−2, E−3 and E−4 clustered)	High	Low	The main point connecting this cluster of contingency factors together is the easiness of urging first-tier suppliers to participate in activities on the management of lower-tier suppliers' sustainability considering the amount of effort required for performing this task and the benefits they gain in exchange for their effort.	The facilitators of delegating the lower-tier supplier's sustainability management responsibility to first-tier supplier (E, F, G, H, I and J clustered)	Exist	Do Not Exist	The central point reflected in these contingency factors is the condition that facilitates the delegation of the responsibility of managing lower-tier suppliers' sustainability to first-tier suppliers.
	E−2. Coordination between sustainability and purchasing departments at focal company	High	Low								
	E−3. Benefits for first-tier supplier for disseminating sustainability towards lower-tier supplier	High	Low								
	E−4. Lower-tier suppliers are monitored for adherence to the environmental dimension of sustainability	True	False								
	F-1. Focal company's buyer-power over first-tier supplier	High	Low	F. Power asymmetry in focal company-first-tier supplier relationship, which favours focal company (F-1 and F-2 clustered)	High	Low	The contingency factors under this cluster reflect a state in which difference in power exist between focal company and first-tier supplier, which originates from the high purchase volume of the focal company or its size.				
	F-2. Focal company size	Large	Small								
	G-1. First-tier supplier's sustainability training	High	Low	G. The capability of first-tier supplier for disseminating sustainability towards lower-tier supplier (G-1, G-2 and G-3 clustered)	High	Low	Factors such as sustainability-related training, the availability of internal resources and power that contribute to first-tier suppliers' capability for managing their suppliers' sustainability.				
	G-2. First-tier supplier's possession of internal resources	High	Low								

(*continued on next page*)

Table 4 (*continued*)

The relevant SGA	The basic contingency factors	The relevant SGA effectiveness		The primary clusters of contingency factors	The relevant SGA effectiveness		The pivotal point connecting each cluster in the primary clusters of contingency factors	The secondary clusters of contingency factors	The relevant SGA effectiveness		The pivotal point connecting each cluster in the secondary clusters of contingency factors
		Effective	Not Effective		Effective	Not Effective			Effective	Not Effective	
	G-3. Power asymmetry in first-tier supplier-lower-tier supplier relationship, which favours first-tier supplier	High	Low								
	H-1. The capability of lower-tier supplier to comply with focal company's sustainability standards	High	Low	H. The enablers of sustainability compliance by lower-tier supplier (H-1 and H-2 clustered)	Exist	Do Not Exist	The contingency factors of this group are related to the lower-tier supplier enabling factors, such as lower-tier supplier's capability and the benefits the lower-tier suppliers are given, in order to comply with the sustainability standards set by focal company.				
	H-2. Benefits for lower-tier supplier for meeting focal company's sustainability requirements	High	Low								
	I-1. Geographical distance between focal company, and the suppliers of first tier and lower tiers	Low	High	I. Ease of communication between focal company and its supply base (I-1, I-2 and I-3 clustered)	High	Low	Communication difficulties between supply chain partners as they are geographically distant and of dissimilar cultures. This can be intensified with adding the increased horizontal complexity level (number of suppliers) at first-tier supplier stage.				
	I-2. Cultural distance between focal company, and the suppliers of first tier and lower tiers	Low	High								
	I-3. Horizontal complexity level at first-tier supplier stage	Low	High								
	J-1. Mutual trust in lower-tier supplier-first-tier supplier relationship	High	Low	J. Cooperation and trust in lower-tier supplier-first-tier supplier relationship (J-1 and J-2 clustered)	High	Low	A first-tier supplier-lower-tier supplier relationship that goes on in an environment of trust, partnership and commitment.				
	J-2. Committed, long-term lower-tier supplier-first-tier supplier relationship	Exists	Does Not Exist								
The work with third parties approach	K-1. Partnership with external stakeholders for spreading sustainability towards suppliers at lower tiers	High	Low	K. The motives for engaging external stakeholders in programmes for disseminating sustainability towards suppliers at lower tiers (K-1 and K-2 clustered)	Exist	Do Not Exist	The contingency factors included in this cluster act as motivators for focal company to invite external stakeholders to participate in initiatives for promoting sustainability among lower tier suppliers.	The expected participation rate of external stakeholders in lower-tier supplier's sustainability management plans (cluster of K)	High	Low	The motivators of involving external stakeholders in programmes for cascading sustainability towards suppliers at lower tiers pave the way for the increased participation of these parties in such programmes.
	K-2. Horizontal complexity level at lower-tier supplier stage	High	Low								

and Rahman, 2016; Seuring and Müller, 2008; Meixell and Luoma, 2015; Nath and Eweje, 2021). These risks can be put under three general categories: (i) *focal company's sales (revenue) decline*, (ii) *focal company's damaged reputation*, and (iii) *increased total expenses incurred by focal company*.

4.1.3. The BN-based DSS and its implementation

4.1.3.1. The outline of the causal BN diagrams for the risk management of the SGAs. Fig. 2 acts as a conceptual basis for the causal BN models of SGAs in multi-tier supply chain and indicates the cause and effect relationships between the variables of interest. In Fig. 2, from left to right, the first layer represents the basic contingency factors that influence the primary clusters of contingency factors which in turn influence the secondary clusters of contingency factors. The secondary clusters of contingency factors directly determine the degree of effectiveness of each SGA. The more effective a given SGA become, the less sustainability noncompliance can be expected from lower-tier suppliers. There is positive relationship between *sustainability noncompliance by lower-tier suppliers* and the related risk variables for focal company, so that increase in the probability of *sustainability noncompliance by lower-tier suppliers* makes the occurrence of the related risk variables more likely, and vice versa.

4.1.3.2. Causal BN models of the SGAs. The conceptual model outlined in Fig. 2 is considered as a basis in constructing the causal BN models of

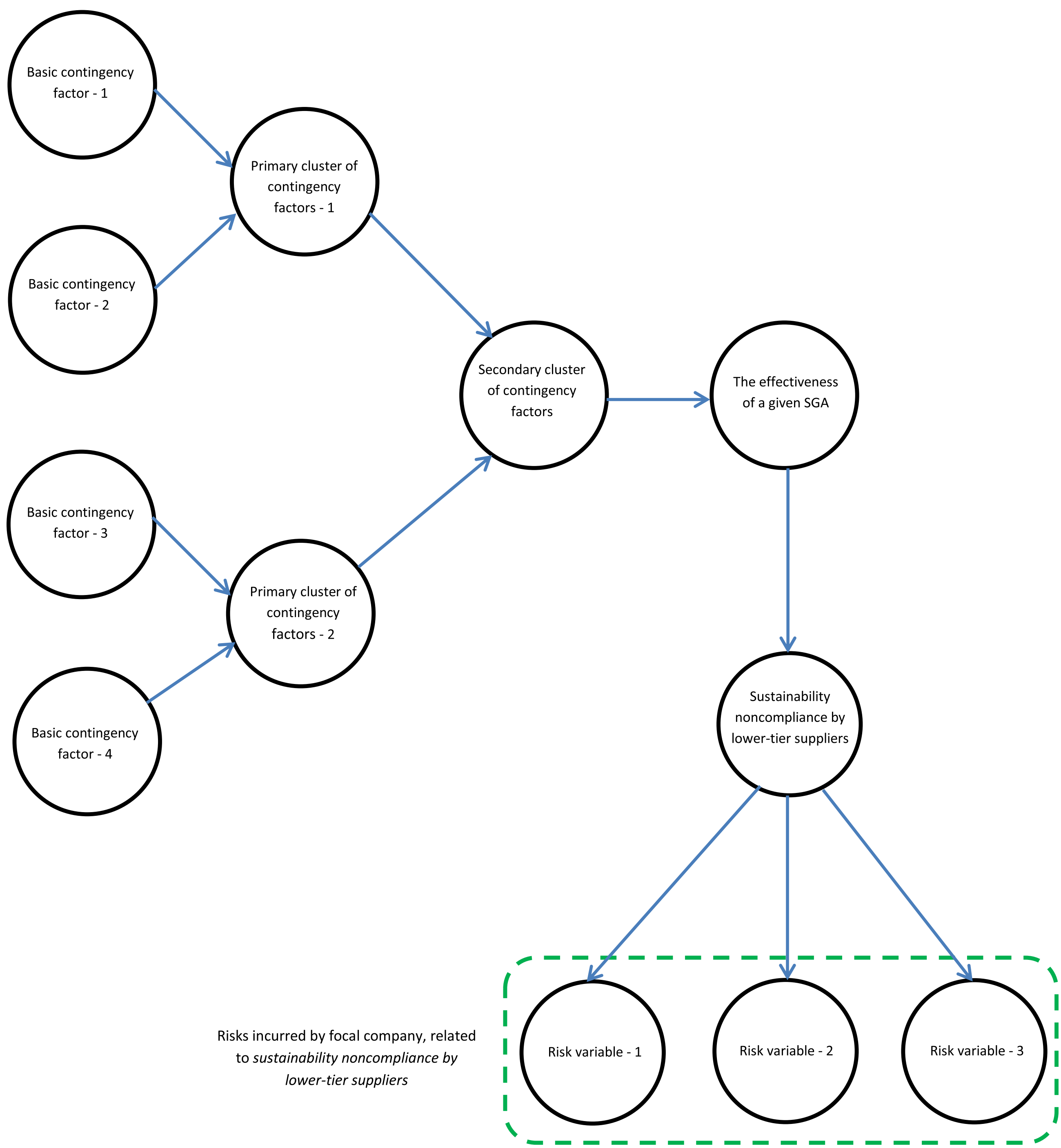


Fig. 2. The outline of the risk-based, causal BN diagrams for the SGAs in multi-tier supply chain.

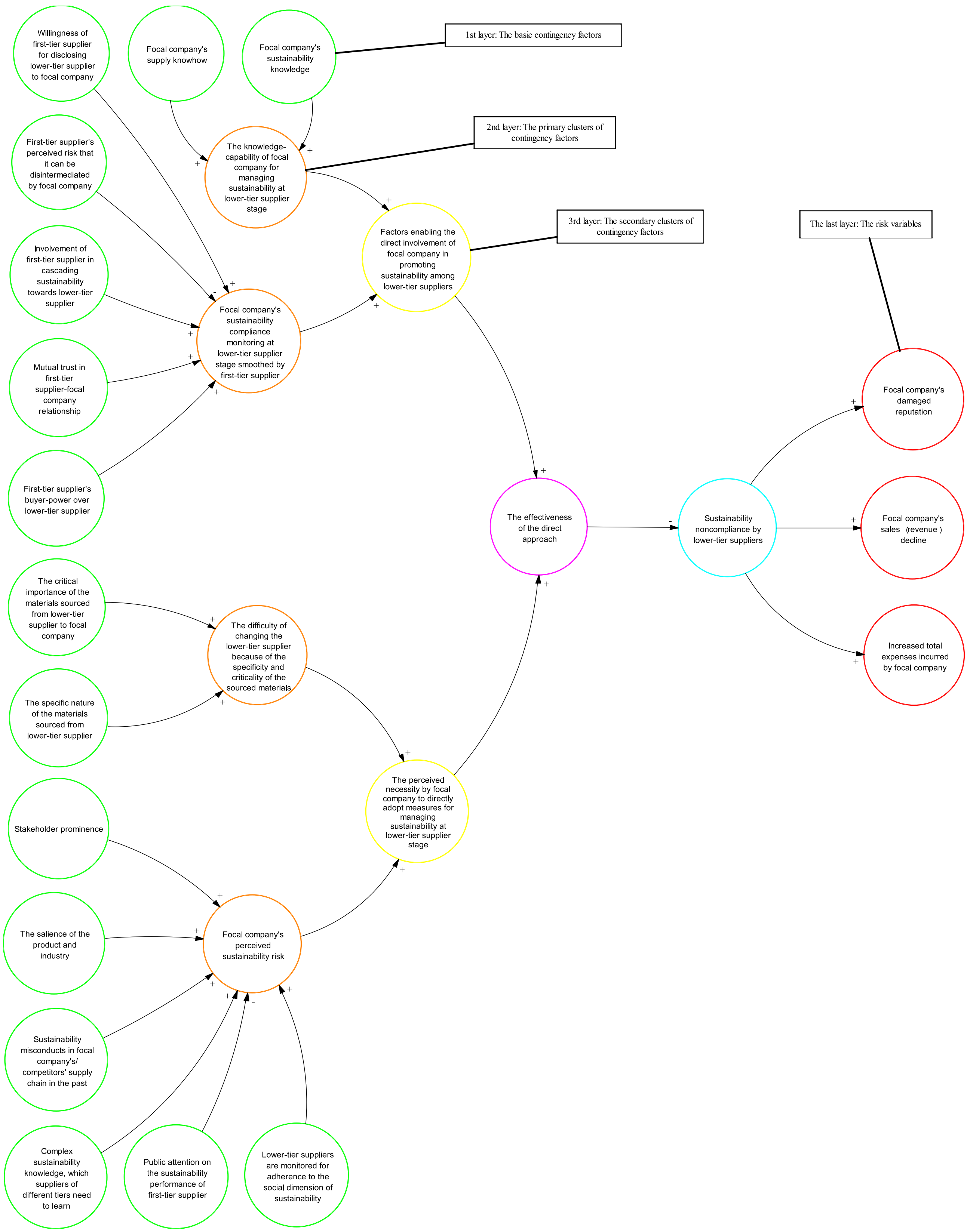


Fig. 3. (a) The causal BN diagram of the direct approach, (b) The causal BN diagram of the indirect approach, (c) The causal BN diagram of the work with third parties approach.

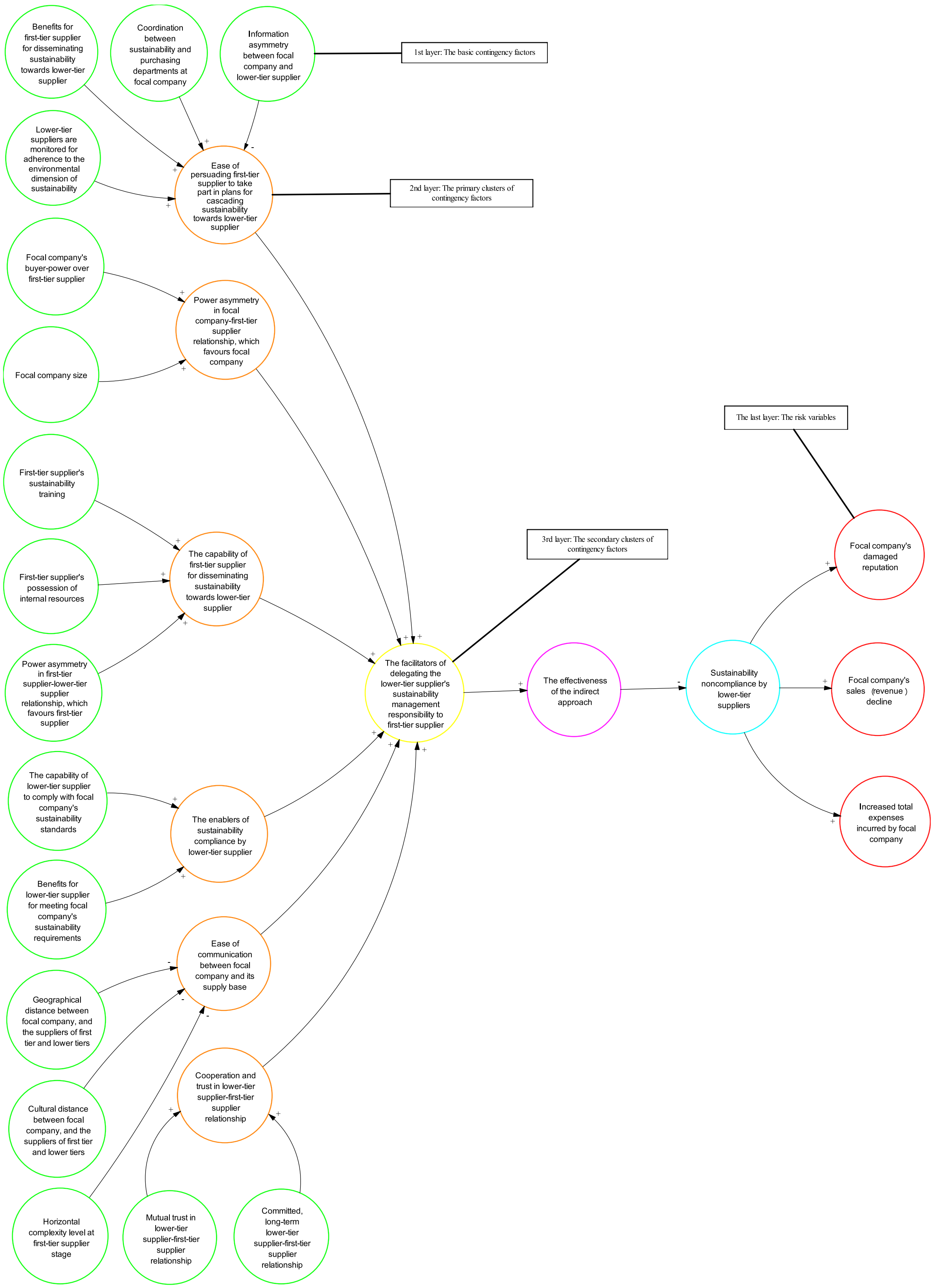


Fig. 3. (*continued*).

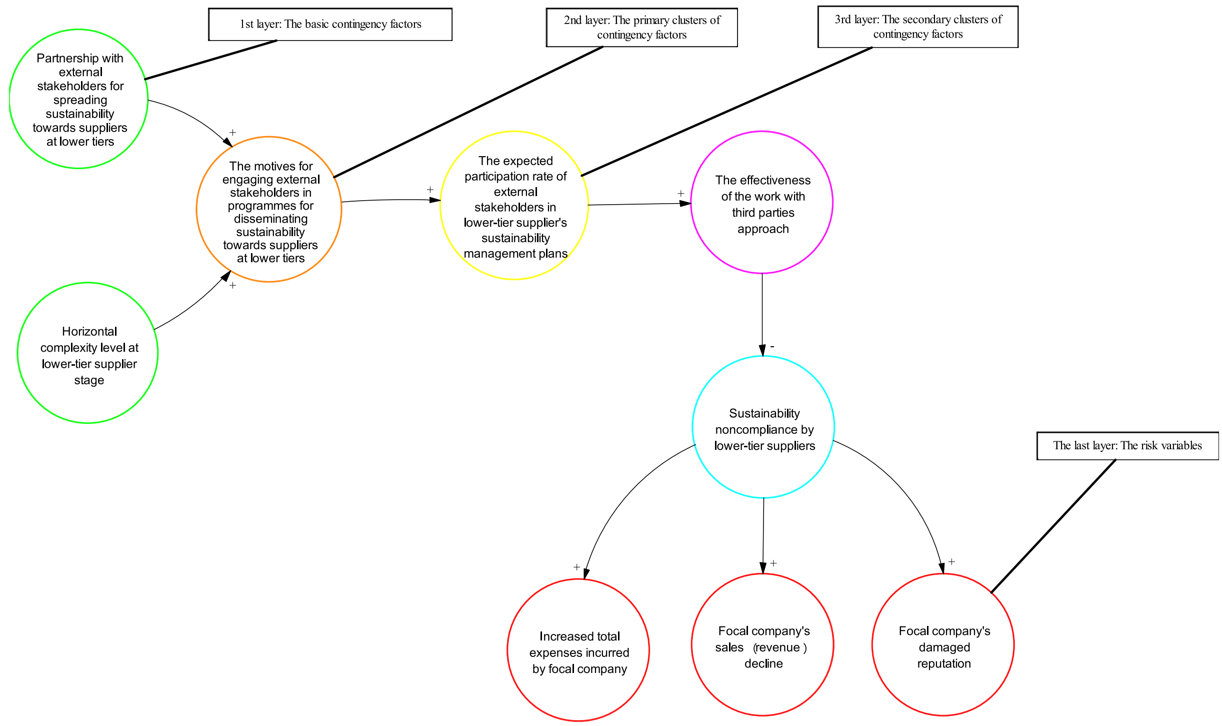


Fig. 3. (*continued*).

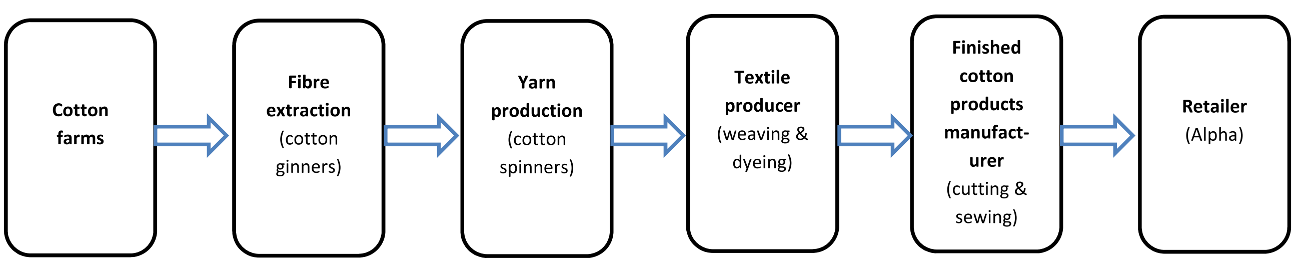


Fig. 4. A typical cotton-textile supply chain of Alpha.

the SGAs. Fig. 3a-c respectively depict the causal BN diagrams for the direct, indirect and work with third parties strategies.

The signs "+'' and "-'' on the arrowheads in Fig. 3a-c respectively show the positive and negative relationships between the parent nodes and child nodes. For instance, in Fig. 3a, when *the critical importance of the materials sourced from lower-tier supplier to focal company* increases, *the difficulty of changing the lower-tier supplier because of the specificity and criticality of the sourced materials* also increases, and vice versa. The opposite is true about *first-tier supplier's perceived risk that it can be dis-intermediated by focal company* and *Focal company's sustainability compliance monitoring at lower-tier supplier stage smoothed by first-tier supplier*, so that when the former increases, the latter becomes less true and more false.

All nodes in the constructed causal BN diagrams are of ranked or Boolean nature. In defining the states of the nodes two issues were considered: (i) the type of the nodes (e.g. ranked or Boolean), and (ii) defining the set of states for each node in such a way that generating the node probability tables automatically using the software, AgenaRisk 10, becomes possible. The latter is especially important considering the relatively large number of the contingency factors and the rather large number of parent nodes for several child nodes in the constructed BN models which could make manually-generating the node probability tables quite exhausting and time-consuming with less accurate and less consistent node probability tables.

The states of the Boolean nodes are of "True'' and "False'' type, and many ranked nodes have "High'', "Medium'' and "Low'' states. Some contingency factors can have both Boolean and ranked nature. An example is "Sustainability misconducts in focal company's/competitors' supply chain in the past''. If we assume that this factor is of Boolean nature, its states could be "Frequent'' and "Not Frequent''. To automatically generate the node probability table for a child node using AgenaRisk 10 software, all its parent nodes need to be of the same type, e.g. they all must be ranked nodes or Boolean nodes. If we consider the node for this factor as a Boolean node, we cannot use the software to automatically generate the node probability table for its child node "Focal company's perceived sustainability risk'' because the co-parent nodes are ranked nodes. However, if we add a middle state, "Rather Frequent'', to the set of states of this contingency factor, then this factor with the set of states (Frequent, Rather Frequent, Not Frequent) will be of ranked nature. This procedure has been applied for the contingency factors with similar condition.

4.1.3.3. Generating the node probability tables. In the constructed causal BN models, the node probability tables for the ranked nodes with at least two parent nodes were generated using the AgenaRisk 10 software by providing the comparative weights of the parent nodes for each child node. The Boolean nodes in the developed BN models do not have more than one parent node, and hence their node probability tables are generated manually which will be detailed later, although AgenaRisk 10 software has the capability to automatically generate node probability

Table 5
The summary of the case study in terms of the basic contingency factors and the observations.

The relevant SGA	The basic contingency factors	Observation (evidence)
Direct	Focal company's sustainability knowledge	High
	Focal company's supply knowhow	High
	Willingness of first-tier supplier for disclosing lower-tier supplier to focal company	Medium
	First-tier supplier's perceived risk that it can be disintermediated by focal company	Low
	Involvement of first-tier supplier in cascading sustainability towards lower-tier supplier	High
	Mutual trust in first-tier supplier-focal company relationship	High
	First-tier supplier's buyer-power over lower-tier supplier	High
	The critical importance of the materials sourced from lower-tier supplier to focal company	High
	The specific nature of the materials sourced from lower-tier supplier	Low
	Stakeholder prominence	High
	The salience of the product and industry	High
	Sustainability misconducts in focal company's/competitors' supply chain in the past	Rather Frequent
	Public attention on the sustainability performance of first-tier supplier	Medium
	Complex sustainability knowledge, which suppliers of different tiers need to learn	Partially True
	Lower-tier suppliers are monitored for adherence to the social dimension of sustainability	Partially True (both social and environmental aspects are to be monitored)
Indirect	Information asymmetry between focal company and lower-tier supplier	Medium
	Coordination between sustainability and purchasing departments at focal company	High
	Benefits for first-tier supplier for disseminating sustainability towards lower-tier supplier	High
	Lower-tier suppliers are monitored for adherence to the environmental dimension of sustainability	Partially True (both social and environmental aspects are to be monitored)
	Focal company's buyer-power over first-tier supplier	High
	Focal company size	Large
	First-tier supplier's sustainability training	High
	First-tier supplier's possession of internal resources	High
	Power asymmetry in first-tier supplier-lower-tier supplier relationship, which favours first-tier supplier	High
	The capability of lower-tier supplier to comply with focal company's sustainability standards	Medium
	Benefits for lower-tier supplier for meeting focal company's sustainability requirements	High
	Geographical distance between focal company, and the suppliers of first tier and lower tiers	Medium
	Cultural distance between focal company, and the suppliers of first tier and lower tiers	Low
	Horizontal complexity level at first-tier supplier stage	High
	Mutual trust in lower-tier supplier-first-tier supplier relationship	High
	Committed, long-term lower-tier supplier-first-tier supplier relationship	Exists
Work with third parties	Partnership with external stakeholders for spreading sustainability towards suppliers at lower tiers	High
	Horizontal complexity level at lower-tier supplier stage	High

table for Boolean nodes with at least two parent nodes. Eleven practitioners, four at focal frim level, four at first-tier supplier level and three at lower-tier supplier level, and four members of the authors team, whose research interests lie primarily in the field of MT-SSCM, participated in the process of providing the comparative weights of the parent nodes of each child node. Five of the practitioners are from an East Asian country and six of them are from a West Asian country. Their jobs fall mainly under ‘‘supply Chain Manager'', ‘‘Operations Manager'', ‘‘Purchasing and Procurement Manager'' and ‘‘Logistics Manager'' categories, and they are employed in furniture and home appliances, dairy, oil and gas, and petroleum industries. Their work experience ranges from 8 to 26 years, and all of them have university education which ranges from bachelor's degree to PhD. Three of the four members of the authors team are faculty members at business schools in Western Europe and one of them is a faculty member at a business school in West Asia.

The contingency factors set, their causal relationships and tables which present the parent nodes and the relevant child nodes were sent to the practitioners online together with the required explanations. Upon the request from the authors, the practitioners first approved the relevance of the contingency factors with regard to each SGA and the cause and effect relationships between the contingency factors. They were then requested to assign the comparative weights to the parent nodes in terms of their impact on the child nodes using a 0–10 scale, where 0 and 10 respectively indicate the lowest and the highest impact. The highest weight score necessarily starts from 10 and the other weight scores are compared to this highest weight score. The four members of the authors team also assigned the comparative weights to the parent nodes regarding their impact on the child nodes in a similar way, which is influenced by their understanding from the reviewed literature. Afterwards, the arithmetic mean of the weights for the parent nodes with shared child node is calculated, where there are fifteen participants, i.e. the eleven practitioners and four authors. The judgements of the practitioners and the participating authors are assumed to be of equal importance.

In order to enter these weights into AgenaRisk 10 software, the node probability table mode is selected as ‘‘Expression'', and under ‘‘Insert weight expression'', ‘‘WeightedMean'' is chosen. Please note that the default weight scale of the AgenaRisk 10 software is 0–5 but it accepts the 0–10 scale as well if it is entered manually in the ‘‘Mean'' box. The software uses these weights to automatically generate the node probability tables.

For the child nodes that have only one parent node, whether ranked or Boolean, the node probability tables were generated manually. Since the practitioners may not be familiar with the concept of conditional probability, we supposed it may be difficult for them to provide the node probability tables by themselves. Therefore, each of the four members of the authors team, first, provided a node probability table for each child node with only one parent node based on their understanding from the relevant literature and then an aggregated node probability table was made, where the columns of this node probability table were the arithmetic mean of the columns of each individual node probability table. To ensure that the summation of the probabilities in all columns of

Table 6
The results of running the BN models of each SGA for the case study.

	The effectiveness of the given SGA			Sustainability noncompliance by lower-tier suppliers	
	Effective	Moderately Effective	Not Effective	True	False
Direct	55.83%	43.85%	0.32%	20.06%	79.94%
Indirect	85.14%	12.27%	2.59%	8.11%	91.89%
Work with third parties	93.55%	3.97%	2.48%	4.26%	95.74%

	Focal company's damaged reputation		Focal company's sales (revenue) decline		Increased total expenses incurred by focal company	
	True	False	True	False	True	False
Direct	18.45%	81.55%	17.65%	82.35%	19.66%	80.35%
Indirect	7.46%	92.54%	7.14%	92.86%	7.95%	92.05%
Work with third parties	3.92%	96.08%	3.75%	96.25%	4.18%	95.82%

the aggregated node probability table was equal to 1, we normalised the aggregated node probability table by dividing all numbers in each column by the summation of the numbers in that column. The final aggregated node probability tables for each child node were sent to the practitioners online and they were requested to adjust the probabilities in the node probability tables if they think they need modification, otherwise just approve them. In case they adjusted the node probability tables, the above-described aggregation and normalisation were applied again. The final comparative weights and node probability tables together with the types of the nodes and their states are presented in Part C of Supplementary Materials (available at the link which was already provided in Section 3).

4.1.3.4. Implementation of the developed DSS: the cotton-textile supply chain of the multinational company Alpha

4.1.3.4.1. Data collection. The multi-tier, sustainable cotton-textile supply chain of Alpha as a multinational company operating in China is considered in this study to show the applicability of the proposed DSS to a real-world case.

Please note that the selection of the company Alpha case or any other case is just for the illustration purpose, and does not have any impact on the contingency factors prioritisation and then risk treatment, the overall conclusions and the whole risk management process since the data that is presented in Subsection 4.1.3.4.2 is only about the states of the basic contingency factors not the conditional node probability tables.

We chose the company Alpha case for this study because (i) we have a more complete dataset from this company with regard to the purpose of the current study, (ii) we observed that Alpha is highly mature in addressing the sustainability issues in its long, multi-tiered supply chain, and (iii) we intend to apply primary data from a real-world case for showing the applicability of the developed DSS instead of applying hypothetical or secondary data.

One of the co-authors collected the data through semi-structured interviews in three rounds. An interview protocol was customised for the company Alpha, and in total 22 supply chain actors across different tiers of the Alpha's supply chain, including the focal company, first-tier supplier and several tiers of lower-tier suppliers were interviewed. In addition to Alpha's supply chain actors, several interviews were conducted with government agencies, NGOs and other third parties with relevant knowledge on the issue under study to gain multiple perspectives. Formal interviews were complemented by a number of informal interviews and conversations, factory/plant tours (including the visits from the sites of suppliers at first tier and lower tiers) and attending the training sessions.

The Chinese Mandarin was used as the primary language in conducting the interviews, but in few cases the interviews were conducted in English. The interviews were mostly conducted in face to face mode, and in some cases interviews were performed by telephone because of the distance or conflicting time schedules of the interviewees. The digitally-recorded interviews were then transcribed with the help of a professional company. Finally, data were coded and analysed. In case we required additional data which was not present in the original data, we contacted the interviewees again via telephone and email.

4.1.3.4.2. The case description. As a multinational company, Alpha designs and retails ready-to-assemble furniture and home appliances. Cotton is Alpha's second most crucial raw material after timber, and is used in producing home furniture such as sofas, mattresses, cushions and lampshades. A portion of the cotton used in Alpha's products is produced by cotton farms in China, mainly in the northwest inland, the Yellow River valley and the Yangtze River valley regions. Cotton production is associated with sustainability issues, including excessive water consumption, pesticide use, low-wage farm workers and employing child labour.

As Alpha is a publicly-known brand with highly visible products, pressures from salient stakeholders, e.g. governments, media, NGOs, shareholders and consumer organisations, have motivated Alpha towards sustainable sourcing. Alpha's annual gross profit has been growing on average over the recent years, and this makes investing in the sustainability management of lower-tier suppliers financially convenient. Alpha has assigned a sustainable cotton team to a project that aims to promote sustainable practices among cotton farmers and ensure that Alpha's final products are produced from cotton that are fully sourced from sustainable cotton suppliers.

Alpha has provided a detailed mapping of its supply chain, including the suppliers at different tiers and their operations, to comprehend its supply base better and learn how to make it socially and environmentally sustainable. This has reduced the information asymmetry between Alpha and the lower-tier suppliers regarding their processes and how to make those processes sustainable.

A typical cotton-textile supply chain of Alpha is exhibited in Fig. 4. The cotton that is directly harvested from the fields is called seed cotton, which is ginned to remove the seeds and waste (stems, leaves and dirt). The remaining fibre is known as lint. Further processing of the lint in a spinner creates yarn. Yarn is used for textile producing through weaving and dyeing. The manufacturer produces finished cotton products by cutting and sewing the textile. The final products are sold by retailers.

Alpha's supply base in China includes first-tier suppliers (manufactures of finished cotton products), middle-tier suppliers (suppliers at second and third tiers which are respectively involved in dyeing and weaving, and spinning for yarn businesses) and the far upstream suppliers (cotton ginners and cotton farmers as the fourth-tier and fifth-tier suppliers respectively). By lower-tier suppliers, the middle-tier and far upstream suppliers are meant.

The materials sourced from the suppliers at lower tiers are highly critical to Alpha as the quality of the raw cotton and the cotton textile will greatly impact the final products quality, but these materials are not specific as their suppliers can be switched rather easily.

Top management of Alpha and its personnel are highly committed to extending sustainability to lower-tier suppliers. Purchasing department at Alpha is also concerned with sustainable sourcing issues and interacts closely with sustainable cotton team for cotton quality check and the suppliers' sustainability compliance. The large number of the suppliers especially at lower tiers makes it practically impossible for Alpha to maintain direct contact with all cotton farms and cotton ginners, which underscores the role of key first-tier suppliers in managing sustainability issues at lower-tier supplier level. The geographical location of the entire supply base in China, that results in lowered socio-economic and cultural distance, has facilitated monitoring their adherence to sustainability requirements, so that except few cases of water pollution by textile dyers, sustainability-related past incidents in Alpha's supply chain have not been very frequent.

Alpha possesses extensive sustainability-related knowledge and skills in cotton-textile industry. It regularly provides sustainability training to suppliers of the first tier and second tier and then requests them to inform their suppliers of the sustainability knowledge and requirements.

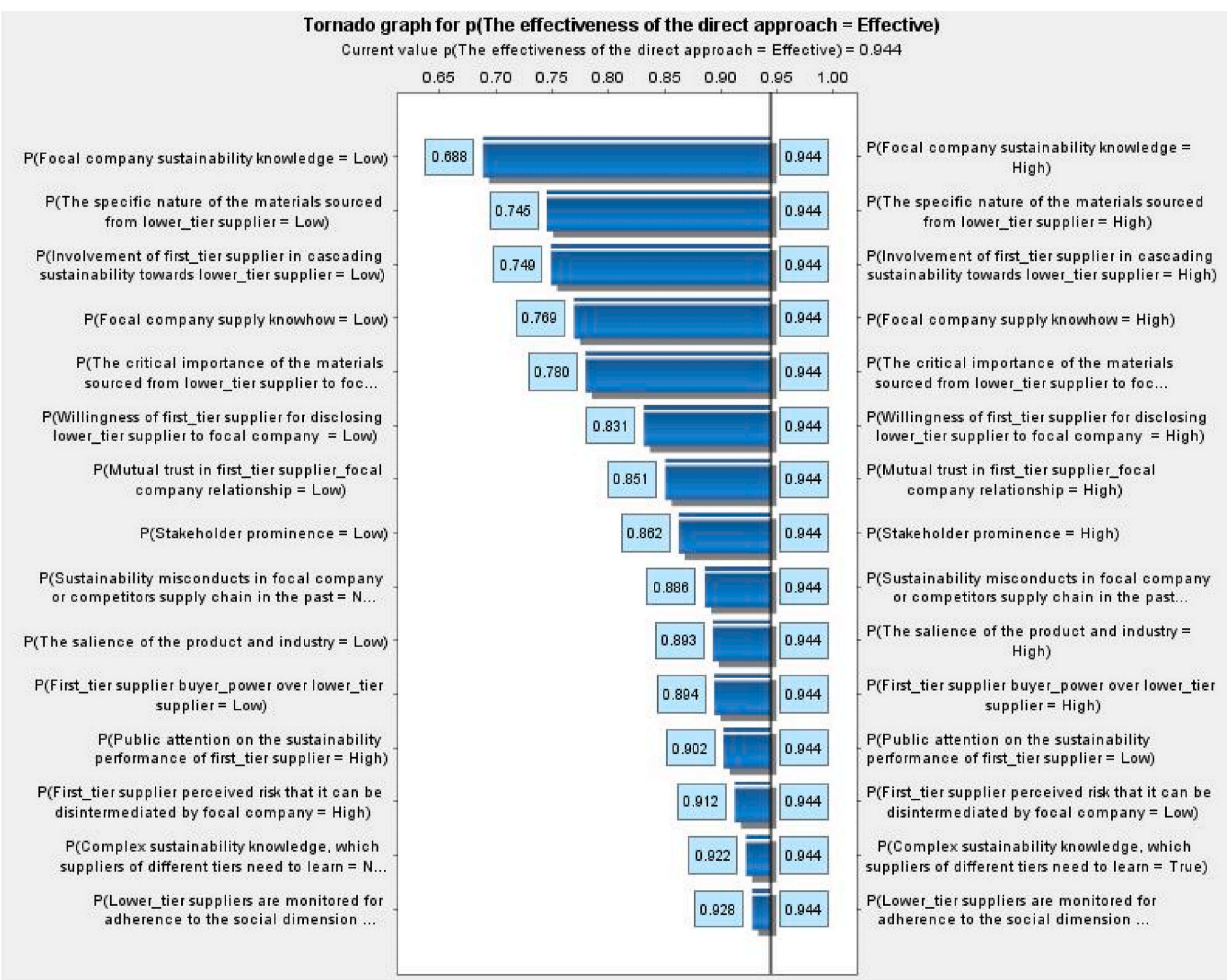
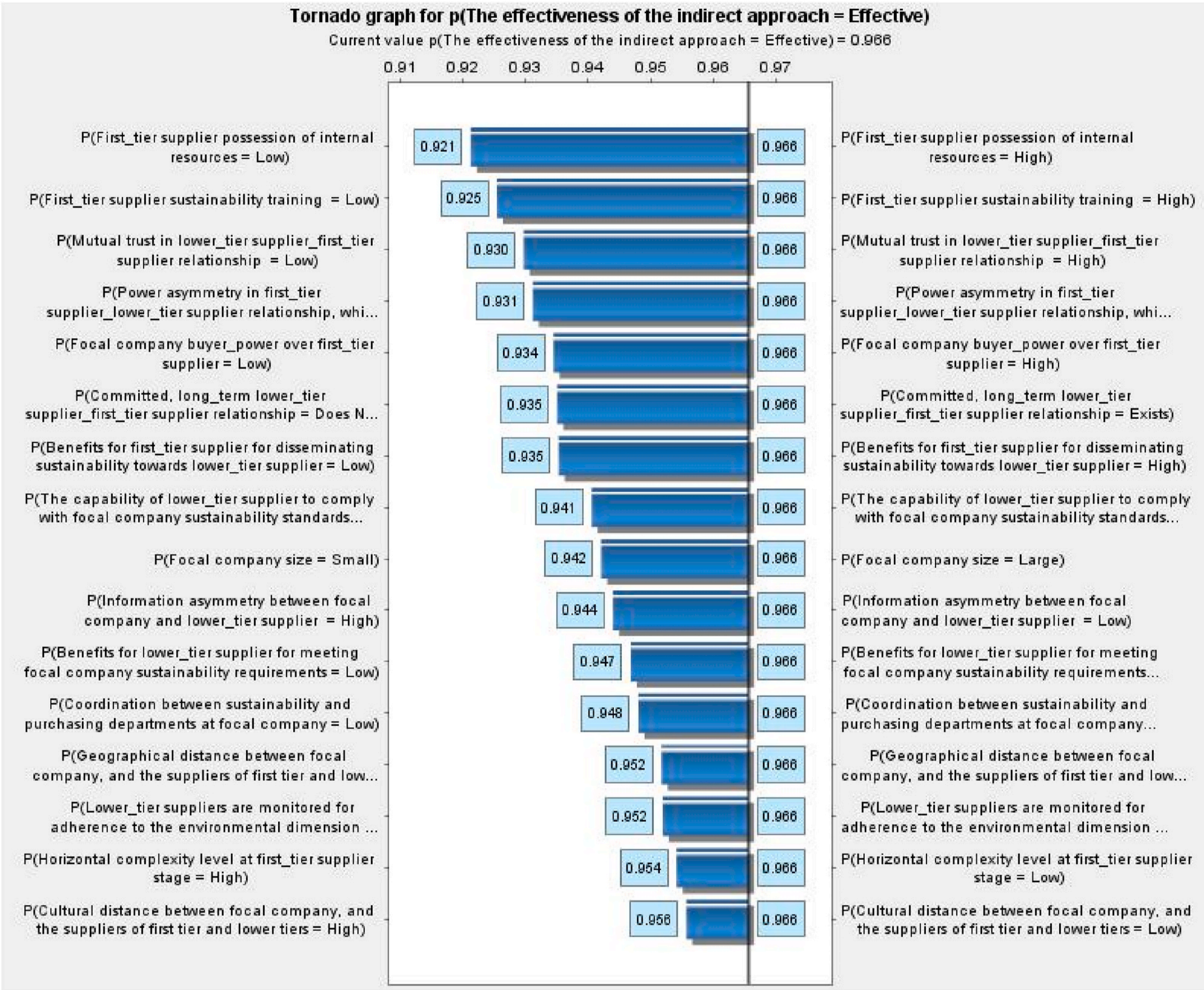


Fig. 5. (a) Sensitivity analysis for the basic contingency factors influencing the direct approach, (b) Sensitivity analysis for the basic contingency factors influencing the indirect approach, (c) Sensitivity analysis for the basic contingency factors influencing the work with third parties approach.



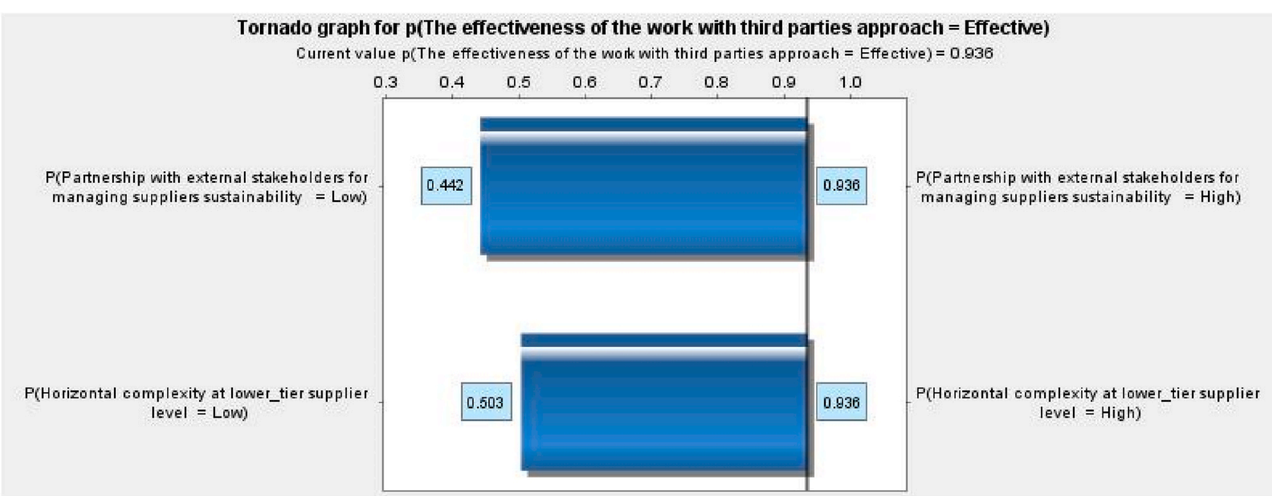


Fig. 5. (*continued*).

This transmission of the sustainability knowledge and requirements continues until the third tier. Also, Alpha collaborates with Better Cotton Initiative , a global platform established by Alpha and other world-leading brands for promoting social and environmental aspects related to cotton-textile supply chain, in order to educate all tiers of the suppliers, especially the cotton farmers and cotton ginners, on how to incorporate sustainability into their business operations. These trainings on modern, sustainable farming and ginning can be rather complex for the cotton farmers and cotton ginners to learn since the content could be completely new for them. Alpha strives to assist the middle-tier and far upstream suppliers that have difficulties in developing capabilities to comply with Alpha's sustainability standards. However, the contracts of the lower-tier suppliers that do not have the motivation for developing these capabilities are terminated.

Table 7a
Prioritising the basic contingency factors regarding the direct approach.

	The basic contingency factors	The most favourable state – the least favourable state	The impact of switching from the most favourable state to the least favourable state on "The effectiveness of the direct approach"	Priority order
Upper-tier	Focal company's sustainability knowledge	High – Low	−25.60%	1
	The specific nature of the materials sourced from lower-tier supplier	High – Low	−19.90%	2
	Involvement of first-tier supplier in cascading sustainability towards lower-tier supplier	High – Low	−19.50%	3
	Focal company's supply knowhow	High – Low	−17.50%	4
	The critical importance of the materials sourced from lower-tier supplier to focal company	High – Low	−16.40%	5
	Willingness of first-tier supplier for disclosing lower-tier supplier to focal company	High – Low	−11.30%	6
	Mutual trust in first-tier supplier-focal company relationship	High – Low	−9.30%	7
Lower-tier	Stakeholder prominence	High – Low	−8.20%	8
	Sustainability misconducts in focal company's/ competitors' supply chain in the past	Frequent – Not Frequent	−5.80%	9
	The salience of the product and industry	High – Low	−5.10%	10
	First-tier supplier's buyer-power over lower-tier supplier	High – Low	−5%	11
	Public attention on the sustainability performance of first-tier supplier	Low – High	−4.20%	12
	First-tier supplier's perceived risk that it can be disintermediated by focal company	Low – High	−3.20%	13
	Complex sustainability knowledge, which suppliers of different tiers need to learn	True – Not True	−2.20%	14
	Lower-tier suppliers are monitored for adherence to the social dimension of sustainability	True – Not True	−1.60%	15

Table 7b
Prioritising the basic contingency factors regarding the indirect approach.

	The basic contingency factors	The most favourable state – the least favourable state	The impact of switching from the most favourable state to the least favourable state on "The effectiveness of the indirect approach"	Priority order
Upper-tier	First-tier supplier's possession of internal resources	High – Low	−4.50%	1
	First-tier supplier's sustainability training	High – Low	−4.10%	2
	Mutual trust in lower-tier supplier-first-tier supplier relationship	High – Low	−3.60%	3
	Power asymmetry in first-tier supplier-lower-tier supplier relationship, which favours first-tier supplier	High – Low	−3.50%	4
	Focal company's buyer-power over first-tier supplier	High – Low	−3.20%	5
	Committed, long-term lower-tier supplier-first-tier supplier relationship	Exists – Does Not Exist	−3.10%	6
	Benefits for first-tier supplier for disseminating sustainability towards lower-tier supplier	High – Low	−3.10%	7
	The capability of lower-tier supplier to comply with focal company's sustainability standards	High – Low	−2.50%	8
Lower-tier	Focal company size	Large – Small	−2.40%	9
	Information asymmetry between focal company and lower-tier supplier	Low – High	−2.20%	10
	Benefits for lower-tier supplier for meeting focal company's sustainability requirements	High – Low	−1.90%	11
	Coordination between sustainability and purchasing departments at focal company	High – Low	−1.80%	12
	Geographical distance between focal company, and the suppliers of first tier and lower tiers	Low – High	−1.40%	13
	Lower-tier suppliers are monitored for adherence to the environmental dimension of sustainability	True – Not True	−1.40%	14
	Horizontal complexity level at first-tier supplier stage	Low – High	- 1.20%	15
	Cultural distance between focal company, and the suppliers of first tier and lower tiers	Low – High	- 1%	16

Although the first-tier suppliers are not known to end consumer, they still receive a medium level of attention from the public due to the salience of the product and industry and the presence of social media. A number of key first-tier suppliers feel dependent on Alpha because of its high demand volume and continued business, which can be an indicator of Alpha's buyer-power over first-tier suppliers. Alpha's high purchase volume would also act as a motivation for the first-tier suppliers for cooperation in management of lower-tier suppliers' sustainability. The manufacturers of finished cotton products, as first-tier suppliers, pay attention to lower-tier supplier's sustainability management requests from Alpha as they maintain long-term relationship with lower-tier suppliers. They possess internal resources such as financial resources

Table 7c
Prioritising the basic contingency factors regarding the work with third parties approach.

The basic contingency factors	The most favourable state – the least favourable state	The impact of switching from the most favourable state to the least favourable state on "The effectiveness of the work with third parties approach"	Priority order
Partnership with external stakeholders for spreading sustainability towards suppliers at lower tiers	High – Low	−49.40%	1
Horizontal complexity level at lower-tier supplier stage	High – Low	−43.30%	2

and sustainability specialists, which are utilised in extending sustainability to lower-tier suppliers. Textile producers respond to sustainability requirements from first-tier suppliers in a trustworthy environment, since they see themselves as preferred suppliers with whom the first-tier suppliers would like to establish long-term relationship.

In response to Alpha's request, first-tier suppliers incentivise the textile producers to comply with sustainability requirements through increased purchase volume of the products made from the cottons that meet the sustainability requirements of Alpha. Likewise, the textile producers increase their purchase volume from the cotton spinners that comply with Alpha's sustainability standards. This increased purchase volume reaches the cotton ginners and cotton farmers that continue to operate in accordance with Alpha's sustainability requirements. High level of mutual trust between Alpha and key first-tier suppliers has yielded more information disclosure regarding lower-tier suppliers' sustainability-related activities but the first-tier suppliers may still keep some business secrets with lower-tier suppliers. Apart from long-term, strong collaboration between Alpha and first-tier suppliers, since Alpha, as furniture retail company, sources the processed cotton products from first-tier suppliers and does not have facilities to process textile, yarn or raw cotton, the first-tier suppliers think it is unlikely that Alpha bypass them and directly source from the lower-tier suppliers.

4.1.3.4.3. The developed DSS solution for the company Alpha case. The above-described case in terms of the basic contingency factors and the observations (evidences) is summarised in Table 5.

Three causal BN models for different SGAs with regard to the conditions of the case study described above are run by AgenaRisk 10 software. The constructed BN models can be run on any standard BN software package. The results are presented in Tables 6.

As it can be seen from Tables 6, and if a pure SGA is going to be applied, the results recommend applying the work with third parties approach since it has the highest probability to be effective compared with other SGAs, followed by the indirect approach by an 8.41% margin if the "Effective" state is to be considered. Table 6 also indicates that there is an opposite relationship between the probability of *sustainability noncompliance by lower-tier suppliers* and the probability of effectiveness of a given SGA in multi-tier supply chains. That is, when a given SGA in multi-tier supply chains is more likely to be effective, *sustainability noncompliance by lower-tier suppliers* becomes less likely.

Furthermore, Table 6 shows that when *sustainability noncompliance by lower-tier suppliers* becomes more probable for each SGA, the three risk variables *focal company's damaged reputation*, *focal company's sales (revenue) decline* and *increased total expenses incurred by focal company* also become more probable.

In practice, best single (pure) SGA in multi-tier supply chain may not

Table 8
Experiments with the upper-tier and lower-tier, basic contingency factors and the impact on the variables of interest.

SGAs	The most favourable states of all basic contingency factors are assigned the probability of 1				The most favourable states of lower-tier, basic contingency factors and the least favourable states of upper-tier, basic contingency factors are assigned the probability of 1			
Direct	The effectiveness of the direct approach	Effective: 94.49% Moderately Effective: 5.50% Not Effective: 0.01%	Focal company's damaged reputation	False: 97.72% True: 2.28%	The effectiveness of the direct approach	Effective: 1.75% Moderately Effective: 63.79% Not Effective: 34.46%	Focal company's damaged reputation	False: 41.89% True: 58.11%
	Sustainability noncompliance by lower-tier suppliers	False: 97.52% True: 2.48%	Focal company's sales (revenue) decline	False: 97.81% True: 2.19%	Sustainability noncompliance by lower-tier suppliers	False: 36.83% True: 63.17%	Focal company's sales (revenue) decline	False: 44.41% True: 55.59%
			Increased total expenses incurred by focal company	False: 97.57% True: 2.43%			Increased total expenses incurred by focal company	False: 38.10% True: 61.90%
Indirect	The effectiveness of the indirect approach	Effective: 96.61% Moderately Effective: 2.34% Not Effective: 1.05%	Focal company's damaged reputation	False: 98.06% True: 1.94%	The effectiveness of the indirect approach	Effective: 26.98% Moderately Effective: 53.91% Not Effective: 19.10%	Focal company's damaged reputation	False: 60.10% True: 39.90%
	Sustainability noncompliance by lower-tier suppliers	False: 97.89% True: 2.11%	Focal company's sales (revenue) decline	False: 98.15% True: 1.85%	Sustainability noncompliance by lower-tier suppliers	False: 56.63% True: 43.37%	Focal company's sales (revenue) decline	False: 61.84% True: 38.16%
			Increased total expenses incurred by focal company	False: 97.94% True: 2.06%			Increased total expenses incurred by focal company	False: 57.50% True: 42.50%

exist, and thus the combination of SGAs is applied (called mixed approach). In situations that none of the SGAs dominate others in terms of the degree of effectiveness, recourse to the mixed approach is highly recommended. It is obvious that the don't bother approach can only be applied as a pure approach and cannot be applied in combination with other SGAs.

As a rule of thumb, to apply the mixed approach, the decision maker is advised to use the combination of the SGAs that have the relatively higher probability of effectiveness in a given situation. For example, in present case study if the decision maker is willing to employ the mixed approach, he/she is recommended to apply the indirect and work with third parties strategies simultaneously as they have comparatively higher probability of effectiveness.

4.2. Prioritising the basic contingency factors

A sensitivity analysis is conducted to prioritise the basic contingency factors based on their impact on the effectiveness of different SGAs in multi-tier supply chain and thus the risks of *sustainability noncompliance by lower-tier suppliers* for focal company. In each causal BN model developed for these SGAs, the most favourable states are assigned the highest possible probability, or 1, and the impact on the effectiveness of the given SGA is examined. The most favourable states are those states that have the highest positive impact on the effectiveness of a given SGA. For example, in the causal BN model for the direct approach, the states ''High'' and ''Low'' respectively for the basic contingency factors ''Focal company's sustainability knowledge'' and ''Public attention on the sustainability performance of first-tier supplier'' are considered as the most favourable states. Then, the least favourable states are assigned the highest possible probability, or 1, and the impact on the effectiveness of the given SGA is observed. The least favourable states are the opposite extreme of the most favourable states. For instance, in the causal BN model for the direct approach, the states ''Low'' and ''High'' respectively for the basic contingency factors ''Focal company's sustainability knowledge'' and ''Public attention on the sustainability performance of first-tier supplier'' are regarded as the least favourable states.

The most favourable and the least favourable states for each contingency factor can be easily inferred from Table 4 based on how variation in a contingency factor contributes to the effectiveness or ineffectiveness of a given SGA. For example, it can be seen from Table 4 that, when *focal company's sustainability knowledge* is high, *the effectiveness of the direct approach* increases, and vice versa. Thus, ''High'' and ''Low'' are the most favourable and the least favourable states respectively for this contingency factor.

Fig. 5a-c, as tornado graphs, illustrate the results of running the models according to the above-described condition if state ''Effective'' is considered for the effectiveness of each SGA. Fig. 5a-c and Tables 7a–7c indicate the variation in the degree of effectiveness of each SGA when the most favourable and the least favourable states of the basic contingency factors are assigned the highest possible probability.

The basic contingency factors are then prioritised according to the resulting degree of variation in the effectiveness of the relevant SGA, which is presented in Tables 7a–7c. In Table 7a, −25.60% in the row for ''Focal company's sustainability knowledge'', for instance, means that if the direct approach is considered, switching from the most favourable state to the least favourable state in assigning the highest possible probability for this contingency factor causes a 94.4%–68.8% = 25.60% decline in *the effectiveness of the direct approach*.

Finally, the basic contingency factors are divided into two categories, the ''upper-tier'' and the ''lower-tier'', according to their corresponding degree of variation in the effectiveness of the relevant SGA. The scores of degree of variation in the effectiveness of each SGA with respect to the relevant basic contingency factors fall above 50th percentile for the upper-tier, basic contingency factors if the positive values of the numbers presented in third and seventh columns of Tables 7a–7c are considered. The opposite is true about the lower-tier, basic contingency factors. Dividing the basic contingency factors into upper-tier and lower-tier categories can be particularly important for the risk treatment purpose, which is discussed in the next subsection.

4.3. Risk treatment

When the effectiveness of a SGA in multi-tier supply chain decreases, the probability of occurrence of the aforementioned three risk variables for focal company, related to *sustainability noncompliance by lower-tier suppliers*, increases accordingly. There would be two possibilities for the ineffectiveness of a SGA: the SGA is applied for unsuitable situation without properly taking the pertinent contingency factors into consideration, or the condition that demanded applying a certain SGA is no longer present due to the variations in the relevant contingency factors. In both cases, the decision makers are advised to re-assess the situation to ensure that they apply the most suitable SGA/SGAs. But, because several contingency factors, especially for the direct and indirect approaches, are involved in determining the level of effectiveness of a SGA, it would be more efficient and convenient to assess a smaller but high-priority group of contingency factors, e.g. the upper-tier, basic contingency factors, regularly for the purpose of ensuring that the most effective SGA/SGAs is/are applied.

The upper-tier, basic contingency factors would have a major impact on the effectiveness of SGAs and, as a result, on the occurrence probability of the risk variables related to *sustainability noncompliance by lower-tier suppliers*. To indicate this, the least favourable states of the upper-tier, basic contingency factors in the causal BN models developed for the direct and indirect approaches are assigned the highest possible probability, or 1, while the most favourable states of the lower-tier, basic contingency factors in the causal BN models developed for these SGAs are assigned the highest possible probability, or 1, and the impact on the effectiveness of these SGAs is evaluated. For the work with third parties approach, only two basic contingency factors are involved in determining the effectiveness of this approach, and therefore they need to be assessed regularly according to their priority order to confirm it is still the most effective approach.

The results of this analysis are presented in Table 8. The results show the sharp decline in the probability of effectiveness of the both direct and indirect approaches, and rise in the probability of sustainability noncompliance by lower-tier suppliers and the related risk variables, although the most favourable states of the lower-tier, basic contingency factors in the causal BN models developed for these SGAs are assigned the probability of 1.

According to the results presented in Table 8, for the risk treatment purpose, the upper-tier, basic contingency factors need to be assessed more regularly to assure that the most effective SGA is applied.

4.4. Managerial/policy implications

From what has been presented yet, the following managerial/policy implications are drawn.

- There could be situations where the DSS proposed in current study result in a condition that none of the SGAs are meaningfully dominant in terms of the probability of effectiveness. In such cases, adopting the mixed approach which utilises combination of at least two SGAs is recommended. This is supported by the MT-SSCM literature that in practice one best SGA that the firms should apply may not exist and the application of multiple SGAs in parallel can be more beneficial (Gong et al., 2018a; Wilhelm et al., 2016a). When considering application of the mixed approach, it should be noted that the don't bother approach cannot be applied in conjunction with other SGAs.
- The condition that required applying a specific SGA may change over time. For instance, *mutual trust in lower-tier supplier-first-tier supplier relationship* and*committed, long-term lower-tier supplier-first-tier*

supplier relationship may deteriorate gradually and make the indirect approach not effective or less effective. Therefore, operations managers are required to evaluate the situation with respect to the relevant contingency factors regularly to ensure that they use the most useful SGA/SGAs.
- Tracing sustainability noncompliance at the lower tiers of a supply chain can be difficult, for example, because of *horizontal complexity level at lower-tier supplier stage* (the number of suppliers at lower-tier supplier stage) and the *geographical distance* between the focal company and lower-tier suppliers. However, the newly emerging Industry 4.0 technologies such as Internet of Things (IoT), Blockchain and Big Data analysis tools can be used for remotely monitoring the lower-tier suppliers' adherence to sustainability standards, tracing sustainability violations at lower-tier supplier level, and processing the social media data to acquire information on possible sustainability noncompliance by the suppliers of lower tiers respectively. These technologies can even reduce the reliance of the focal company on the first-tier suppliers or third parties for monitoring lower-tier suppliers for possible sustainability violations and make the possibly less effective direct approach more effective.
- There could be interrelationships and even overlaps among the basic contingency factors and consequently among the clustered contingency factors. For example, there can be interrelationship and possibly a slight overlap between *focal company size* and *focal company's buyer-power over first-tier supplier* so that when the *focal company size* (determined by the total number of employees and/or annual revenue) increases, *focal company's buyer-power over first-tier supplier* which directly depends on the purchasing volume of focal company from first-tier supplier also increases. In selecting and screening the basic contingency factors two issues were ascertained: (i) the possible overlaps between these factors are as little as possible, and (ii) in case that overlap exists, the distinction between the factors is enough to consider them as separate factors. Apart from avoiding the further complexity, the possible interrelationships among the contingency factors were ignored in the developed BN models in order to measure the distinct contribution of each of these factors to making a given SGA approach effective or ineffective.
- The cause and effect relationships and how variation in each contingency factor impacts the effectiveness of each SGA were inferred from the literature. In real world, unknown relationships might exist between the contingency factors considered in the present study and the degree of effectiveness of SGAs in multi-tier supply chain which have not yet been studied by the existing literature.

5. Conclusions and future research

In this study, a model-driven DSS was developed using BN to help operations managers select the most effective SGA/SGAs in a given situation with regard to the pertinent contingency factors. Through a systematic literature review, a set of contingency factors and the risk variables for focal company because of *sustainability noncompliance by lower-tier suppliers* were identified, and the impact of variations in the contingency factors on the effectiveness degree of each SGA and thus on the risk variables were determined, which were fundamental in constructing the BN-based causal diagrams of the DSS. To prove the applicability of the developed DSS, it was applied to the multi-tier, sustainable cotton-textile supply chain of a multinational company operating in China. The developed DSS was also used in the risk management of the SGAs which entailed core steps such as identification of the contingency factors and risk variables, prioritisation of the contingency factors and risk treatment.

To identify the basic contingency factors that have the highest influence on the effectiveness of each relevant SGA and consequently on the risks of *sustainability noncompliance by lower-tier suppliers* for focal company, these factors were categorised into the upper-tier and lower-tier factors. Within the upper-tier, basic contingency factors, the factors ‘‘Focal company's sustainability knowledge'', ‘‘The specific nature of the materials sourced from lower-tier supplier'' and ‘‘Involvement of first-tier supplier in cascading sustainability towards lower-tier supplier'', and ‘‘First-tier supplier's possession of internal resources'', ‘‘First-tier supplier's sustainability training'' and ‘‘Mutual trust in lower-tier supplier-first-tier supplier relationship'' were identified as the three most important factors regarding their impact on the effectiveness of the direct and indirect approaches respectively and therefore on the risks of *sustainability noncompliance by lower-tier suppliers* for focal company. The basic contingency factor ‘‘Partnership with external stakeholders for spreading sustainability towards suppliers at lower tiers'' has the highest impact on the effectiveness of the work with third parties approach, and then comes ‘‘Horizontal complexity level at lower-tier supplier stage''.

The risk treatment which was based on the basic contingency factors prioritisation, indicated the high significance of the upper-tier, basic contingency factors in determining the most effective SGA/SGAs in a given situation and that the states of these factors need to be monitored regularly to ensure that the most effective SGA/SGAs is/are applied with regard to the current situation to finally minimise the risks of *sustainability noncompliance by lower-tier suppliers* for focal company.

This research can be extended in future in several directions:

First, multiple contingency factors with respect to the direct, indirect and work with third parties approaches point to cooperation and partnership as policies that can make the SGAs effective. In addition, cooperation mechanisms such as resource sharing, revenue sharing, cost sharing and cartelisation in the supply chain have been studied by the literature (for example, see Henry and Wernz, 2015; Bai and Sarkis, 2016; Qin et al., 2020), but the extant literature lacks studying the effectiveness of the SGAs in multi-tier supply chain considering these cooperation mechanisms. The cooperative interactions between different members of a multi-tier supply chain, e.g. between first-tier supplier and lower-tier supplier, and first-tier supplier and focal company, and the impact on the SGAs effectiveness can be modelled and analysed using the techniques of management science, especially game theory, simulation and mathematical optimisation.

Second, information sharing in supply chains has attracted the attention of many researchers and practitioners over the past two decades (Dwaikat et al., 2018), and the existing literature have applied different management science methods such as BN (for example, see Sener et al., 2021; Sharma and Routroy, 2016), game theory (for example, see Shang et al., 2016; Fan et al., 2020) and mathematical optimisation (for example, see Lei et al., 2020; Khan et al., 2016) to study the significance of information sharing in the supply chain management. Information sharing is essential to the accomplishment of the three important Cs (coordination, cooperation and collaboration) of supply chain management (Maskey et al., 2020). Thus, information sharing is a concept connected to the cooperative behaviours in supply chains and regarding its special significance among cooperation mechanisms, it needs to be considered separately. An interesting direction for future research would be to evaluate the importance of information sharing in enhancing the SGAs' effectiveness in cooperative, multi-tier supply chains using appropriate management science methods.

Third, return on investment and companies' desire to create products and services with lower costs to gain competitive advantage in the market are among the primary reasons for focal companies' unwillingness to invest in programmes for disseminating sustainability towards lower-tier suppliers (Ageron et al., 2012; Walker et al., 2008; Mangla et al., 2018; Zhu and Geng, 2013). As applying the SGAs normally entails investment costs, future research can compare the SGAs from cost/financial perspective.

Data availability

The data is included in the paper

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