Assessing Green Supply Chain Practices in the Ghanaian Mining Industry: A Framework and Evaluation

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ABSTRACT

Production and consumption in our industrial systems typically begin in the extractive, mining, industries. Typically these activities begin in emerging economies, such as Ghana. It is also clear that supply chain activities in mining operations may have severe environmental and social problems with serious economic consequences. Greening the supply chain of mining operations are an important avenue that can provide beneficial consequences. Developing, evaluating, assessing, and selecting essential green supply chain management (GSCM) practices are a goal for successful GSCM implementation. These practices may have interrelated and complex relationships. Understanding them and their relative importance is an initial step for achieving the assessment goals for successful GSCM implementation in the mining industry. This study adopts a proposed comprehensive and integrative GSCM major practices and sub-practices (framework); determines the relative relationships and influences within this GSCM framework, and identifies the perceived impact of the GSCM framework on organizational sustainable performance (economic, environmental, and social – triple bottom-line) pertinent to the mining industry, in the emerging economy nation of Ghana. An integrated methodology identifying and limiting interdependencies within GSCM factors will be utilized. The methodology uses fuzzy-DEMATEL and analytical network process (ANP) for the evaluation. Multiple field studies within Ghana’s mining industry are used to illustrate the applicability of the proposed methodology. The results can provide valuable clues and guidelines to decision-makers and analysts inside and outside the mining industry, for improving corporate sustainable production and consumption. Future research and practical implications are also introduced in the paper.

Keywords: Green Supply Chain Management (GSCM) Practices; Fuzzy Theory; Decision-Making Trial and Evaluation Laboratory (DEMATEL); Analytic Network Process (ANP); Mining Industry; Ghana.
1. Introduction

Mining operations supply chain activities are mired with serious environmental and social dangers, with economic implications underlying all these activities (Vintró et al., 2014; Söderholm, et al., 2015). Environmental concerns and discourse in mining and other industries has grown to include extended producer responsibility for environmental impacts (Niza et al., 2014) as well as sustainable production and consumption concerns. These philosophies support life cycle logic and assessment enabling a holistic approach to mitigate environmental issues from mining operations. Thus, supply chain activities represent both production and consumption dimensions facing organizations. These activities include materials purchase and used, the nature of the production processes and activities (i.e. exploration, mining, mineral processing and extractive metallurgy), and how waste generated are utilized, whether it is closed-loop, industrial ecosystem,¹ or disposal focused.

Managing these supply chain issues will help address environmental problems associated with mining operations. For example, mining activities such as exploration result in the removal of vegetation causing soil erosion and habitat destruction. Drilling may lead to serious soil and water contamination through oil spills. Mining activities (digging, loading and hauling/transportation of the ore) cause diversion of natural body water flows, increased sediment load in rivers, and waste rock and overburden disposal resulting in airborne dust, acid drainage, and erosion. These activities require careful attention and mitigation as internal mining operations. In addition to internal operational mining activities, the purchasing function, as part of supply chain management, plays a greater role in the reduction of mining operations environmental burdens. The purchasing function needs to

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¹ Closed-loop practices within supply chain management bring the product back into the supply chain system or can be used in another system as a useful input (industrial ecosystem). This would require the “Re” practices such as recycling, reclamation, reuse or remanufacturing. Reverse logistics or reverse supply chain activities would also be needed to be integrated into these systems.
consider environmental friendly inputs or equipment, such as inputs with lower environmental impact and low-energy consumption (Azevedo et al., 2012; Mangla et al., 2015).

The mining industry is known to have a poor environmental reputation (Muduli et al., 2013). This reputation and their operations and supply chain activities have forced many mining companies to face competitive, regulatory, and community/social pressures causing increased consideration of greening their supply chains. Thus far, mining companies’ green solutions have primarily focused on internal supply chain activities of the focal company. These localized and reactive green environmental management practices do not systemically reduce pollution emissions and focus on expensive investments in waste management, cleanup or remediation. To minimize or eliminate the adverse ecological influence of mining company supply chains, there is the need to holistically address this issue.

The green supply chain concept can aid in evaluating global and systemic environmental footprint reduction (Muduli et al., 2013; Kumar et al., 2014). Green supply chain management (GSCM) is a systematic and integrated approach that can help companies to develop ‘win-win’ strategies resulting in profit and market share objectives achievement and environmental efficiency (Tseng, 2011; Tseng & Chiu, 2013; Wong et al., 2015). Most studies on the practices of GSCM implementation in the mining industry have only considered environmental management practices, failing or overlooking the implementation of GSCM practices from a holistic perspective. Understanding the importance and relationships, as viewed by mining industry managers, especially in emerging economies can help clarify and aid the implementation and management of GSCM practices. Ghana is prime example of an emerging economy country whose environmental burdens and economic development is closely tied to its mining industry. Literature that has considered GSCM context in Ghana’s mining industry

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is non-existent. To help address this gap in literature and practice the GSCM practices, their relationships, and level of importance set the stage for their management and implementation in the mining industry in an emerging nation, Ghana, are presented in this paper. This study uses a multiple criteria decision-making (MCDM) tool characterized by multiple conflicting criteria (Hwang and Yoon, 1981).

The integrated MCDM methodology includes fuzzy-DEMATEL and the Analytical Network Process (ANP) and is composed of two main phases. First, the fuzzy-DEMATEL aspect of the methodology is used to develop the level of relative relationships and influence on each of these GSCM practices and sub-practices. ANP uses the network interrelationships identified in the fuzzy-DEMATEL stage to determine the relative impact of the major GSCM practices and sub-practices to organizational sustainable performance. Field study data within Ghana’s mining industry are used to illustrate the applicability of the proposed methodology. An assessment of the level of influence of the practices and sub-practices will enable decision-makers to determine implementation priority and resources to be allocated to each of these practices and sub-practices.

The motivation and objectives for this paper are twofold. First, the literature provides some previous studies on the use of DEMATEL and ANP methods, but the literature has not explicitly combined these methods together to form a more efficient decision network for ANP. These two synergistic tools (DEMATEL and ANP) can improve computational efficiencies and practical decision making for managers seeking to evaluate complex initiatives and programs. These efficiency gains occur by helping to limit the number of interrelationships that ANP will have to evaluate based on the upfront DEMATEL network formation process.

A second motivation is that studies have been completed on green supply chain management initiatives and programs implementation in the mining industry from both developed and developing nations. China (Haibin and Zhenling, 2010; Si et al., 2010) and Australia (Berkel, 2007; Giurco and
Cooper, 2012), have seen investigations, but smaller emerging economy nations such as Ghana have not been investigated. Studies on environmental (green) sustainability in Ghana’s mining industry produce an unclear picture about the industry’s environmental impacts, especially from supply chain-based environmental initiatives (e.g. Fei-Baffoe et al., 2013). Thus GSCM and its relationship to sustainable development in Ghana’s mining industry will help to add clarity to this concern. This investigation will set the foundation for future GSCM research in the mining industry and provide managers and researchers with a better understanding of the different sustainable operational factors and management interventions that can enhance sustainability performance in Ghana’s mining industry and in general mining.

The following research questions are addressed in this paper:

(1) How effective a methodology is a joint DEMATEL analysis and ANP for evaluation purposes?

(2) What are the relative relationships and influences of GSCM factors and sub-factors in an emerging country mining industry context, especially Ghana?

(3) What are the relative relationships of GSCM factors and sub-factors on organizational sustainability performance measures in an emerging country mining industry context?

The contributions of this study are manifold. First, the issue of GSCM and its relationships to organizational performance has only seen limited discussion in the literature. This paper contributes to this discussion. Second, a focused investigation of GSCM in the Ghanaian mining industry context is non-existent; this work is the first to investigate this issue. Third, the focus on Ghana represents an emerging economy country focus on GSCM, an area that has not seen significant research in general, or specifically to the mining industry. Fourth, for the first time, this paper proposes a hybrid multi-criteria decision-making (MCDM) methodology based on fuzzy-DEMATEL and ANP with a focus on computational efficiencies that contributes to decision making application.
The study provides researchers and policy makers with an understanding of how GSCM can be used to reduce mining industry environmental impact. Researchers and policy makers can also use this study to help determine how impact can be lessened through improved designs, efficient operations and supply chain synergies (McLellan et al., 2009). At the firm level the results are useful managing implementation of GSCM initiatives.

The rest of the paper is organized in the following manner. The paper first reviews GSCM literatures, introduces and adopts a previously developed GSCM practices framework for the mining industry and discusses GSCM factors implementation benefits and organizational sustainable performance in Section 2. Section 3 presents the technical background of the various methodologies within the proposed novel MCDM methodology. The proposed novel hybrid MCDM methodology with case application using the GSCM practices framework in the Ghanaian Mining Industry is presented in section 4. Section 5 discusses the results from the evaluation and section 6 concludes by summarizing the findings and managerial implications are identified.

2. Literature Review

Industrialization has caused damage to natural environmental and human systems. These issues have resulted in growing interest on GSCM (Dam and Petkova, 2014; Fabbe-Costes et al., 2014; Tseng et al., 2015). The mining and extractive industries, representing the source of most virgin materials, are at the core of these many concerns.

GSCM is gaining interest amongst researchers and practitioners (Beske and Seuring, 2014; Brandenburg et al., 2014; Tseng & Chiu, 2013). GSCM practices include upstream, internal processes (focal firms) and downstream activities (Tseng, 2011; Tseng & Chiu, 2013; Wong et al., 2015). Literature has shown that many mining companies are gradually adopting some sustainable (green) practices such as environmental management systems (EMS) and cleaner production (CP) (Vintró et al., 2014). Various forces have caused mining organizations to adopt these practices including
regulations (Dupuy, 2014; Luthra et al., 2015), community activism (Lin et al., 2015, Moffat & Zhang, 2014; Falck & Spangenberg, 2014), investors (Dashwood, 2014) and increasing organizational efficiencies (Mangla et al., 2015). The rest of this literature review section overviews GSCM practices in the mining industry, multiple criteria decision making and evaluation techniques for GSCM, and background on green practices in Ghana and mining. These topics set the foundation for the remainder of the paper.

2.1 GSCM practices in the mining industry

Many environmentally oriented efforts can be applied to help reduce the mining industry’s environmental burden (Edraki et al., 2014). Technology, regulatory and industrial policies have each facilitated improvement in mining industry environmental performance (Mathiyazhagan et al., 2014; Govindan et al., 2014a; Söderholm, et al., 2015). Various barriers have also prevented the implementation of cleaner technologies and cleaner production (CP) practices, as part of GSCM, in the mining industries including legislative, technological, and economic barriers (Corder et al., 2014; Pooe & Mhelembe, 2014). Overcoming these barriers requires various managerial and educational initiatives, especially in the mining industry (Govindan et al., 2014b; Muduli et al., 2013). Although there are many studies on mining industry practices and environmental issues (e.g. Vintró et al., 2014), none have focused on addressing the mining industry socio-environmental problems holistically and at the GSCM level.

2.1.1 A Green Supply Chain Management Evaluation Framework for the Mining Industry

A proposed comprehensive and integrative green supply chain practices and sub-practices framework for the mining industry has been developed (Kusi-Sarpong et al., 2015). The framework focused on six practices and thirty sub-practices. These practices include Green Information Technology and Systems, Strategic Supplier Partnership, Operations and Logistics Integration,
Internal Environmental Management, Eco-innovative Practices and End-of-life Practices. This framework is evaluated in this study.

Summarizing:

(1) *Green Information Technology and Systems (GITS)*

Information Technology and Systems (ITS) are an important avenue to drive environmental footprints and sustainable practices (Molla et al., 2014; Koo & Chung, 2014; Bai and Sarkis, 2013; Sarkis et al, 2013). However, there has been a neglect of the IT function in environmental evaluation programs over the years (Savita et al., 2014). In the mining industry, equipment and employees use ITS. ITS use result in significant environmental footprints (Faucheux and Nicolaï, 2011; Uddin and Rahman, 2012). ‘Green’ ITS can help to mitigate these environmental footprints (Bhadauria et al., 2014) and optimize overall energy consumption of mines (Bilal et al., 2014). The use of energy efficient hardware and data center, consolidating servers using virtualization software, reducing waste associated with obsolete equipment, collaborative group software and telepresence systems and eco-labeling of IT products are all part of Green IT initiatives.

(2) *Strategic Supplier Partnership (SSP)*

Strategic supplier partnership (SSP) is a long-term and exclusive alliance between focal organizations and suppliers (Ramanathan & Gunasekaran, 2014). Mining companies can use strategic supplier partnerships to involve their strategic suppliers in green supply chain planning to communicate sustainability goals and as a baseline to monitor these suppliers’ environmental compliance status and operational practices. Mining companies can also use SSP to jointly develop environmental management solutions and programs to reduce or eliminate material use, share environmental management techniques and knowledge, and collaboratively manage reverse flows of materials and packages (Wong et al., 2015; De Giovanni & Vinzi, 2014, Govindan et al., 2015; Blome et al., 2014).
(3) Operations and Logistics Integration (OLI)

Effective operations and logistics integration in the mining operations will provide time, equipment and capacity utilities (Wiengarten et al., 2014) with improved economic and reduced environmental impact. Internal and external integration promote real-time information flow supporting lean production, green logistics, green purchasing/electronic-ordering and tracking system replacing paper-based ordering system and help minimize environmental impact associated with the flow of materials (Drohomeretski et al., 2015; Wong et al., 2015; Govindan et al., 2014b).

(4) Internal Environmental Management (IEM)

Environmental concerns in the mining industry require systematic and holistic approaches with internal environmental management to help address these problems (Vintró et al., 2014; Mangla et al., 2015). IEM systematic implementation requires monitoring and auditing for environmental compliance of mining operations. Introducing reward and incentive systems for environmental suggestions, top management support and incorporation of total quality environmental management (TQEM) into IEM systems can help reduce suppliers’ environmental degradation (Maslen & Hopkins, 2014; Lee et al., 2014).

(5) Eco-Innovation Practices (ECO)

Eco-innovation may be novel systems to an organization and result in environmental risk and resource use burden reduction throughout the operational life-cycle (Bocken et al., 2014). Byproducts from mining operations can be transformed into useable materials and feedback into operations through eco-innovative approaches (Lutandola and Maloba, 2013). Substituting chemicals for gold recovery can reduce negative environmental consequences and risk (Azevedo et al., 2012). Mining companies can modify their processing plant by shifting from “dirty” to cleaner technology to improve efficiency of mineral recovery and byproduct values and use of resources and fewer inputs, and represent eco-innovations (Azevedo et al., 2012; Voigt et al., 2014).
(6) End-of-Life Practices (EOL)

End-of-life initiatives can help reduce life cycle environmental burdens of materials (Cucchiella et al., 2014; Wang and Gaustad, 2012). Mining machinery maintenance produces significant wastes (worn-out parts/components) which can be put through component exchange programs (reverse logistics) by returning them to suppliers in exchange of new parts/components with little or no additional cost (Bell et al., 2013). These worn-out parts and components can be recaptured for value or proper disposal to avoid environmental impact (Pishvae et al., 2014; Li & Wu, 2014; Govindan & Popiuc, 2014). Managing carbon and tailings wastes at the end of life lessens environmental burdens (Edraki et al., 2014).

The major six factors and thirty sub-factors are summarized in Table 1.

[Insert Table 1 about here]

2.1.2 GSCM Implementation Benefits and Organizational Sustainable Performance Outcomes

Performance with a GSCM context may include economic, environmental and social performance.

GSCM implementation offers many important economic benefits (Lee et al., 2014; Govindan et al., 2014b, 2015; Dubey et al., 2015) which presents a "win-win" situation for the company and the environment (Beckmann et al., 2014). GSCM practices reduce both direct environmental cost and financial costs of the mines including reduced environmental fines, reduced energy consumption cost, reduced cost of material purchasing and improved tailings residual enabling reduced tailings facility cost. These initiatives enhance resource efficiency which relates directly to economic performance (Zhang et al., 2012).

Mining companies can use GSCM practices to evaluate and hence mitigate the impact of their operations on the environment. The raison d'etre for GSCM is to help mines and industry achieve better environmental performance. Eco-innovative initiatives can help reduce solid/liquid waste and emissions mitigating environmental risks and impacts associated with mines’ operations.
Social performance in the mining industry has been poor resulting in local mining communities and general public opposing mining developments, questioning, and challenging mining companies to justify their existence and legitimacy (Muduli et al., 2013; Ranängen et al., 2014). These stakeholder group concerns on mining operations are linked to environmental and social health issues resulting from unhealthy and unsafe practices (Mzembe & Meaton, 2014; Muduli et al., 2013), impacts on local land-use (mainly agricultural land) and lack of community engagement (Lawson & Bentil, 2014; Dare et al., 2014). GSCM practices can be used to help address these socio-environmental issues and improving social performance.

2.2 MCDM methods for GSCM evaluation

Green supply chain evaluation is a multi-criteria task involving conflicting choices requiring the support of MCDM tools. Many researchers have utilized a variety of MCDM tools such as ANP and fuzzy-ANP (Theißen & Spinler, 2014; Büyükozkan & Çifçi, 2012a), fuzzy-DEMATEL (Lin, 2013), AHP and fuzzy-AHP (Govindan et al., 2014b; Wang et al. 2012; Rostamy et al. 2013), fuzzy-DEA (Mirhedayatian et al., 2014), fuzzy-AHP-TOPSIS (Wang and Chan, 2013), fuzzy-Delphi-ANP (Tseng et al. 2015) and ANP-QFD-ZOGP (Jayakrishna et al., 2013) for investigating different kinds of green initiatives. We build on this work by integrating fuzzy-DEMATEL and ANP for GSCM multiple criteria evaluation.

2.2.1 Integrating DEMATEL and ANP

The integration of DEMATEL and ANP has seen limited investigation, although they have natural linkages. In ANP, the criteria within the system are compared through pair-wise comparisons to determine their weights based on predetermined interactions amongst criteria. Too many interactions amongst the criteria can cause an inordinate amount of comparisons within ANP, making it difficult for the decision maker to handle, rendering ANP less practical and causing decision maker fatigue due to the interactive nature of ANP information elicitation. The focus of this integration with
DEMATEL is on how these interactions and relationships can be designed to reduce the volume of pair-wise comparisons required by decision makers within ANP.

In the literature, there have been two main attempts to link DEMATEL and ANP. However, these attempts and approaches have not really utilized DEMATEL networking results for ANP network design. One approach transfers the normalized total-relation matrix from the DEMATEL into the ANP inner dependencies part to form the weighted super-matrix (e.g. Büyüközkan and Çifçi, 2012b). This approach does not involve the decision-makers involvement in ANP, nor aids in improving ANP performance. The other approach multiplies the normalized total-relation matrix from the DEMATEL with the acquired ANP inner dependencies matrix to form the weighted super-matrix (e.g. Huang et al., 2014). This approach also does not use DEMATEL to help achieve efficiencies in ANP.

In summary, with this integrative approach the criteria relationships and interrelationships established from the DEMATEL technique provide a structure for determining the factor interdependencies in an ANP network. Fewer interdependencies mean exponential reduction in the number of relationships to be investigated in the ANP stage. Thus, this procedure greatly reduces the number of pair-wise comparison to be evaluated in the ANP stage.

2.3 Environmental and Green Supply Practices in the Ghanaian Mining Industry Context

Many studies have been completed on green supply chain management initiatives and programs implementation in the mining industry in both developed and developing nations. For example, investigations have occurred in China (Haibin and Zhenling, 2010; Si et al., 2010); Australia (Van Berkel, 2007; Giurco and Cooper, 2012); India (Barve and Muduli, 2013; Luthra et al., 2015); Brazil (Gomes et al., 2014) and Spain (Vintró et al., 2014). No studies have been completed in the Ghanaian mining industry context. More specifically, studies into environmental (green) sustainability in
Ghanaian mining industry produces an unclear picture about the industry’s environmental impacts, as environmental initiatives involving the supply chains are rare (e.g. Fei-Baffoe et al., 2013).

Fei-Baffoe et al. (2013) recently conducted a study involving two large mining companies from Ghana to investigate the impact of ISO 14001 environmental management systems (EMS) on key environmental performance indicators. According to the study, implementation of ISO 14001 EMS by two gold mining companies result in environmental performance improvement, particularly in waste management, reported environmental incidents, and energy consumption. Segregation of waste was adopted in both companies to ensure appropriate disposal mechanisms to mitigate pollution. These are examples where Ghanaian mining company environmental performance improvement are internally focused and cleanup initiatives. While these attempts are notable efforts, the capabilities developed may not fully address the broader ecological influence of supply chains in the mining industry. These localized and reactive environmental management initiatives focus on expensive and remedial investments (Hilson and Nayee, 2002).

Mining in Ghana and specific Ghanaian company field study discussion are further presented in section 4.1.

3. Technical Background

This section presents some background information of the methodologies incorporated into the proposed hybrid multiple criteria evaluation tool, fuzzy-DEMATEL and ANP.

3.1 Overview of the various aspects of the proposed novel hybrid methodology

3.1.1 The Fuzzy-DEMATEL method

The DEMATEL method is a structured analytical tool used for causal mapping (Fontela and Gabus, 1976; Gabus and Fontela, 1973). DEMATEL uses graph theory to categorize attributes into cause and effect groups (Senvar et al., 2014). The resulting digraphs (directed graphs) from DEMATEL represent a conceptual relationship among the elements in the system, with the strength of influence
identified (Miao et al., 2014; Liu et al., 2014; Patil & Kant, 2014a). This methodology has been successfully applied in various fields including emergency management (Li et al., 2014), blogging (Hsu & Lee, 2014), knowledge management (Patil & Kant, 2014a, 2014b), and green supply chain management (Wu & Chang, 2015).

The DEMATEL approach will utilize triangular fuzzy numbers (Zadeh, 1965). Fuzzy numbers are convex fuzzy sets characterized by a given interval of real numbers, with their grade of membership between 0 and 1 (Patil & Kant, 2014a, 2014b). This study adopts triangular fuzzy numbers (TFN) to obtain solutions from the experts. TFN use three-values: the lowest possible value \(l\), the most promising value \(m\) and the upper possible value \(u\). The TFN, membership function \(\mu_{\tilde{A}}(x)\) can be defined by (1):

\[
\mu_{\tilde{A}}(x) = \begin{cases} 
0, & x < l \\
\frac{x-l}{m-l}, & l < x \leq m \\
\frac{u-x}{u-m}, & m < x \leq u \\
0, & x > u 
\end{cases}
\]  

(1)

where \(l, m\) and \(u\) are real numbers and \(l \leq m \leq u\), and \(l, m\) and \(u\) are the lower, the mean and upper bounds of fuzzy number \(\tilde{A}\), respectively. Let \(\tilde{A}_1 = (l_1, m_1, u_1)\) and \(\tilde{A}_2 = (l_2, m_2, u_2)\) be two triangular fuzzy numbers. The triangular fuzzy numbers mathematical operations are defined by expressions (2-6) (Yu and Hu, 2010):

\[
\tilde{A}_1 \oplus \tilde{A}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) 
\]  

(2)

\[
\tilde{A}_1 \otimes \tilde{A}_2 = (l_1 l_2, m_1 m_2, u_1 u_2) 
\]  

(3)

\[
\tilde{A}_1 \oslash \tilde{A}_2 = (l_1 - l_2, m_1 - m_2, u_1 - u_2) 
\]  

(4)

\[
\frac{\tilde{A}_1}{\tilde{A}_2} = (\frac{l_1}{l_2}, \frac{m_1}{m_2}, \frac{u_1}{u_2}) 
\]  

(5)

\[
\tilde{A}_1 \odot \lambda = (l_1 \lambda, m_1 \lambda, u_1 \lambda), \lambda \geq 0, \lambda \in \mathbb{R} 
\]  

(6)
Defuzzification to a crisp number is needed. Defuzzification takes into account the spread, height and shape of the triangular fuzzy numbers as imperative characteristics of the fuzzy number (Cheng and Lin, 2002; Chang et al., 2011). The modified-CFCS (Converting Fuzzy data into Crisp Scores) defuzzification will be used to identify a crisp value (Opricovic and Tzeng, 2003; Patil & Kant, 2014b). Details on the fuzzy DEMATEL approach will be presented in section 4 in the field study application.

3.1.2. The ANP method

The ANP method is an extension of the analytical hierarchy process (AHP) (Saaty, 1996). ANP does not just use a strict hierarchical network like AHP (Aragonés-Beltrán et al., 2014). ANP is capable of modeling interrelationships among the decision echelons and elements, which AHP does not do (Zaim et al., 2014; Meade and Sarkis, 1998; Wong et al., 2014). The major steps of ANP and its relationship with DEMATEL, as introduced in this paper, are described in the next section as part of the field study process.

4. Field study of GSCM Practices Importance and Performance

The two-stage fuzzy-DEMATEL and ANP methodology is detailed in this section with an application to a multiple case field study in the Ghanaian mining industry. The proposed methodology is used to assist practitioners in mining and other industries to make strategic, in this case GSCM, decisions. Initially an overview of the field study environment, Ghana’s mining industry, is provided as background.

4.1 The Ghanaian mining industry

Ghana was selected as the case country for this study because of its unique mining industry positioning (Bloch & Owusu, 2012; Boon and Ababio, 2009). It consistently ranks as one of Africa’s top producers of precious metals and minerals such as gold and diamonds. Mining and minerals contribute 5% of Ghana’s GDP and 37% of their total exports (Boon and Ababio, 2009). Gold, the main focus of Ghana’s mining and mineral development industry contributes over 90% of the total
minerals exports (Aryee, 2001). Ghana’s mining industry has attracted nearly US$2 billion of foreign direct investment (FDI) in both mineral exploration and mine development representing over 56% of the total FDI inflows (Awudi, 2002). The country currently has twenty-three large-scale mining companies producing gold, diamonds, bauxite and manganese, and, there are also over three hundred registered small scale mining groups and ninety mine support service companies, important partners within the supply chain (Mbendi, 1995-2013).

The Ghanaian mining industry has been perceived as a socio-environmentally disruptive industry (Peck and Sinding, 2003). Negative environmental impacts from the mining industry's supply chain operations are numerous and include toxic reagent releases, acid drainage, air quality reduction, habitat modification or displacement and pollution (Wasylycia-Leis et al., 2014). Mineral extraction has resulted in severe and irreversible socio-environmental damages and challenges such as resource degradation, uprooting and displacement of communities. Environmental impacts such as drinking water contamination and air pollution also result, translating into serious health problems for residents (Shandro et al., 2011).

These issues have challenged the mining companies’ license to operate and legitimacy due to protestations of various socio-environmental advocacy groups at both local and international levels (Bice, 2014; Moffat & Zhang, 2014; Owen & Kemp, 2013). These pressures have caused mining organizations to carefully evaluate their direct and indirect environmental burdens and unsustainable consumption and production practices. Mine operators have to work against a backdrop of a legacy of extensive and severe socio-environmental pollution issues associated with metal mining that have resulted from poor practices and non-existent or non-enforced regulatory policy (Johnson, 2013). Furthermore, tailings generated from mineral processing streams (e.g. gold mines) can also contain large quantities of toxic substances, such as cyanides reagents and heavy metals, which can pose significant human health and ecological risks (Adams, 2013; Kuyucak & Akcil, 2013).
It has become imperative to strike a ‘win-win’ balance between mineral and mining economic development and environmental protection, in this emerging economy. Investigating GSCM and its relationship in Ghana’s mining industry is important for both direct and indirect environmental consumption and production sustainability improvement. This study on environmental sustainability concerns in the mining sector and Ghanaian mining industry context is meant to initially address serious negative environmental consequences from supply chain and organizational operations of the mining industry, especially in developing economies.

4.2 The proposed hybrid multi-criteria evaluation methodology computational steps

To illustrate the applicability of the hybrid methodology using the GSCM practices framework, we employ real world multiple case (field) studies using selected multi-national mining companies from Ghana. The application is in two phases. The first phase applies the fuzzy-DEMATEL aspect of the model to obtain interrelationships and influences within the GSCM practices and sub-practices. In the second phase ANP, using the interrelationships identified in the DEMATEL step, is applied to determine the relative impact of the GSCM practices and sub-practices to organizational sustainable performance (environmental, economic and social) based on input from the field study companies and managers.

**Phase 1: The fuzzy-DEMATEL methodology to identify significant interrelationships.** This phase has five major stages with a number of sub-steps. Each stage is now detailed.

**Stage 1.** Determine the decision goal and select participants. In this step, the decision goal is set and the decision-making team is formed. This stage used six selected managers, one each from the six selected mining companies. Characteristics of the managers in this study are summarized in Table 2.

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3 Selection of the six mining companies was based on the high interest exhibited by these mining companies in greening their mining supply chains. Thus, purposive sampling was used in selecting the final six managers/companies.
Stage 2. Develop the evaluation model and design fuzzy evaluation scale. The framework previously introduced in sections 2.1.1 and 2.1.2, and depicted in Figure 1 is adopted. A five-point measurement scale ranging from (N) ‘no influence’ to (VH) ‘very high influence’ is developed for managerial perceptions on influences amongst factors using pair-wise comparisons. Triangular fuzzy number assignments for the linguistic values are shown in Table 3.

Stage 3. Determine causal relationship using fuzzy-based DEMATEL

Step 3.1: Linguistic-based DEMATEL survey questionnaire design and pilot testing

At this stage, a survey questionnaire involving various pair-wise comparisons is developed and further pilot tested with feedback incorporated into the questionnaire.

Step 3.2: Construct pair-wise comparison matrix for DEMATEL

Given $L$ experts and $n$ factors a pair-wise comparison matrix is developed. The influence of factor $i$ compared to factor $j$ is obtained from decision maker perceptions. Pair-wise comparisons between any two factors are denoted by $f_{ij}$. The result is an $n \times n$ non-negative direct relation matrix $U^r = [f_{ij}]_{n \times n}$, with $1 \leq r \leq L$. Thus, $U^1, U^2, ... U^L$ are response matrices for each of the $L$ experts and each element of $U^X$ is a linguistic value denoted by $f_{ij}^r$. The diagonal elements of each response matrix $U^r$ are set to zero.

The six selected managers were emailed the questionnaire. The direct-relation matrices are populated with linguistic variables, see Table 4 for manager 1 linguistic responses to the major factors. Then the linguistic numbers are replaced by triangular fuzzy numbers for the linguistic variables, see Table 5 (matrix $A$).
Step 3.3: Defuzzify direct-relation matrix into crisp numbers

Let $f_{ij}^r = (l_{ij}^r, m_{ij}^r, u_{ij}^r)$, be an equivalent triangular fuzzy number for the level of influence of factor $i$ on factor $j$ for expert $r$ rating with $1 \leq r \leq L$. Then, the modified-CFCS defuzzification method, using equations (7)-(13), is applied to get crisp numbers.

Step 3.3.1: Normalize upper $(x_u)$, mean $(x_m)$ and lower $(x_l)$ fuzzy numbers:

$$x_{u}^r_{ij} = (u_{ij}^r - \text{min}l_{ij}^r)/\Delta_{min}^\text{max}$$  \hspace{1cm} (7)
$$x_{m}^r_{ij} = (m_{ij}^r - \text{min}l_{ij}^r)/\Delta_{min}^\text{max}$$  \hspace{1cm} (8)
$$x_{l}^r_{ij} = (l_{ij}^r - \text{min}l_{ij}^r)/\Delta_{min}^\text{max}$$  \hspace{1cm} (9)

Where $\Delta_{min}^\text{max} = \text{max}u_{ij}^r - \text{min}l_{ij}^r$,

$maxu_{ij}^r$ = the maximum upper value amongst the upper bound of fuzzy number values for expert $r$, and $\text{min}l_{ij}^r$ = the minimum lower value amongst the lower bound of fuzzy number values for expert $r$.

Step 3.3.2: Compute upper $(x_{us})$ and lower $(x_{ls})$ normalized values:

$$x_{us}^r_{ij} = x_{u}^r_{ij}/(1 + x_{u}^r_{ij} - x_{m}^r_{ij})$$  \hspace{1cm} (10)
$$x_{ls}^r_{ij} = x_{m}^r_{ij}/(1 + x_{m}^r_{ij} - x_{l}^r_{ij})$$  \hspace{1cm} (11)

Step 3.3.3: Compute total normalized crisp values $(x)$:

$$x_{ij}^r = [x_{ls}^r_{ij}(1 - x_{ls}^r_{ij}) + x_{us}^r_{ij} * x_{us}^r_{ij}]/[1 - x_{ls}^r_{ij} + x_{us}^r_{ij}]$$  \hspace{1cm} (12)

Step 3.3.4: Compute crisp values $(Z)$:

$$Z_{ij}^r = \text{min} l_{ij}^r + (x_{ij}^r * \Delta_{min}^\text{max})$$  \hspace{1cm} (13)

The initial direct-relation matrix $Z$, using Table 5 data, with crisp numbers for manager 1 and major factors is given in Table 6.
Step 3.3.5: Aggregate direct-relation crisp matrices and normalize. All decision makers’ direct-relation crisp matrices are then aggregated into a single (average) overall crisp direct-relation matrix using equation (14):

\[
Z_{ij} = \frac{1}{h} (Z_{ij}^1 + Z_{ij}^2 + \cdots + Z_{ij}^h)
\]  

(14)

Then the generalized direct-relation matrix \( P \) can be obtained by normalizing the aggregated direct-relation matrix using equations (15) and (16):

Let \( v = \frac{1}{\max_{i=1}^{n} \sum_{j=1}^{n} f_{ij}} \) where \( v > 0 \)

\[ v \]

and, \( P = v \cdot Z \)

(16)

The generalized direct-relation matrix \( P \), using Table 6 data for all decision makers’ and major factors, is given in Table 7.

[Insert Table 7 about here]

Step 3.4: Compute the total relation matrix. The total-relation matrix \( T \) is determined using equation (17), where \( I \) represents an identity matrix

\[
T = (P^1 + P^2 + \cdots P^m) = P(I - P)^{-1}
\]

(17)

Step 3.5: Compute Cause/Effect and Prominence of Factors

Using the total-relation matrix \( T \), get to the total row \( (R_i) \) and column \( (C_j) \) sum using expressions (18) and (19):

\[
R_i = (\sum_{j=1}^{n} t_{ij}) \text{ for each row } i
\]

(18)

\[
C_j = (\sum_{i=1}^{n} t_{ij}) \text{ for each column } j
\]

(19)

To determine prominence \( P_i \) and net cause/effect \( E_i \) of the factors, use expressions (20) and (21);

\[
P_i = \{C_j + R_i/i = j\}
\]

(20)

\[
E_i = \{C_j - R_i/i = j\}
\]

(21)
A graph can then be plotted by mapping the \((C_j + R_i, C_j - R_i)\) dataset, where prominence \(P_i\) represents the X-axis and the net effect \(E_i\) represents the Y-axis.

The total-relation matrix \(T\), the row \(R_i\) and the column \(C_j\), and the prominence \(P_i\) and the net cause/effect \(E_i\) for all major factors, using Table 7 data for major factors, are shown in Table 8.

[Insert Table 8 about here]

**Step 3.6: Set a threshold value and obtain the network relationship map (NRM).** A threshold value \(\beta\) is set to filter and select the relationships in matrix \(T\) with values above the threshold value. A network relationship map (NRM) is determined for those relationships that meet or exceed the threshold value.

A threshold value of the mean\(^4\) of all values in the \(T\) matrix is set and agreed upon by the decision makers.

Table 9 (matrix \(T_{\beta}\)) shows the relationships whose values are greater than calculated threshold of 0.903. Fig. 2 shows the network relationship map, using data from Table 9, for the major practices. A \(T_{\beta}\) is developed for major factors and sub-factors. It is these factor/sub-factor relationships and interrelationships that will be evaluated by ANP in the next phase of the methodology.

[Insert Table 9 & Figure 2 about here]

**Phase 2:** Determine the relative perceived impact of factors on organizational sustainability performance using ANP.

**Stage 6.** ANP is applied in four steps to determine factor importance weights on the overall organizational sustainability goals.

**Step 6.1:** Goal formulation decision structuring (interactions) using the total-relation matrices \(T_{\beta}\) from DEMATEL. This step requires a clearly defined goal and the formation of a decision structure. The goal for this paper is identifying the perceived impact of major GSCM practices and sub-practices on

\(^4\)The threshold values can be raised or lowered depending on how many interrelationships are viewed as useful for ANP analysis by analysts. For example, setting a threshold of one or two standard deviations above the mean can also be utilized, but that would mean fewer interrelationships from the DEMATEL analysis for ANP analysis.
organizational sustainability performance (environmental, economic and social). The criteria within the system are compared through pair-wise comparisons to determine weights through ANP. It is important to most effectively design the decision interactions within ANP. Too many interactions can cause an inordinate amount of comparisons within ANP, causing decision maker fatigue making ANP less practical, too few and a full interaction effect may be lost. The DEMATEL steps in the previous section help to reduce the number of factor interdependencies for evaluation. Using DEMATEL in this way aids ANP to be more practical and feasible to apply. Although DEMATEL and ANP have been used together previously (Büyüközkan and Çifçi, 2012b; Huang et al., 2014), none have explicitly used the two together to form a more efficient decision network for ANP.

Table 9 is representative of the DEMATEL output used for factor interactions within ANP. The identified interrelationships are used to develop an ANP pair-wise comparison sub-matrix. Sub-matrices for each of the sub-factor interrelationships are determined in the same way, but are not shown here.

Step 6.2: Design survey questionnaire and conduct pair-wise comparison. Once the interdependencies within the major and sub-factors clusters have effectively been determined, the data gathering can commence. A survey questionnaire using the matrices was developed and administered.

The survey questionnaire was emailed to ten selected managers with their characteristics and companies given in Table 2. These pair-wise comparisons were rated using the recommended 9-point (1-9) measurement scale as shown in Table 10 (Saaty, 1996).

[Insert Tables 10 about here]

---

5 Purposive sampling was used in selecting these 10 managers. Individually emails were sent to two managers from each of the six selected mining companies requesting their participation in the ANP survey and providing them with full information on the objective of the research. Two of the managers from two different mining companies declined.
Step 6.3: Compute local priority vectors of factors and, form un-weighted and weighted (limiting) super-matrix.

Given that \( A \) is a pair-wise comparisons matrix, the priority vectors/relative importance weights \( w_i \) can be computed using equation (22):

\[ Aw_i = \lambda_{max} w_i \]  

(22)

where \( \lambda_{max} \) is the largest eigen-value of \( A \). Many authors have proposed several algorithms to approximate the \( w_i \) value (Saaty & Takizawa, 1986; Saaty & Hu, 1998; Meade and Sarkis, 1998; Saaty, 2004). Several online-based multi-criteria decision-support softwares have also been designed to help compute these relative importance weights including Web-HIPRE3+ (http://hipre.aalto.fi/) (Mustajoki & Hamalainen, 2000) and Super-Decisions (http://www.superdecisions.com/).

The relative importance weights determined from the various pair-wise comparisons matrices are used to construct the un-weighted super-matrix. The un-weighted super-matrix is formed as a partitioned matrix involving various sub-matrices modeling the factor interrelationships. The un-weighted super-matrix needs to be made column stochastic. The super-matrix is then raised to the power of \( 2^k \), where \( k \) is a large number to converge and arrive at a long-term stable set of weights.

Super-Decisions software can generate the un-weighted and limiting super matrices after inputting the relative importance weights. Table 11 shows Manager 1’s final converged super-matrix for the major GSCM factor. Table 12 averages the weights of all managers for major GSCM factors.

[Insert Tables 11-12 about here]

Step 6.4: Identification and Selection of best factor influence on the overall organizational sustainability performance. A desirability index table is used to determine the final aggregation of factor and sub-factor weights (local weights when separate) into a single numeric score (global weights when aggregated). The greater the index value, the more important the factor.

Due to the preponderance of zero weighted values from the previous super-matrix stages, three aggregation models are used: multiplicative, additive and exponential (multiplicative) powers. The
purpose was to compare and analyze the sensitivity of the ANP desirability matrix methodology whether zero values can cause a very different ranking.

(1) **Multiplicative model**: In this aggregation, the factor importance is evaluated by simply multiplying the weights associated with each factor/sub-factor. In this situation if any of the factor or sub-factor importance weights is equal to zero, then the global weight is zero. For this aggregation the penalty is very severe because of a lack of an interrelationship and is reflected in the overall desirability index value (Natoli and Zuhair, 2011). Although the multiplicative approach is the most popular approach, two other techniques, the additive and exponential (power) multiplication, can provide a more balanced results from aggregation.

(2) **Additive model**: In this aggregation, the factor importance is simply the sum of the weights associated with each factor/sub-factor. The additive aggregation model allows for a more balanced inclusion of poor or lower value individual evaluating criterion (Munda and Nardo, 2005; Nardo et al., 2005). Less important weights of any of the evaluating factor/sub-factor will result in relatively less sensitivity in the overall importance of an alternative. Thus, for the additive aggregation model, there exists better substitution between the individual evaluating criteria influencing the overall desirability index value for an alternative (Natoli and Zuhair, 2011).

(3) **Multiplicative Exponential-weighting model**: In this aggregation, the importance weight is raised to a power, in this case with an exponential base. For this aggregation a complete nullification of a factor and associated sub-factors does not occur due to lack of network interdependencies after application of the DEMATEL interrelationship evaluation.

The global relative importance desirability indices \( i \) of the organizational sustainability sub-factor \( k \) for aggregation method \( z \) is denoted as \( i_k^z \) and are computed in two stages. A multiplicative \( i_k^M \), additive \( i_k^A \) and exponential multiplicative power \( i_k^E \) are determined for each factor using equations (23)-(25). Then, the relative factor importance for each of the individual organizational sustainability
dimensions results under each of the three aggregation models are further averaged to determine the global relative importance desirability indices $i$ of the organizational sustainability sub-factor $k$ for aggregation method $z$, $i^z_k$. The second stage can be ignored should there be only one organizational sustainability dimension.

$$i^M_{lk} = U^D_l P^D_{jl} P^I_{jl} A^D_{kj} A^I_{kj}$$

$$i^A_{lk} = U^D_l + P^D_{jl} + P^I_{jl} + A^D_{kj} + A^I_{kj}$$

$$i^E_{lk} = e^{(U^D_l + P^D_{jl} + P^I_{jl} + A^D_{kj} + A^I_{kj})}$$

$U^D_l$ represents the relative importance weight of organizational sustainability dimension $l$ as part of the hierarchical (D) relationship.

$P^D_{jl}$ represents the relative importance weight for major factor $j$ of organizational sustainability dimension $l$ for the hierarchical (D) relationship.

$P^I_{jl}$ represents the stable relative importance weight for the major factor $j$ of organizational sustainability dimension $l$ for the interdependent (I) relationship.

$A^D_{kj}$ represents the relative importance weight for sub-factor $k$ of major factor $j$ for the hierarchical (D) relationship.

$A^I_{kj}$ represents the stable relative importance weight of sub-factor $k$ of major factor $j$ for interdependency (I) relationship.

$L$ is the index set for organizational sustainability dimensions where $l = 1,2,3$, respectively representing economic, environmental, and social sustainability dimensions.

$J$ is the index set for the major factors where $j = 1 \ldots 6$.

$K$ is the index set for the sub-factors where $k = 1 \ldots 30$. 

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z is the index set for the aggregated methods where \( z= \) multiplicative, \( M \), additive \( A \) and multiplicative exponential \( E \).

\( i \) is the index for the global relative importance desirability indices.

\( e \) is the exponential base value.

An example calculation for each aggregation technique is now shown for the SSP/SSP1 sub-factor (factor, \( j = 2 \), sub-factor, \( k = 6 \) and organizational sustainability dimensions, \( l = 1, 2, 3 \)) in Table 13 (the italicized and bolded values).

(1) Multiplicative model:

Multiplicative Exponential

\[ i_{1,6}^M = U_1^D P_{2,1}^D P_{2,1}^I A_{6,2}^D A_{6,2}^I = 0.7144 \times 0.2462 \times 0.3784 \times 0.3492 \times 0.3175 = 0.00738 \]

\[ i_{2,6}^M = U_2^D P_{2,2}^D P_{2,2}^I A_{6,2}^D A_{6,2}^I = 0.2027 \times 0.1854 \times 0.3784 \times 0.3492 \times 0.3175 = 0.00158 \]

\[ i_{3,6}^M = U_3^D P_{2,3}^D P_{2,3}^I A_{6,2}^D A_{6,2}^I = 0.0829 \times 0.2003 \times 0.3784 \times 0.3492 \times 0.3175 = 0.00070 \]

Sustainability \( i_6^M = (i_{1,6}^M + i_{2,6}^M + i_{3,6}^M)/3 = (0.00738 + 0.00158 + 0.00070)/3 = 0.00322 \) (column 13)

(2) Additive model:

Additive Exponential

\[ i_{1,6}^A = U_1^D + P_{2,1}^D P_{2,1}^I + A_{6,2}^D + A_{6,2}^I = 0.7144 + 0.2462 + 0.3784 + 0.3492 + 0.3175 = 2.00569 \]

\[ i_{2,6}^A = U_2^D + P_{2,2}^D P_{2,2}^I + A_{6,2}^D + A_{6,2}^I = 0.2027 + 0.1854 + 0.3784 + 0.3492 + 0.3175 = 1.43318 \]

\[ i_{3,6}^A = U_3^D + P_{2,3}^D P_{2,3}^I + A_{6,2}^D + A_{6,2}^I = 0.0829 + 0.2003 + 0.3784 + 0.3492 + 0.3175 = 1.32827 \]

Sustainability \( i_6^A = (i_{1,6}^A + i_{2,6}^A + i_{3,6}^A)/3 = (2.00569 + 1.43318 + 1.32827)/3 = 1.58905 \) (column 15)

(3) Multiplicative Exponential-weighting model:

Multiplicative Exponential

\[ i_{1,6}^E = e^{(U_1^D P_{2,1}^D + P_{2,1}^I A_{6,2}^D + A_{6,2}^I)} = e^{(0.7144 + 0.2462 + 0.3784 + 0.3492 + 0.3175)} = 7.43122 \]

\[ i_{2,6}^E = e^{(U_2^D P_{2,2}^D + P_{2,2}^I A_{6,2}^D + A_{6,2}^I)} = e^{(0.2027 + 0.1854 + 0.3784 + 0.3492 + 0.3175)} = 4.19199 \]

\[ i_{3,6}^E = e^{(U_3^D P_{2,3}^D + P_{2,3}^I A_{6,2}^D + A_{6,2}^I)} = e^{(0.0829 + 0.2003 + 0.3784 + 0.3492 + 0.3175)} = 3.77452 \]

Sustainability \( i_6^E = (i_{1,6}^E + i_{2,6}^E + i_{3,6}^E)/3 = (7.43122 + 4.19199 + 3.77452)/3 = 5.13258 \) (column 17)

Table 13 summarizes all the results and rankings.
5. Discussion of Results

In this section the results of the fuzzy-DEMATEL are first discussed, followed by discussion of the integrated DEMATEL-ANP methodology then an overview of managerial inputs.

5.1 The fuzzy-DEMATEL results – causal relationship (relative relationship and influences)

The results of the fuzzy-DEMATEL (Figure 2 and Table 8) provide insights for making GSCM managerial decisions. Figure 2 shows strategic supplier partnership (SSP) as the factor with the highest connectivity degree, making it the most critical GSCM factor. Strategic supplier relationships set the foundation for short- and long-term successful inter-organizational programs, GSCM is not an exception. Prominence rankings also show the following relationships SSP>EOL>ECO>IEM>OLI>GITS. It is not clear if this is an implementation path, but does provide a hierarchy of what might be most important to these organizations. This industry and country may be less reliant on information technology and may explain the lower prominence of GITS.

The net cause/effect shows that SSP, OLI and EOL factors are net causes for other factors. IEM, ECO and GITS factors are effected (resultant causes) by the other factors. Thus, SSP, OLI and EOL are the cause factors influencing the other factors more so than being effected by them. SSP is the most influential cause factor whilst IEM is considered the most influenced factor amongst the effect group. For these mining companies implementing GSCM programs will require an initial focus on SSP and have that foundation built. The relative prominence and causation does not necessarily mean the most important or least important overall. The reason for this relative importance may be that foundational activities such as SSP may have been developed already, with a need to focus on other less mature GSCM practices that have yet to be implemented. The linkage of this relationship to ANP
relative importance results, in the next section, will help identify which GSCM practices should be the focus of this Ghanaian mining industry.

The findings from the empirical study tell us that stronger strategic supplier partnership is critical to fostering successful GSCM implementation in the mining industry. The finding supports the consensus and the importance placed on inter-organizational partnership during cross-organizational implementation programs (Palinkas et al., 2014; Chen et al., 2014). This result does complement recent empirical studies. For example, environmental partnerships between organizations and their primary strategic suppliers are positively linked with improved environmental and operational performance (Bowen et al., 2001; Vachon and Klassen, 2008). This result implies that environmental performance of mining companies can be improved by extending internal activities beyond a mining organization’s boundaries (external) to partner with strategic suppliers. This systemic perspective considers both internal and external factors and helps to strengthen greening capabilities and competencies. Engaging strategic suppliers’ in early GSCM program planning stages will most likely result in greater acceptance and performance of other practices. It may also strengthen the program’s capabilities and competencies through shared environmental management techniques and knowledge.

5.2 ANP results - weight measurements for ranking the best criteria on the overall goal

Table 13 columns \( i_{lk}^M, i_{lk}^A \) and \( i_{lk}^E \), depict the final results and the rankings for the aggregated models of perceived GSCM practices influence on organizational sustainable performance. Table 14 shows the rank order of the top 10 GSCM most influential sub-practices that contribute to sustainability of Ghana’s mining industry.

[Insert Table 14 about here]

OLI1 “lean and green operations” is the GSCM practice that is perceived to contribute greatly to sustainability in the mining industry. The multiplicative weighting model (MW) transposes the top two sub-factors, but is consistent with the other techniques. Overall, each of the models shows a relatively
consistent grouping of practices in the top 10. SSP1 “Jointly develop environmental management solutions” are reinforced as one of the other top sub-practices. But, even with a general consistency in the rankings, there are some significant shifts, for example SSP2 falls from a 4 to a 7 ranking. Many more such shifts do occur in the broader sets. Thus, care must be taken on how values would be aggregated if this tool was to be used as a decision support tool for decided on specific programmatic alternatives.

The DEMATEL-ANP approach resulted in some factors being left out of the analysis in the multiplicative aggregation model when using the desirability indices aggregation approach. Practically, these less linked factors should not be zero valued when calculating desirability index values and why some non-zero valuation using additive or exponential aggregation approaches are needed. It is more accurate to not completely eliminate factors that lack interdependencies in ANP. ANP weighting aggregation with desirability aggregation approaches; need to be adjusted to not fully penalize the lack of linkages for a factor which occur in the ANP-DEMATEL approach.

Overall, it is not surprising that the results favored the general SSP, OLI and EOL factors. These practice factors were found to be the most influential causes, where SSP was the most important and connected factor. This result implies that the relationship between supplier and buyer may lead to joint greening capabilities and competencies development which may result in collaborative competitive advantages (Gottschalk and Solli-Sæther, 2006). Thus, building relational capabilities are important for addressing the environmental impact of these mining companies supply chains. The mining companies can develop these relational greening capabilities and competencies by engaging their strategic suppliers in early joint environmental discussions and learning activities. This engagement can result in shared interpretation of environmental concerns to formulate collective environmental solutions to achieve environmental goals (Geffen and Rothenberg, 2000; Tseng, 2011; Vachon and Klassen, 2008; Wong, 2013). This concurrent result also shows that the mining industry in Ghana is still early in
GSCM practices implementation because the focus and greatest opportunities to improve corporate sustainability are from the more foundational (causation) sub-practices. Further study, after implementation of practices needs to be completed to determine if the outcomes were as predicted or expected.

5.3 Managerial Feedback

As a post-hoc analysis of the results, we sent a small survey asking managers about the approach and results. Three managers replied. The major concern of the managers with this technique was the many factors and sub-factors involved in the analysis. Trying to understand the definitions while completing the data acquisition survey was one of the major limitations mentioned. This may cause the results to be a bit biased, maybe toward those activities and concerns that the managers understood more completely. Thus, a user friendly or face-to-face detailed implementation with a facilitator who can explain dimensions and factors clearly, will be needed for effective implementation of this approach. This consideration further supports the need for filtration of relationships and factors that are used in ANP. It is assumed that the amount of process frustration with ANP was lessened, although the DEMATEL portion may still have been cumbersome.

Managers were also provided with some mathematical background associated with the technique. The reason for this is to allow for transparency and exemplify the robustness of the methodology, giving managers a more secure feeling that the technique is based on scientific and mathematical principles and logic. Unfortunately, the respondent managers (and informally other managers) felt that the mathematical descriptions of the technique was not enlightening and even a hindrance to understanding. Thus, presentation of these complex techniques may have been best presented (as one manager stated) at the highest level of analysis, maybe as a general flow chart.

The final major issue we tried to address in getting management replies was the validity and confidence in the final results as summarized in a simple table. Even after some disillusionment with
the process, the managers felt that the final results were what was expected and what they wished to convey. Thus, although the means to arrive at some solution may have been mired in the complexity of the process and definitions, the final results could be viewed as managerially valid and reliable.

These are some final feedback results, different settings, managers, preparation and backgrounds may have arrived at different results.

6. Conclusion

6.1 Summary of findings

Mining industry environmental impact is extensive and persistent; it is especially pernicious in emerging economy countries such as Ghana. Greening the supply chain is one important and strategic sustainable production and consumption option for addressing these serious environmental impacts. Given the novelty of GSCM in mining it is important to better understand how it can be managed. This study is one of the first to investigate this topic. The focus of this investigation is the first contribution; the second major contribution is introducing a multi-stage DEMATEL and ANP-DEMATEL approach to quantitatively investigate influence and importance perceptions of GSCM practices and their role in supporting organizational sustainability.

This paper adopted a previously developed comprehensive and integrative GSCM practices framework partially developed and practically validated using mining industry managers from Ghana, an important African emerging economy nation. Multiple-field studies were used to gather data and evaluate the methodology. The fuzzy-DEMATEL aspect of the methodology was first applied to develop the interrelations/interdependencies amongst GSCM practices and sub-practices. SSP was found to be the most prominent and networked, to other GSCM practices. This result was confirmed in the next stage when ANP was utilized with the DEMATEL input to arrive at the perceived most influential sub-practices to organizational sustainability.
From a methodological perspective, this study is the first to fully integrate DEMATEL with ANP. DEMATEL allows for clearly identifying which interdependencies are most influential, and thus reducing, exponentially, the number of pairwise comparisons needed for ANP. Unfortunately, it was found that if interdependency did not exist, that the unconnected practice would receive a zero value when using the multiplicative form of desirability indices. Thus, aggregation techniques that did not completely penalize a set of relationships because of the lack of explicit interdependent connections were introduced. Both additive and exponential aggregation approaches were studied. It was found that differences and sensitivities do exist among the three aggregated techniques, though not as large as would be assumed, at least not on the highest ranking sub-practices.

The practical implications from the results are that managers believe and should probably focus on early foundational practices such as strategic supplier collaborations and operations and lean initiative practices to get the greatest potential sustainability returns for their organization. From a methodological perspective, researchers and decision analysts should be careful when seeking to integrate DEMATEL as a simplifying agent for ANP network analysis. Too much simplification in the network connections may cause significant changes to what practices will arrive at a final solution, especially when using a multiplicative aggregation for the desirability index. Alternative aggregation measures should be used to not overly penalize those sub-practices or factors that are missing interdependencies.

The results of this study provide valuable clues and guidelines to decision-makers and analysts inside and outside the mining industry for making strategic sustainability decisions such as GSCM implementation decisions. The methodology introduced in this paper has generalizability to many ANP and multi-attribute applications. Yet, there are limitations to this study and additional investigation is required, which provides fertile ground for further studies. Some general limitations are now identified.
6.2 Limitations of the study

One of the principle limitations of this study is its reliance on a small group of managers in one industry in Ghana. Generalizations to other countries and other industries cannot be made. This investigation is exploratory, and more investigation is required with broader empirical studies. Also, the study is just a snap-shot in time. Longitudinal investigation to determine if and how GSCM practice requirements and importance change over time is needed.

Methodologically we investigated the use of ANP using desirability indices. There are various other approaches to arrive at ANP solutions such as complete super-matrix and algebraic matrix operations. The sensitivities of the techniques in these other scenarios need to be investigated. In addition, the mental mapping of DEMATEL is only one approach to develop the network relationships and interdependencies, interpretative structural modeling and other mental modeling causal analysis tools may be investigated to determine whether the interdependent relationships would change.

As can be seen there is still significant work that can be completed in integrating ANP with other tools, and further investigation into the mining industry in emerging economy and developed nations. The work presented here helps to set the foundation for additional and important methodological and sustainable supply chain (organizational) investigations.

6.3 Managerial implications

From a practical perspective, if there existed greater similarities among the three desirability index rank orders, this would have more clearly provided managers with a consensus set of factors that should be pursued. Given that some sub-factors were left out (zero valued) in the multiplicative (weighting) aggregation model analysis when using the desirability aggregation approach, managers and decision makers should be more comfortable with the alternative ANP AW and MEW weighting schemes. The results from the two aggregation weighted approaches (AW and MEW), do provide general consistency in the rankings, and may be an option to consider as an initial step for green
operational initiatives implementation. In such situations, managers and decision-makers in the mining industry may focus on those sub-factors that are highly ranked within the top ten sub-factors across the ANP AW and MEW weighting schemes.

This paper provided some managerial and methodological insight into GSCM in an emerging economy (Ghana) mining industry. The effectiveness of a DEMATEL and ANP linkage was presented. Clearly, more work across emerging economies with respect to the role of GSCM in sustainable consumption and production is needed. We believe that this work sets the foundation for additional work on this important sustainable development topic.

References


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<thead>
<tr>
<th>No.</th>
<th>GSCM Factors and Sub-factors</th>
<th>Literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Green Information Technology and Systems (GITS)</strong></td>
<td></td>
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<tr>
<td></td>
<td>Sub-Factors</td>
<td></td>
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<tr>
<td>1</td>
<td>GIT51 Use of energy efficient hardware and data centers</td>
<td>Watson et al., 2008; Jenkin et al., 2011; Chou et al., 2012; Setterstrom, 2008; Sarkis and Zhu, 2008; Wagner et al., 2009; Uddin and Rahman, 2012</td>
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<td>2</td>
<td>GIT52 Consolidating servers using virtualization software</td>
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<td>3</td>
<td>GIT53 Reducing waste associated with obsolete equipment</td>
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<td>4</td>
<td>GIT54 Collaborative group software and telepresence systems</td>
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</tr>
<tr>
<td>5</td>
<td>GIT55 Eco-labeling of IT products</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td><strong>Strategic Suppliers Partnership (SSP)</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sub-Factors</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>SSP1 Jointly develop environmental management solutions</td>
<td>Vachon et al. 2001; Rao 2002; Geffen and Rothenberg 2000; Simpson and Power, 2005; Simpson et al., 2007</td>
</tr>
<tr>
<td>2</td>
<td>SSP2 Jointly build programs to reduce or eliminate materials use</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>SSP3 Share environmental management techniques and knowledge</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>SSP4 Collaborate with suppliers to manage reverse flows of materials and packaging</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>SSP5 Communicate goals of sustainability to suppliers</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>SSP6 Monitor environmental compliance status and practices of supplier’s operations</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td><strong>Operations and Logistics Integration (OLI)</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sub-Factors</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>OLI1 Lean and green operations</td>
<td>Kleindorfer et al., 2005; Hajmohammed et al., 2012; Vachon, 2007; Wee &amp; Quazi, 2005; Min and Galle, 2001; Carter and Easton, 2011; Zsidisin and Hendrick, 1998</td>
</tr>
<tr>
<td>2</td>
<td>OLI2 Process redesign to reduce use of scarce or toxic resources and energy consumption</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>OLI3 Community/environmental, employee health and safety concerns</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>OLI4 Internal process integration and production automation</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td><strong>Internal Environmental Management (IEM)</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sub-Factors</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>IEM1 Total quality environment management</td>
<td>Vachon and Klassen, 2008; Min and Gall, 2001; Azevedo et al., 2012; Simpson et al., 2007; Vachon and Klassen, 2006a; Baram and Partan, 1990</td>
</tr>
<tr>
<td>2</td>
<td>IEM2 Environmental compliance monitoring and auditing</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>IEM3 Pollution prevention plans</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>IEM4 Environmental manager and training for employees</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>IEM5 Environmental standards/ISO14001 certification by suppliers</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>IEM6 Employee incentive programs for environmental suggestions</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td><strong>Eco-Innovation practices(ECO)</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sub-Factors</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>ECO1 Substituting toxic inputs with environmentally friendly ones</td>
<td>Carter and Easton, 2011; Vachon, 2012; Azevedo et al., 2012; Paulraj, 2009; Rao &amp; Holt, 2005</td>
</tr>
<tr>
<td>2</td>
<td>ECO2 Use of fewer inputs to minimize the environmental risks and impacts</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>ECO3 Switching from &quot;dirty&quot; to cleaner technologies</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>ECO4 Internal recycling of inputs, materials and wastes</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td><strong>End-of-Life practices (EOL)</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sub-Factors</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>EOL1 Resale of used parts or components</td>
<td>Stock, 2001; Sarkis, 2003; Rogers and Tibben-Lembke, 2001; Bell et al., 2013</td>
</tr>
<tr>
<td>2</td>
<td>EOL2 Recondition and refurbishing of used parts or components</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>EOL3 Old/obsolete items being replaced</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>EOL4 Cyanide and arsenic solution recovery and carbon regeneration</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>EOL5 Mining of Tailings</td>
<td></td>
</tr>
</tbody>
</table>

Source: Kusi-Sarpong et al, 2015

**Table 3** The General Linguistic Scales used in the Fuzzy-DEMATEL analysis

<table>
<thead>
<tr>
<th>Linguistic Terms</th>
<th>Triangular Fuzzy Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Influence (N)</td>
<td>(0,0,0.25)</td>
</tr>
<tr>
<td>Very Low Influence (VL)</td>
<td>(0,0.25,0.50)</td>
</tr>
<tr>
<td>Low Influence (L)</td>
<td>(0.25,0.50,0.75)</td>
</tr>
<tr>
<td>High Influence (H)</td>
<td>(0.50,0.75,1.00)</td>
</tr>
<tr>
<td>Very High Influence (VH)</td>
<td>(0.75,1.00,1.00)</td>
</tr>
</tbody>
</table>
### Table 4 Initial direct-relation linguistic matrix $\mathbf{U}$ of major factors from Manager1

<table>
<thead>
<tr>
<th>Major factors</th>
<th>GITS</th>
<th>SSP</th>
<th>OLI</th>
<th>IEM</th>
<th>ECO</th>
<th>EOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>GITS</td>
<td>0</td>
<td>L</td>
<td>N</td>
<td>VL</td>
<td>VL</td>
<td>N</td>
</tr>
<tr>
<td>SSP</td>
<td>H</td>
<td>0</td>
<td>H</td>
<td>L</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>OLI</td>
<td>VL</td>
<td>L</td>
<td>0</td>
<td>VL</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>IEM</td>
<td>VL</td>
<td>L</td>
<td>N</td>
<td>0</td>
<td>L</td>
<td>N</td>
</tr>
<tr>
<td>ECO</td>
<td>N</td>
<td>L</td>
<td>L</td>
<td>H</td>
<td>0</td>
<td>H</td>
</tr>
<tr>
<td>EOL</td>
<td>L</td>
<td>H</td>
<td>L</td>
<td>H</td>
<td>H</td>
<td>0</td>
</tr>
</tbody>
</table>

### Table 5 Initial direct-relation matrix $\mathbf{A}$ of major factors with triangular fuzzy numbers

<table>
<thead>
<tr>
<th>Major factors</th>
<th>GITS</th>
<th>SSP</th>
<th>OLI</th>
<th>IEM</th>
<th>ECO</th>
<th>EOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>GITS</td>
<td>0</td>
<td>(0.25, 0.50, 0.75)</td>
<td>(0,0,0.25)</td>
<td>(0,0.25,0.50)</td>
<td>(0,0.25,0.50)</td>
<td>(0,0,0.25)</td>
</tr>
<tr>
<td>SSP</td>
<td>(0.50,0.75,1.00)</td>
<td>0</td>
<td>(0.50,0.75,1.00)</td>
<td>(0.25, 0.50, 0.75)</td>
<td>(0.50,0.75,1.00)</td>
<td>(0.50,0.75,1.00)</td>
</tr>
<tr>
<td>OLI</td>
<td>(0,0.25,0.50)</td>
<td>(0.25, 0.50, 0.75)</td>
<td>0</td>
<td>(0,0.25,0.50)</td>
<td>(0.25, 0.50, 0.75)</td>
<td>(0.25, 0.50, 0.75)</td>
</tr>
<tr>
<td>IEM</td>
<td>(0,0.25,0.50)</td>
<td>(0.25, 0.50, 0.75)</td>
<td>(0,0.25)</td>
<td>0</td>
<td>(0.25, 0.50, 0.75)</td>
<td>(0,0,0.25)</td>
</tr>
<tr>
<td>ECO</td>
<td>(0,0,0.25)</td>
<td>(0.25, 0.50, 0.75)</td>
<td>(0.25, 0.50, 0.75)</td>
<td>(0.50,0.75,1.00)</td>
<td>0</td>
<td>(0.50,0.75,1.00)</td>
</tr>
<tr>
<td>EOL</td>
<td>(0.25, 0.50, 0.75)</td>
<td>(0.50,0.75,1.00)</td>
<td>(0.25, 0.50, 0.75)</td>
<td>(0.50,0.75,1.00)</td>
<td>(0.50,0.75,1.00)</td>
<td>0</td>
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</tbody>
</table>

### Table 6 Initial direct-relation matrix $\mathbf{Z}$ of major factors after defuzzification for Manager1

<table>
<thead>
<tr>
<th>Major factors</th>
<th>GITS</th>
<th>SSP</th>
<th>OLI</th>
<th>IEM</th>
<th>ECO</th>
<th>EOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>GITS</td>
<td>0.000</td>
<td>0.500</td>
<td>0.033</td>
<td>0.267</td>
<td>0.267</td>
<td>0.033</td>
</tr>
<tr>
<td>SSP</td>
<td>0.733</td>
<td>0.000</td>
<td>0.733</td>
<td>0.500</td>
<td>0.733</td>
<td>0.733</td>
</tr>
<tr>
<td>OLI</td>
<td>0.267</td>
<td>0.500</td>
<td>0.000</td>
<td>0.267</td>
<td>0.500</td>
<td>0.500</td>
</tr>
<tr>
<td>IEM</td>
<td>0.267</td>
<td>0.500</td>
<td>0.033</td>
<td>0.000</td>
<td>0.500</td>
<td>0.033</td>
</tr>
<tr>
<td>ECO</td>
<td>0.033</td>
<td>0.500</td>
<td>0.500</td>
<td>0.733</td>
<td>0.000</td>
<td>0.733</td>
</tr>
<tr>
<td>EOL</td>
<td>0.500</td>
<td>0.733</td>
<td>0.500</td>
<td>0.733</td>
<td>0.733</td>
<td>0.000</td>
</tr>
</tbody>
</table>

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Table 7 The generalized direct-relation matrix $P$ for major factors across All Managers

<table>
<thead>
<tr>
<th>Major factors</th>
<th>GITS</th>
<th>SSP</th>
<th>OLI</th>
<th>IEM</th>
<th>ECO</th>
<th>EOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>GITS</td>
<td>0.000</td>
<td>0.191</td>
<td>0.152</td>
<td>0.163</td>
<td>0.152</td>
<td>0.102</td>
</tr>
<tr>
<td>SSP</td>
<td>0.211</td>
<td>0.000</td>
<td>0.202</td>
<td>0.182</td>
<td>0.202</td>
<td>0.202</td>
</tr>
<tr>
<td>OLI</td>
<td>0.172</td>
<td>0.192</td>
<td>0.000</td>
<td>0.132</td>
<td>0.142</td>
<td>0.182</td>
</tr>
<tr>
<td>IEM</td>
<td>0.162</td>
<td>0.142</td>
<td>0.101</td>
<td>0.000</td>
<td>0.182</td>
<td>0.162</td>
</tr>
<tr>
<td>ECO</td>
<td>0.152</td>
<td>0.132</td>
<td>0.142</td>
<td>0.222</td>
<td>0.000</td>
<td>0.192</td>
</tr>
<tr>
<td>EOL</td>
<td>0.112</td>
<td>0.192</td>
<td>0.152</td>
<td>0.231</td>
<td>0.212</td>
<td>0.000</td>
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</tbody>
</table>

Table 8 The total-relation matrix $T$ and prominence and net cause/effect for major factors across all managers

<table>
<thead>
<tr>
<th>Major factors</th>
<th>GITS</th>
<th>SSP</th>
<th>OLI</th>
<th>IEM</th>
<th>ECO</th>
<th>EOL</th>
<th>R</th>
<th>Prominence</th>
<th>Net Cause/effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C+R</td>
<td>C-R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GITS</td>
<td>0.692</td>
<td>0.876</td>
<td>0.776</td>
<td>0.919</td>
<td>0.884</td>
<td>0.809</td>
<td>5.214</td>
<td>10.170</td>
<td>-0.258</td>
</tr>
<tr>
<td>SSP</td>
<td>1.044</td>
<td>0.903</td>
<td>0.980</td>
<td>1.139</td>
<td>1.117</td>
<td>1.069</td>
<td>5.411</td>
<td>11.663</td>
<td>0.842</td>
</tr>
<tr>
<td>OLI</td>
<td>0.887</td>
<td>0.931</td>
<td>0.692</td>
<td>0.955</td>
<td>0.933</td>
<td>0.920</td>
<td>4.864</td>
<td>10.182</td>
<td>0.453</td>
</tr>
<tr>
<td>IEM</td>
<td>0.817</td>
<td>0.828</td>
<td>0.727</td>
<td>0.772</td>
<td>0.897</td>
<td>0.842</td>
<td>5.909</td>
<td>10.792</td>
<td>-1.026</td>
</tr>
<tr>
<td>ECO</td>
<td>0.875</td>
<td>0.889</td>
<td>0.817</td>
<td>1.029</td>
<td>0.815</td>
<td>0.933</td>
<td>5.692</td>
<td>11.050</td>
<td>-0.335</td>
</tr>
<tr>
<td>EOL</td>
<td>0.899</td>
<td>0.984</td>
<td>0.873</td>
<td>1.094</td>
<td>1.047</td>
<td>0.827</td>
<td>5.399</td>
<td>11.123</td>
<td>0.324</td>
</tr>
<tr>
<td>C</td>
<td>4.956</td>
<td>6.252</td>
<td>5.318</td>
<td>4.883</td>
<td>5.358</td>
<td>5.724</td>
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</tbody>
</table>

Table 9 Matrix $T_β$ with established relations above threshold value from the total-relation matrix $T$

<table>
<thead>
<tr>
<th>Major factors</th>
<th>GITS</th>
<th>SSP</th>
<th>OLI</th>
<th>IEM</th>
<th>ECO</th>
<th>EOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>GITS</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.919**</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>SSP</td>
<td>1.044**</td>
<td>0.000</td>
<td>0.980**</td>
<td>1.139**</td>
<td>1.117**</td>
<td>1.069**</td>
</tr>
<tr>
<td>OLI</td>
<td>0.000</td>
<td>0.931**</td>
<td>0.000</td>
<td>0.955**</td>
<td>0.933**</td>
<td>0.920**</td>
</tr>
<tr>
<td>IEM</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>ECO</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>1.029**</td>
<td>0.000</td>
<td>0.933**</td>
</tr>
<tr>
<td>EOL</td>
<td>0.000</td>
<td>0.984**</td>
<td>0.000</td>
<td>1.094**</td>
<td>1.047**</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Threshold $V_{value}=0.903$

**Values above the threshold value
### Table 10 General Linguistic Scale use for the ANP Analysis

<table>
<thead>
<tr>
<th>Linguistic Terms</th>
<th>Numerical-Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely More Important (EM)</td>
<td>9</td>
</tr>
<tr>
<td>Very Much More Important (VM)</td>
<td>7</td>
</tr>
<tr>
<td>More Important (M)</td>
<td>5</td>
</tr>
<tr>
<td>Moderately More Important (MM)</td>
<td>3</td>
</tr>
<tr>
<td>Same important (S)</td>
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</tr>
<tr>
<td>Moderately Less Important (ML)</td>
<td>1/3</td>
</tr>
<tr>
<td>Less Important (L)</td>
<td>1/5</td>
</tr>
<tr>
<td>Very Much Less Important (VL)</td>
<td>1/7</td>
</tr>
<tr>
<td>Extremely Less Important (EL)</td>
<td>1/9</td>
</tr>
</tbody>
</table>

### Table 11 Limiting super-matrix with stable weights for manager 1

<table>
<thead>
<tr>
<th>Major</th>
<th>ECO</th>
<th>EOL</th>
<th>GITS</th>
<th>IEM</th>
<th>OLI</th>
<th>SSP</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.176972</td>
<td>0.176972</td>
<td>0.176972</td>
<td>0.176972</td>
<td>0.176972</td>
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<tr>
<td>EOL</td>
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<td>0.257419</td>
<td>0.257419</td>
<td>0.257419</td>
<td>0.257419</td>
<td>0.257419</td>
</tr>
<tr>
<td>GITS</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<tr>
<td>IEM</td>
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<td>0</td>
</tr>
<tr>
<td>OLI</td>
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<td>0.243619</td>
<td>0.243619</td>
<td>0.243619</td>
<td>0.243619</td>
<td>0.243619</td>
</tr>
<tr>
<td>SSP</td>
<td>0.32199</td>
<td>0.32199</td>
<td>0.32199</td>
<td>0.32199</td>
<td>0.32199</td>
<td>0.32199</td>
</tr>
</tbody>
</table>

### Table 12 Group aggregated (mean) weights for major factors cluster interdependencies

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<tr>
<th>Factors</th>
<th>Mgr1 Wght</th>
<th>Mgr2 Wght</th>
<th>Mgr3 Wght</th>
<th>Mgr4 Wght</th>
<th>Mgr5 Wght</th>
<th>Mgr6 Wght</th>
<th>Mgr7 Wght</th>
<th>Mgr8 Wght</th>
<th>Mgr9 Wght</th>
<th>Mgr10 Wght</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>GITS</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>SSP</td>
<td>0.322</td>
<td>0.404</td>
<td>0.389</td>
<td>0.389</td>
<td>0.413</td>
<td>0.372</td>
<td>0.418</td>
<td>0.403</td>
<td>0.278</td>
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<td>Local Weights- Env Dim on Goal</td>
<td>Local Weights- Social Dim on Goal</td>
<td>Dimensions</td>
<td>Local Weights - Major factors on Econ Dim</td>
<td>Local Weights - Major factors on Envir. Dim</td>
<td>Local Weights - Major factors on Social Dim</td>
<td>local Stable - Major Practices</td>
<td>local Stable - Sub-factors on Major Practices</td>
<td>local Stable - Sub-factors</td>
<td>Final Global Weights - Overall Sustainability Multiplicativ e</td>
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<td></td>
<td>SSP</td>
<td>0.2462 0.1854 0.2003 0.3784</td>
<td>SSP1 0.3492 0.3175 0.00322</td>
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<td>Sustainability</td>
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<td></td>
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Table 13 General Aggregation Desirability Index Table
Table 14 Respective GSCM sub-factors rankings from the three desirability and ranking models

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<tr>
<th>Technique</th>
<th>Ranks</th>
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<td>SSP2</td>
<td>SSP4</td>
<td>OLI4</td>
<td>EOL1</td>
<td>SSP3</td>
<td>ECO1</td>
<td>SSP5</td>
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<tr>
<td>AW</td>
<td>OLI1</td>
<td>SSP1</td>
<td>OLI2</td>
<td>ECO1</td>
<td>OLI4</td>
<td>SSP4</td>
<td>SSP2</td>
<td>EOL1</td>
<td>SSP3</td>
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<tr>
<td>MEW</td>
<td>OLI1</td>
<td>SSP1</td>
<td>OLI2</td>
<td>ECO1</td>
<td>OLI4</td>
<td>SSP4</td>
<td>SSP2</td>
<td>EOL1</td>
<td>SSP3</td>
<td>GITS2</td>
<td></td>
</tr>
</tbody>
</table>

MW: Multiplicative Weighting Model; AW: Additive Weighting Model; MEW: Multiplicative Exponential Weighting Model

Figure 1 Decision Structure for GSCM Implementation

Figure 2 Network Relationship Map (NRM)/Diagraphs of the GSCM Major practices
Table 2: Characteristics of the sixteen mining industry managers and their companies involved in the study

<table>
<thead>
<tr>
<th>Manager &amp; Company</th>
<th>Manager 4 &amp; Company 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manager 1 &amp; Company 1</strong></td>
<td><strong>Manager 4 &amp; Company 4</strong></td>
</tr>
<tr>
<td><strong>Position:</strong> Supply Manager</td>
<td><strong>Position:</strong> Assistant Supply Chain Manager</td>
</tr>
<tr>
<td><strong>Role:</strong> Management of sourcing/procurement, contract &amp; warehouse</td>
<td><strong>Role:</strong> Management of sourcing/procurement, contract &amp; warehouse</td>
</tr>
<tr>
<td><strong>Number of Mining Working Years:</strong> 19 years</td>
<td><strong>Number of Mining Working Years:</strong> 10 years</td>
</tr>
<tr>
<td><strong>Manager 2 &amp; Company 3</strong></td>
<td><strong>Manager 5 &amp; Company 5</strong></td>
</tr>
<tr>
<td><strong>Position:</strong> Local Supplier &amp; Contractor Development Reg. Manager</td>
<td><strong>Position:</strong> Commercial Business Optimization Assistant Manager</td>
</tr>
<tr>
<td><strong>Role:</strong> Develops &amp; monitors local suppliers and contractors capacity</td>
<td><strong>Role:</strong> Commercial (supply, account &amp; admin) business improvement</td>
</tr>
<tr>
<td><strong>Number of Mining Working Years:</strong> 15 years</td>
<td><strong>Number of Mining Working Years:</strong> 11 years</td>
</tr>
<tr>
<td><strong>Manager 3 &amp; Company 2</strong></td>
<td><strong>Manager 6 &amp; Company 6</strong></td>
</tr>
<tr>
<td><strong>Position:</strong> Environmental Manager</td>
<td><strong>Position:</strong> Senior Procurement Manager</td>
</tr>
<tr>
<td><strong>Role:</strong> Env’tal program implementations and compliance monitoring</td>
<td><strong>Role:</strong> Procurement &amp; contract program implementation &amp; training</td>
</tr>
<tr>
<td><strong>Number of Mining Working Years:</strong> 22 years</td>
<td><strong>Number of Mining Working Years:</strong> 14 years</td>
</tr>
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</table>

The ten (10) mining industry managers involved in the ANP method

<table>
<thead>
<tr>
<th>Manager &amp; Company</th>
<th>Manager 6 &amp; Company 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manager 1 &amp; Company 1</strong></td>
<td><strong>Manager 6 &amp; Company 4</strong></td>
</tr>
<tr>
<td><strong>Position:</strong> Supply Manager</td>
<td><strong>Position:</strong> Assistant Supply Chain Manager</td>
</tr>
<tr>
<td><strong>Role:</strong> Management of sourcing/procurement, contract &amp; warehouse</td>
<td><strong>Role:</strong> Management of sourcing/procurement, contract &amp; warehouse</td>
</tr>
<tr>
<td><strong>Number of Mining Working Years:</strong> 19 Years</td>
<td><strong>Number of Mining Working Years:</strong> 10 years</td>
</tr>
<tr>
<td><strong>Manager 2 &amp; Company 1</strong></td>
<td><strong>Manager 7 &amp; Company 5</strong></td>
</tr>
<tr>
<td><strong>Position:</strong> Finance Manager</td>
<td><strong>Position:</strong> Commercial Business Optimization Assistant Manager</td>
</tr>
<tr>
<td><strong>Role:</strong> Management of the company’s financial account and budgetary</td>
<td><strong>Role:</strong> Commercial (supply, account &amp; admin) business improvement</td>
</tr>
<tr>
<td><strong>Number of Mining Working Years:</strong> 10 Years</td>
<td><strong>Number of Mining Working Years:</strong> 11 years</td>
</tr>
<tr>
<td><strong>Manager 3 &amp; Company 2</strong></td>
<td><strong>Manager 8 &amp; Company 5</strong></td>
</tr>
<tr>
<td><strong>Position:</strong> West Africa Regional Contract Manager</td>
<td><strong>Position:</strong> Head of Information Communications &amp; Technology-ICT</td>
</tr>
<tr>
<td><strong>Role:</strong> General management of contracts across the West Africa region</td>
<td><strong>Role:</strong> ICT program implementation, monitoring &amp; improvement</td>
</tr>
<tr>
<td><strong>Number of Mining Working Years:</strong> 13 years</td>
<td><strong>Number of Mining Working Years:</strong> 13 years</td>
</tr>
<tr>
<td><strong>Manager 4 &amp; Company 3</strong></td>
<td><strong>Manager 9 &amp; Company 6</strong></td>
</tr>
<tr>
<td><strong>Position:</strong> Parts and Warehouse Manager</td>
<td><strong>Position:</strong> Senior Procurement Manager</td>
</tr>
<tr>
<td><strong>Role:</strong> Management of sourcing/procurement, contract &amp; warehouse</td>
<td><strong>Role:</strong> Procurement &amp; contract program implementation &amp; training</td>
</tr>
<tr>
<td><strong>Number of Mining Working Years:</strong> 15 years</td>
<td><strong>Number of Mining Working Years:</strong> 14 years</td>
</tr>
<tr>
<td><strong>Manager 5 &amp; Company 4</strong></td>
<td><strong>Manager 10 &amp; Company 6</strong></td>
</tr>
<tr>
<td><strong>Position:</strong> Senior Maintenance Planning Engineer</td>
<td><strong>Position:</strong> Assistant Environmental Manager</td>
</tr>
<tr>
<td><strong>Role:</strong> Planning of maintenance and materials for maintenance activities</td>
<td><strong>Role:</strong> Env’tal program implementations, monitoring and improvement</td>
</tr>
<tr>
<td><strong>Number of Mining Working Years:</strong> 10 years</td>
<td><strong>Number of Mining Working Years:</strong> 10 years</td>
</tr>
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</table>

The six (6) purposively sampled mining companies interested in greening their operations

<table>
<thead>
<tr>
<th>Company 1</th>
<th>Company 4</th>
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<tbody>
<tr>
<td><strong>Size:</strong> 2.1 million ounces per year with workforce size of 246</td>
<td><strong>Size:</strong> 2.2 million ounces per year with workforce size of 700</td>
</tr>
<tr>
<td><strong>Age:</strong> 4 years +</td>
<td><strong>Age:</strong> 4 years</td>
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<tr>
<td><strong>Type of Minerals:</strong> Gold</td>
<td><strong>Type of Minerals:</strong> Gold</td>
</tr>
<tr>
<td><strong>Stock listings:</strong> TSX(EDV), ASX(EVR) &amp; OTCQX(EDVMF)</td>
<td><strong>Stock listings:</strong> ASX/TSX (PRU)</td>
</tr>
<tr>
<td><strong>Company 2</strong></td>
<td><strong>Company 5</strong></td>
</tr>
<tr>
<td><strong>Size:</strong> 13.3 million tonnes per year with workforce size of 3,500</td>
<td><strong>Size:</strong> 3.5 million tonnes per year with workforce size of 1670</td>
</tr>
<tr>
<td><strong>Age:</strong> 21 years</td>
<td><strong>Age:</strong> 11 years</td>
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<tr>
<td><strong>Type of Minerals:</strong> Gold</td>
<td><strong>Type of Minerals:</strong> Gold</td>
</tr>
<tr>
<td><strong>Stock listings:</strong> JSE Ltd, NYSE, NASDAO DUBAI, NYX &amp; SWX</td>
<td><strong>Stock listings:</strong> TSE/NYSE</td>
</tr>
<tr>
<td><strong>Company 3</strong></td>
<td><strong>Company 6</strong></td>
</tr>
<tr>
<td><strong>Size:</strong> 7.5 million tonnes ounces yearly with workforce size of 8539</td>
<td><strong>Size:</strong> 2.7 million tonnes per year with workforce size of 700</td>
</tr>
<tr>
<td><strong>Age:</strong> 9 years</td>
<td><strong>Age:</strong> 15 years</td>
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<tr>
<td>Type of Minerals</td>
<td>Stock listings</td>
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<tr>
<td>Gold</td>
<td>NYSE (NEM)</td>
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<tr>
<td>Gold</td>
<td>Stock listings: TSX (GSC), NYSE (GSS), &amp; GSE (GSR)</td>
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