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Sustainable Supply Chain Management Practices in Ghana's Mining Industry

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ABSTRACT

The mining industry is very important to the economy of many developing countries, and offers an important source of revenue. Yet, in order to yield benefits on a long term, sustainable management practices are needed. This paper outlines and introduces a comprehensive framework for sustainable supply chain management implementation in the mining industry in Ghana. It evaluates, through a comparative analysis involving a sample of companies, environmentally sustainable supply chain management practices. The theoretical framework focuses on six major constructs. These constructs include Green Information Technology and Systems, Strategic Supplier Partnership, Operations and Logistics Integration, Internal Environmental Management, Eco-innovative Practices and End-of-life Practices. Using a field study approach the identified factors are subjected to an initial review by experts in Ghana to arrive at a preliminary framework. The framework is evaluated using gold mining industry managers in Ghana. Two multi-attribute evaluation approaches DEMATEL and AHP models help to identify and contrast the importance of the factors and attributes to the overall goal. One of the findings is that the framework for sustainable supply chain management practices in the mining industry is acceptable and comprehensive according to industry experts. The multiattribute evaluation tools used in this paper found that Strategic Supplier Partnership (SSP) and End-of-life (EOL) Practices are the two most prominent and influential major/strategic factors whereas Lean and Green Operations (OLI1), Substituting toxic inputs with environmentally friendly ones (ECO1) and Resale of used parts or components (EOL1) are the three most critical and prominent operational/sub-factors among the topmost ranked operational/sub-factors. This study and resulting framework allows practicing managers in the mining industry in Ghana and elsewhere in the developing world to make thoughtful decisions for making their supply chains more environmentally sustainable.

Keywords: Corporate-Social Responsibility (CSR), Sustainable Supply Chain Management (SSCM), Multi-Criteria Decision-making (MCDM) tools, Decision-Making Trial and Evaluation Laboratory (DEMATEL), Analytic Hierarchy Process (AHP), Mining Industry, Ghana

1. Introduction

Mining operations are an important sector of the economy in many developing nations. The mining supply chain operations and activities contribute to numerous socio-environmental concerns in addition to economic repercussions (Poulton *et al.*, 2013). As a result, mining operations have faced significant criticism, pressures, and questioning. All these elements have questioned the legitimacy of the industry from diverse actors including the local communities, government, NGOs and the general public. Within this context, there is a clear need for enhancing social-environmental performance and greening of supply chains (Hall, 2000).

In response to these contextual issues, mining companies have started focusing on internal organizational operational and social-environment practices. These internal practices are limited when attempting to meet these pressures. Many leading organizations in the mining industry have realized the limitations of only focusing on internal practices and sought to expand their responsibility to extended producers that will influence the mines' supply chain socio-environmental effects (Lenzen *et al.*, 2007). Mining companies have thus included their suppliers, who then must share both risk and responsibility (Dey and Cheffi, 2013).

The objective of this paper is to develop and introduce some generic sustainable supply chain implementation factors and practices within the mining industry. The factors are determined and supported using the research literature. The factors are further evaluated with input from industrial leaders and companies in Ghana using two multi-attribute evaluation approaches - DEMATEL and analytical hierarchy process (AHP) techniques.

The major contribution of this paper is as an exploratory study to help comprehend the level of importance and contributions of various environmentally sustainable supply chain practices. The robustness of these findings is methodologically evaluated using two different methodologies. Each of these methodologies provides different conceptual and practical insights. The other major contribution of this work is to evaluate green supply chain practices in one of the more environmentally and socially sensitive regions of the world, equatorial, sub-Saharan Africa. This region and its mining industry are understudied with respect to either or both environmental and social sustainability and the supply chain.

In achieving the goals, some background on sustainable supply chain management in general and in the mining industry is first presented. A review is conducted on various sustainable supply chain practices to set the theoretical foundation for a generic practices analytical framework. This framework is then followed with an introduction to the two multi-attribute evaluation tools, DEMATEL and AHP, which are used to evaluate the factors. Using information from experts, a comparative analysis is completed using Ghana mining companies' inputs. Finally some of the major issues with respect to managerial and research implication are provided in addition to research directions. The overall development of factors, and multiple case comparative study illustration of the two adopted tools, sets the foundation for further research in the area of corporate sustainable supply chain management in the mining industry.

2. Background of the study

Similarly to what is the case in many developing nations, mining has been in existence in Ghana for many decades (Hilson, 2002). Much foreign investment and aid has been invested in this sector (Wamboye *et al.*, 2014). The industry although supported by communities for economic reasons (Bloch and Owusu, 2012), it has been generally perceived as a socio-environmentally disruptive industry (Peck and Sinding, 2003). In response to this negative image and reputation, various attempts have been made by the mining industry to improve its socio-environmental performance. To improve sustainability, the mining industry has sought and should attempt to go beyond its organizational boundaries in an effort to make their supply chain activities and designs more environmentally and socially sound. These efforts including more effective management of depleting natural mineral resources and minimizing environmental footprints (Muduli *et al.*, 2012) over the life cycle of a mine from mineral exploration to mine closure (Hilson and Murck, 2000).

Even with these attempts at making mining more sustainable, decision tools that support sustainable mining operations and development which incorporate mining industry sustainability and sustainable supply chain efforts are unavailable. There are many sustainable supply chain practices available to organizations for implementation. Choosing which programs and practices to implement and making sense of the influences on these practices, which is important to practicing managers in the mining industry, has not been completed in practice or in study.

To set the stage for starting to address this issue, a literature review of potentially important sustainable supply chain practices, with a primary focus on environmental or greening issues, is provided in the next section. This literature review provides a characterization (framework) of the practices that sets the foundation for further methodological evaluation.

3. Literature Review

3.1 Sustainable Supply Chain Management Factors in the Mining Industry

Various literatures relating to sustainable supply chain management (SSCM) and its elements are introduced. SSCM performance in the mining industry has come under increasing scrutiny by local communities and the general public, in addition to other stakeholders such as supply chain partners. Even though, these mining companies have attempted to adopt some sustainable practices in their operations, the focus has been internal. Sustainable mining practices focusing on the supply chain may be an effective approach in response to stakeholder pressures. A possible barrier for improved sustainable performance in mining is the lack of understanding and existence of sustainable supply chain management practices within this industry.

To help further understanding and nourishing the knowledge of sustainable supply chain practices, an analytical framework covering six major constructs is first developed in this section with a focus on environmental sustainability in the supply chain. An initial literature review is presented and includes SSCM practices in the general context and SSCM practices in the mining industry context resulting in 6 major practices (constructs) and 37 sub-practices. These major 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. Since the focus is on the mining industry and Ghana, mining industrial experts, government officials and academicians within Ghana were consulted to help further evaluate, confirm and focus these practices. That methodology for refinement and development of the final factors is discussed in section 3.2.

The full listing of SSCM practices and sub-practices identified in the literature are now summarized.

3.1.1 Green Information Technology and Systems (GITS)

Information technology and systems (IT) have pervaded most business processes and supply chains, making IT an important focus of environmental footprints and sustainable practices (Molla *et al*., 2008; Dembo, 2008; Siegler and Gaughan, 2008; Erek *et al*., 2009; Sarkis *et al*, 2013). IT energy efficiencies can not only help to mitigate C02 emissions (Amin and Leal Filho, 2014), but also ought to be optimized to achieve better overall energy consumption of mines (Chilamkurti *et al*., 2009). Computers and monitors are considered responsible for the unnecessary creation of millions of tons of greenhouse gases every single year (Arnold, 2004). Yet, over the years, firms have neglected the inclusion of the IT function into environmental assessment programs (Huang, 2008; Siegler and Gaughan, 2008).

In the mining industry, nearly every employee and equipment uses IT, making it heavily reliant on IT for its operations. Since IT has a relatively shorter product life span (Jenkin *et al*., 2011), significant waste is created due to IT obsolescence. With the large amount of IT in use by these mining companies, there is always the need to store huge quantities of data. This data storage demand requires large data centers subsequently increasing overall energy consumption. Given these potentially serious environmental burdens, the use of Green IT by mining companies can reduce a mine's and its supply chain (energy producers and waste streams) ecological footprint. Adopting Green IT can improve energy consumption and efficiency of data centers (Uddin and Rahman, 2012) and hardware; minimize waste related to equipment obsolescence, use virtualization software to consolidate servers, and adopt collaborative group software and telepresence systems to conduct meetings remotely (Watson *et al*., 2008) are all part of Green IT initiatives.

3.1.2 Strategic Supplier Partnership (SSP)

Supply chain partnership is independent/separate supply chain partners coming together with common objectives to build long-term relationships to achieve collaborative advantage (Simatupang and Sridharan, 2005; Cao *et al*., 2010; Sheu *et al*., 2006). This initiative helps organizations to coordinate and integrate products and information flows across supply chains (Caridi *et al*., 2005; Lejeune and Yakova, 2005; Verwaal and Hesselmans, 2004; Cao *et al*., 2010). The involving parties plan and solve problem together, share environmental management techniques and knowledge, and develop/build environmental management solutions/programs to deal with materials use in mining processes (Rao, 2002; Simpson *et al*., 2007; Geffen and Rothenberg 2000). Strategic partnership is required to foster cross-organizational initiatives such as SSCM practices (Sarkis, 2006). Since mining companies happen to find themselves in a 'primary industry'[1], their finish products (precious ores) are still in the raw material stage. High demand for these products exists with considerable competition among customers. Thus, mining companies/industry are typically oriented to the upstream aspect of the partnership (Strategic supplier partnership(SSP)) (Vachon, 2007) giving

[1] Primary industries are involved with primary commodities by extracting natural resources or harvesting raw materials prior to processing.

relatively lessened focus on the downstream partnership, e.g. outbound logistics, since customers provide these services due to the nature of the market competition.

SSP enable mining companies to engage their key suppliers' from the supply chain planning stages to discussion imperative issues. Supply of sodium cyanide for example to the mines requires handling and transporting regulatory body's certification. Engaging such suppliers in early material planning discussions will help them clearly understand the handling and transporting requirements.

3.1.3 Operations and Logistics Integration (OLI)

Operations and logistics integration is production activities and logistics practices that help to coordinate materials flow throughout the mines value chain (Stock *et al.*, 2000). Mining industry logistics activities include procurement and transportation/expediting management, materials management and internal material delivery management. These activities require seamless integration to external partners using Enterprise Resources Planning (ERP) system for effective logistics management (Childerhouse and Towill, 2003; Stock *et al.*, 1998, 2000; Gustin, 2001; Narasimhan and Das, 2001). This further promote real-time information sharing which encourages lean production and green logistics activities (Murphy *et al.*, 2000; Rodrigue *et al.*, 2001; Vachon and Klassen, 2008; Carter and Easton, 2011). Also, company-wide asset reliability system can be adopted to improve core operational activities efficiencies while minimizing wastes and costs. Lack of integration depicts processes working at cross-purposes resulting in low economic and significant environmental burdens for the mining (Pagell, 2004).

3.1.4 Internal Environmental Management (IEM)

Systemic approach to addressing environmental issues in the mining industry requires some company-wide internal environmental management (IEM) practices (Buysse and Verbeke, 2003). These practices include continuous mining operational monitoring to verify compliance levels (Arts *et al.*, 2001; Morrow and Rondinelli, 2002), evaluate suppliers' environmental standards and influence

(Walton *et al.*, 1998; Theyel, 2000), Total Quality Environmental Management (TQEM) techniques to help suppliers reduce environmental pollution (Curkovic and Sroufe, 2007), employee reward and incentive systems to simulate participation and suggestions on possible environmental solutions (Daily *et al.*, 2001; Govindarajulu and Daily, 2004). To achieve this goal requires environmental experts (teams) to continuously train employees on best/important environmental management practices, since IEM success largely relay on employee awareness (Arts *et al.*, 2001). Also environmental pollution prevention plans and policies should be available to guide the trained employees in addressing environmental/safety concerns associated with the operations.

3.1.5 Eco-innovative Practices (ECO)

Eco-innovation practices are production and production process, product assimilation/exploitation, service/management/business methods that are novel to the organization and results in reducing environmental risk, pollution and other negative effect of resources use throughout their life cycle (Arundel and Kemp 2009, pg. 5). For example, to substitute high toxic reagents/chemicals with environmentally friendly-ones (Ren, 2003) such as 'ammoniacal thiosulfate'[2] to replace sodium cyanide (Rath *et al.*, 2003). Mining operations such as mineral processing produces by-products which through innovative approaches are converted into usable materials for reuse, which potentially reduces mining waste (Van Berkel, 2007). Mining operations requires the integration of cleaner production and extraction technologies (Hilson, 2000a, 2000b) to reduce pollution and legacy technologies efficiencies (Tsoulfas and Pappis, 2006; Van Berkel, 2007). Metallurgical plant redesign/modification can improve plant's mineral recovery, minimizing the amount of process waste generation (Carter and Easton, 2011) and potentially improving resources

[2] Ammoniacal thiosulphate is an environmentally friendly replacement to the high toxic sodium cyanide for gold and copper-gold concentrate and ore recovery in the mining industry.

use and material efficiency, minimize energy consumption, greenhouse gas emission and, toxic materials (Tsoulfas and Pappis, 2006).

3.1.6 End-of Life Practices (EOL)

It is practically impossible even for the most sustainable system to consume all it inputs or reuse all its wastes before leaving a facility, hence the need for end-of-life initiatives implementation (Sarkis and Cordeiro, 2001; Wang and Gaustad, 2012). Mining operations are involved basically with **Reverse Logistics (RL)**: components and parts and, **Recovery Activities (RA)**: chemical and re-mining of tailing of EOL practices.

RL in the mining industry encompasses logistics activities in managing warranted-components, components etc from the mines to the supplier/manufacturers for the purpose of recapturing value/proper disposal to minimize ecological effect (Rogers and Tibben-Lembke, 2001; Stock, 2001; Sarkis, 2003). Maintenance of mining machineries produces significant wastes which are held within the mines and may pose health, safety and environmental dangers to the employees. Value can be captured whilst proper disposal achieved by selling these old assets back to the suppliers/ manufactures or certified secondhand market dealers to avoid environmental issues (Atkinson, 2002). RA in the mining industry decreases direct mineral/mining operations pollutants including tailings, chemical/reagents solution and carbon recovery. For example, regeneration of activated carbon for reuse will reduce quantity purchase. The saturated solution in the tailings is required to be reused for mineral processing which reduces quantity of fresh chemical while the remaining tails are mine to recover the mineral concentration.

3.2 Refining the SSCM practices and sub-practices sets

The 37 sub-practices and 6 major practices with brief descriptions and explanations were initially submitted for review to two mining engineers with over 12 years Ghanaian mining working experience and two academicians with environmental management and supply chain management research. This initial review maintained the 6 major practices, but only 34 sub-practices remained after refinement.

These 6 major practices and 34 sub-practices were then sent to an additional four mining industrial experts with 10 years minimum Ghanaian mining working experience including: a supply manager (18 years), an environmental manager (10 years), a health, safety and environmental manager (22 years) and a mining manager (12 years). They were asked to share their opinion as to which GSCM practices are perceived as generally applicable to the mining industry based on a "Yes" or "No" categorization. They were further asked to make suggestions or additions to the list provided to them. No suggestions/additions were made. The responses received from these mining industrial experts were tabulated and based on a minimum of "3 Yes" threshold from the experts for a sub-practice to be included in the final listing. A final set of six (6) major practices and thirty (30) sub-practices emerged. Refer to Table 1 for the final listing.

[Insert Table 1 about here]

4.0 Methodological background

The SSCM analytical framework developed for this study serves as the foundation for evaluating the relative importance of these techniques to the mining industry. Two multi-criteria decision-making methodologies, DEMATEL and AHP, which will use expert opinion input, are used for the relative importance of practices determination. A brief overview of DEMATEL and AHP methodologies is now presented.

4.1 The DEMATEL Methodology

The Decision Making Trial and Evaluation Laboratory (DEMATEL) is a methodology capable of developing and analyzing a structural model to identify the relative importance/prominence of conflicting factors for ranking (Lin and Tzeng, 2009) and net effect of complex factors for grouping (Wu and Lee, 2007). Hsu *et al.*, (2013) provide details of the three major steps involved with the

DEMATEL methodology which this work has applied. The comparison is quantified using a 5-point (0-4) measurement scale (**See table 2**).

[Insert Table 2 about here]

4.2 The AHP Methodology

The Analytic Hierarchy Process (AHP) is a well-known multi-criteria decision making (MCDM) support tool and adopts a multi-level hierarchical categorization of factors and sub-factors to deal with complex decision-making problems (Saaty, 1986, 1998). Al-Harbi (2001) provides details of the first four major steps involved with the AHP methodology which this work has applied. Then, a fifth step uses Web-HIPRE3+ (Mustajoki & Hamalainen, 2000), an online-based multi-criteria decision- support software (http://hipre.aalto.fi/) to compute the relative weights of the factors and apply factors weights in the sixth step to build the desirability index table to identify the relative importance of sustainability practices. The comparison is quantified using a 9-point (1-9) measurement scale (**See Table 3**).

[Insert Table 3 about here]

5. Multiple Case Comparative Evaluations using DEMATEL and AHP Methodologies

5.1 Data collection and analysis

This study adopted a real world multiple field study approach involving twelve mining industrial experts (see Table 4 for the characteristics of experts) selected using a purposive sampling approach with two from each of the six selected multi-national mining companies (see Table 5 for some brief information of these companies) operating in Ghana with the focus of greening their supply chains.

[Insert Table 4 about here]

[Insert Table 5 about here]

The DEMATEL and AHP methodologies are used to identify and contrast the important sustainable factors and attributes to the overall goal during sustainable mining implementation program with specific emphasis on green supply management practices.

We then utilized two non-parametric multivariate tests, the Kendall tau-b test and the Wilcoxon signed rank test, to determine if significant dissimilarities or similarities in the ranking of practices and sub-practices using the two different techniques.

The two methodologies were applied as follows:

5.1.1 The DEMATEL methodology application

The DEMATEL methodology for sustainable supply chain management is used to identify the degree of importance of the sustainable factors and attributes for six mining industrial experts from six mining companies in Ghana.

Applying DEMATEL to the SSCM factors result in overall importance/prominence $\boldsymbol{P_i}$ and net effect $\boldsymbol{E_i}$ valuations. However, for this study, only the overall importance/prominence $\boldsymbol{P_i}$ weights of the factors in rankings are used and thus shown in **Table 6:**

[Insert Table 6 about here]

5.1.2 The application of the AHP methodology

The AHP methodology is now applied using the sustainable supply chain framework on another set of six mining industrial experts from six mining companies to achieve the relative important weights of the factors. Then, the factors weights are applied in the sixth step to build a desirability index table to identify the relative importance of sustainability practices.

Applying steps 1-5 involved in the AHP technique to the SSCM major factors and SSCM sub-factors resulted in relative importance weights of the SSCM major factors and sub-factors as shown in **Table 7:**

[Insert Table 7 about here]

The relative importance weights achieved from the first three steps of the AHP method for the SSCM factors are used to build a desirability index table applying the fourth step and using equation (10) as shown in Table 8. The DEMATEL method importance/prominence $\boldsymbol{P_i}$ weights of the SSCM factor are also imported into Table 8 alongside the AHP results.

[Insert Table 8 about here]

The importance/prominence $\boldsymbol{P_i}$ weights of the DEMATEL method are the influence relationships among the factors and sub-factors whereas the relative importance weights of the AHP methodology is the influence relationships to an overall goal. Therefore, to compare and contrast the rankings of the relationships importance (DEMATEL) and the overall importance toward goals (AHP) for each factor/sub-factor requires normalizing the weights of the two methodologies. Since the output of the DEMATEL technique have the sum of it cluster weights $> \mathbf{1}$, we therefore normalize both the factors and sub-factors weights to achieve a cluster sum of **1**.

5.2 Discussions

The two multi-criteria evaluation tools adopted for the analysis of the sustainable supply chain framework in the mining industry revealed two different and interesting ranking patterns for both the major/strategic factors and the sub-factors/operational.

5.2.1 Major practices

The DEMATEL technique was applied to identify the strategic nature of the major practices in the SSCM implementation program of the mining industry. The final result is displayed in Table 8 column 3 and indicates that, 'Strategic Supplier Partnership (SSP)' has the highest major practice weight of 0.1804 whereas 'Green Information Technology and Systems (GITS)' has the lowest major practice weight of 0.1558. This result could be argued that, SSP is the most prominent and influential SSCM practice whereas GITS is the least considered/prominent major/strategic practice that can influence SSCM implementation program. The implication of this result to the mining industry is that, SSP requires the greatest/urgent managerial/strategic attention/direction to help achieve a desirable sustainability outcome.

The result further suggests that, mining industrial experts strongly support and emphasis the importance of strategic supplier partnership during SSCM implementation programs in the industry. This empirical results, evidently supports the fact that, successful cross-organizational implementation programs require inter-organizational partnerships. Mining companies may engage strategic suppliers' right from the program planning stages to discussion and deal with issues pertaining to materials requirement and their associated safety and environmental concerns. This will possibly strengthen the program capabilities and competencies, and bring about some innovative practices into the program.

This result is also significant showing that, organizations look at GSCM practices from a more strategic perspective, but much of this strategic perspective may be setting initial policies. If this interpretation is used, it shows that the practice and programs are still relatively immature based on the relative importance of focusing on this issue. Alternatively, the reason for this occurrence is that before any other program can be managed/implemented, strategic supplier partnership is critical to the implementation and adoption of other practices.

The AHP technique was also applied to identify the strategic nature of the major practices in the SSCM implementation program of the mining industry. The final result is shown in column 5 of Table 8 and on the other hand depicts that, 'Green Information Technology and Systems (GITS)' has the highest major practice weight of 0.3490 whereas 'Eco-Innovation (ECO) Practices' has the lowest major practice weight of 0.0848. This means that, GITS is the most promising and prominent GSCM practice that can benefit SSCM implementation programs in the mining industry. ECO practice is the least promising and considered major/strategic practice that influences SSCM implementation programs in the mining industry. The above analysis implication to the mining industry is that, GITS should be given the greatest managerial/strategic attention/direction to yield the desirable outcome. From a practical perspective, it may also be that GITS practices are more appropriate for the mining industry, which utilizes substantial information systems and tools, to help manage the sustainability of their supply chains. Eco-design practices may be less prominent and thus these practices are not as important for implementing/managing sustainable supply chain practices. Additionally, greenhouse gases emissions, e-waste generation, and energy consumption at the mines data centers from the use of IT systems are seriously huge and alarming, hence may be enough justification for placing much prominence on the GITS practices.

Comparing the first three highly ranked major/strategic factors from both techniques depicted that, SSP and EOL Practices were the two overlapping major/strategic practices that could be found across both techniques. These major practices are therefore considered the most prominent and influential major/strategic factors across the two techniques and among the six listed major/strategic factors in the mines SSCM implementation program. The outcome may sound right, since mining companies uses SSP initiatives to engage their key suppliers' right from the program planning stages to address issues related to materials need and associated safety and environmental concerns. Yet, no matter how close a system may be, it is practical impossible for the mining companies to consume all their inputs and reuse all their wastes, hence, the end-of-life initiatives are implemented to recapture value/promote proper disposal to minimize ecological effect and decrease direct mineral processing and mining pollutants.

5.2.2 Sub-practices and non-parametric multivariate ranking analyses

The DEMATEL technique was applied to identify the operational influence of the sub-practices on the SSCM implementation program in the mining industry. The results are shown in Table 8 column 9 and indicates that, 'Switching from "dirty" to cleaner technologies (ECO3)' has the highest sub-practice weight of 0.0435 whereas Employee incentive programs for environmental suggestions

(IEM6) has the lowest sub-practice weight of 0.0249, making ECO3 the most promising and prominent sub-practice amongst the thirty sub-practices. The AHP technique was further applied to identify the operational influence of the sub-practices on the SSCM implementation program in the mining industry. The results are depicted in Table 8 column 12 and on the other hand, depicted that, 'Use of energy efficient hardware and data centers (GITS1)' has the highest sub-practice weight of 0.1428 whereas 'Employee incentive programs for environmental suggestions (IEM6)' has the lowest sub-practice weight of 0.0063, making GITS1 the most promising and prominent sub-practice amongst the thirty sub-practices.

This may be the case since cleaner technologies from ECO3 and efficient energy systems from GITS1 is a way for companies to achieve win-win outcomes on both environmental/sustainability factors and economic factors. The incentive system may be viewed as less economically beneficial, as a cost center, and not offer the economic benefits of other programs.

To further determine significant overall differences that exist amongst the sub-factors ranking by the two multi-criteria decision making methodologies, two non-parametric multivariate ranking analyses were conducted. Using the Wilcoxon signed ranks test and the Kendall's tau-b rank test, no evidence of a significant relationship was found in the overall rankings.

The reason for this lack of relationship could be that the goals of the methodology were different. AHP focuses on the relative importance to some general objective (although the factors were compared to each other). DEMATEL does a more direct influence of the practices on each other. Thus, DEMATEL provides broader range of potential influences and influencers. This is a definite cause of the difference. If similarities existed in the rankings, it would more clearly identify the practices that should be pursued initially and which ones can be delayed. This result provides a situation where managers will be at odds over which practices to initiate and which ones to delay. Managerially, taking an average might be appropriate, but the ultimate goals and the feasibility of programs may be additional directions to consider when seeking to implement or adopt certain sustainable supply chain practices.

What these results do show overall is the relative flux and uncertainties involved in the mining industry when it comes to environmentally sustainable supply chain practices. Managers and policy makers, who can encourage adoption of certain practices, may focus on those practices with high rankings. Amongst the thirty sub-practices, the ones that seem most promising using both techniques are Lean and green operations (OLI1), Substituting toxic inputs with environmentally friendly-ones (ECO1) and Resale of used parts or components (EOL1). These three sub-practices are ones that seem most promising from influencing overall sustainable supply chain management success and influence on other sub-practices. Interestingly they are sub-practices that are derived from very different practices. No one practice seemed to dominate the top possibilities. A risk reduction practice, ECO 1, "Substituting toxic inputs with environmentally friendly ones" may be the most influential of specific sub-practices. Economic, technical and operational feasibility of this specific sub-practice should be determined and the sub-practices pursued since it has significant support across managers and companies. A similar analysis can be completed for each initiative. Delaying some initiatives that are less important or influential may also be wise. Given limited resources the organizations and policymakers now have some means to assess, overall, which practices to pursue. Our initial results provide some direction for development and implementation consideration.

6. Concluding remarks and managerial implications

Mining operations face serious environmental issues throughout the supply chain. However, several attempts to address these issues have only seen internally focused solutions. To manage this situation and achieve corporate sustainable operations and development, socially sound practices and environmental thinking should be integrated into mining supply chain design. Also, understanding the influences of the various sustainable supply chain practices on the mining industry socio-environmental impact seriously require investigation and evaluation.

This paper introduced, prioritized and compared and contrasted the solutions/practices of sustainable mining operations adoption into mining supply chains for implementation program using DEMATEL and AHP tools. These solutions will help mining companies/industry policymakers to get focused on only the highly/topmost ranked solutions/practices and build their implementation strategies base on their priorities/prominent on the overall objective. The comparative analysis conducted with these evaluation tools revealed very interesting practical implications and contributions. The outcome depicts that, using only a single evaluation tool to identify solutions for implementation programs will seriously be misleading owning to the fact that, different topmost ranking are depicted in the results of the two evaluations tools. One such major practical implication and contribution drawn from this outcome is that mining industry policymakers should not only focus on a single evaluation tool to identify and prioritize solutions for program implementations but rather requires a very thorough comparative analysis with diverse set of evaluation tools to achieve systemic and robust outcomes for feasibility studies and possible implementation. If either a single evaluation tool or multiple evaluation tools are to be selected for decision-making, the focus of the model or the comparative models should be considered seriously so they can produce more reliable and comparable results. Another contribution is the practicability of the compared models to decision-making, providing mining policymakers with practical and better understanding of the complete decision-making process. Finally, this study and resulting framework allows practicing managers in the mining industry and elsewhere in the developing world to make thoughtful decisions for making their supply chains more environmentally sustainable.

The research results presented here are exploratory by considering only one mining industry (gold mining) and only certain companies in one region (Ghana). These are clearly limitations in attempting to make generalizations of these findings. But, given the homogeneity of the respondents and industry, we can be pretty certain about particular activities and concerns associated with making a sustainable supply chain with Ghana's gold mining, and potentially general mining, industry.

These results also represent a single period of study. Over time this study can and should be replicated as the maturity of adoption of sustainable supply chain practices matures. The results, although representing two tools, may utilize other ranking approaches or integrate these two approaches. For example, given that DEMATEL shows interrelationships amongst factors, expanding the AHP technique to consider these networked interrelationships, using an Analytical Network Process (ANP) methodology, seems like a natural extension of this work. Alternatively, utilization of other ranking and multiple criteria tools (utility theory, outranking approaches, or data envelopment analysis) may also be used to identify characteristics and relative importance of factors.

Overall, methodologically and practically there are many directions to take this exploratory field research to address either limitations or expand the areas of study. Given the complexities and potential costs of sustainable supply chain management, especially within the mining industry prudent and effective tools and analysis of the adoption of these practices are necessary for their success.

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Table 1. SSCM practices (factors) and their sub-factors in the mining industry

Pos	SSCM Factors and Sub-factors		Literature
1	**Green Information Technology and Systems (GITS)**		
Sub-Factors	**GITS1**	Use of energy efficient hardware and data centers	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
	GITS2	Consolidating servers using virtualization software	
	GITS3	Reducing waste associated with obsolete equipment	
	GITS4	Collaborative group software and telepresence systems	
	GITS5	Eco-labeling of IT products	
2	**Strategic Suppliers Partnership (SSP)**		
Sub-Fact	**SSP1**	Jointly develop environmental management solutions	Vachon et al. 2001; Rao 2002; Geffen and Rothenberg 2000,
	SSP2	Jointly build programs to reduce or eliminate materials use	
	SSP3	Share environmental management techniques and knowledge	

	SSP4	Collaborate with suppliers to manage reverse flows of materials and packaging	Simpson and Power, 2005; Simpson et al., 2007
	SSP5	Communicate goals of sustainability to suppliers	
	SSP6	Monitor environmental compliance status and practices of supplier's operations	
3	**Operations and Logistics Integration (IOLI)**		
Sub-Factors	**OLI1**	Lean and green operations	Kleindorfer, 2005; Hajmohammed et al., 2012; Vachon, 2007; Wee & Quazi, 2005; Min and Galle, 2001; Carter and Easton, 2011; Zsidisin and Hendrick, 1998
	OLI2	Process redesign to reduce use of scarce or toxic resources and energy consumption	
	OLI3	Community/environmental, employee health and safety concerns	
	OLI4	Internal process integration and production automation	
4	**Internal Environmental Management (IEM)**		
Sub-Factors	**IEM1**	Total quality environment management	Vachon and Klassen, 2008; Min and Gall, 2001; Azevedo et al., 2012; Simpson et al., 2007; Vachon and Klassen, 2006a; Baram and Partan, 1990
	IEM2	Environmental compliance monitoring and auditing	
	IEM3	Pollution prevention plans	
	IEM4	Environmental manager and training for employees	
	IEM5	Environmental standards/ISO14001 certification by suppliers	
	IEM6	Employee incentive programs for environmental suggestions	
5	**Eco-Innovation practices(ECO)**		
Sub-Factors	**ECO1**	Substituting toxic inputs with environmentally friendly ones	Carter and Easton, 2011; Vachon, 2012; Azevedo et al., 2012; Paulraj, 2009; Rao & Holt, 2005
	ECO2	Use of fewer inputs to minimize the environmental risks and impacts	
	ECO3	Switching from "dirty" to cleaner technologies	
	ECO4	Internal recycling of inputs, materials and wastes	
6	**End-of-Life practices (EOL)**		
Sub-Factors	**EOL1**	Resale of used parts or components	Stock, 2001; Sarkis, 2003; Rogers and Tibben-Lembke, 2001; Bell et al., 2013
	EOL2	Recondition and refurbishing of used parts or components	
	EOL3	Old/obsolete items being replaced	
	EOL4	Cyanide and arsenic solution recovery and carbon regeneration	
	EOL5	Mining of Tailings	

Table 2: General Linguistic scale used in the DEMATEL analysis

Linguistic Terms	Scale
Very High Influence (VH)	4
High Influence (H)	3
Low Influence (L)	2
Very Low influence (VL)	1
No Influence (N)	0

Table 3: General Linguistic Scale use for the AHP Analysis

Linguistic Terms	Alpha-Ratings	Numerical-Rating
Extremely More Important	EM	9

Very Much More Important	VM	7
More Important	M	5
Moderately More Important	MM	3
Same important	S	1
Moderately Less Important	ML	1/3
Less Important	L	1/5
Very Much Less Important	VL	1/7
Extremely Less Important	EL	1/9

Table 4: Characteristics of the Twelve Mining Industry Managers involved with the study

The Six (6) Mining Industry Managers involved with the DEMATEL method	
Manager 1 & Company 1	**Manager 4 & Company 4**
Position: Supply Manager **Role**: Management of sourcing/procurement, contract & warehouse **Number of Mining Working Years**: 19years	**Position**: Assistant Supply Chain Manager **Role**: Management of sourcing/procurement, contract & warehouse **Number of Mining Working Years**: 10years
Manager 2 & Company 2	**Manager 5 & Company 5**
Position: Environmental Manager **Role**: Env'tal program implementations and compliance monitoring **Number of Mining Working Years**: 22years	**Position**: Commercial Business Optimization Assistant Manager **Role**: Commercial (supply, account & admin) business improvement **Number of Mining Working Years**:11years
Manager 3 & Company 3	**Manager 6 & Company 6**
Position: Local Supplier & Contractor Development Reg. Manager **Role**: Develops & monitors local suppliers and contractors capacity **Number of Mining Working Years**: 15years	**Position**: Senior Procurement Manager **Role**: Procurement & contract program implementation & training **Number of Mining Working Years**: 14years
The Six (6) Mining Industry Managers involved with the AHP method	
Manager 1 & Company 1	**Manager 4 & Company 4**
Position: Finance Manager **Role**: Management of the company's financial account and budgetary **Number of Mining Working Years**: 10 Years	**Position**: Senior Maintenance Planning Engineer **Role**: Planning of maintenance and materials for maintenance activities **Number of Mining Working Years**: 10years
Manager 2 & Company 2	**Manager 5 & Company 5**
Position: Parts and Warehouse Manager **Role**: Management of sourcing/procurement, contract & warehouse **Number of Mining Working Years**: 15years	**Position**: Head of Information Communications & Technology-ICT **Role**: ICT program implementation, monitoring & improvement **Number of Mining Working Years**: 13years
Manager 3 & Company 3	**Manager 6 & Company 6**
Position: West Africa Regional Contract Manager **Role**: General management of contracts across the west Africa region **Number of Mining Working Years**: 13years	**Position**: Assistant Environmental Manager **Role**: Env'tal program implementations, monitoring and improvement **Number of Mining Working Years**: 10years

Table 5: Brief data on the six (6) purposively sampled mining companies interested in greening their operations

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

Table 6: Prominence (R+C) and Net Effect (R-C) values for SSCM Major Factors and Sub-Factors

Factors	R	C	R+C	R-C
Major Factors				
GITS	4.582	4.844	9.426	-0.263
SSP	5.880	5.035	10.915	0.844
OLI	4.947	4.488	9.435	0.46
IEM	4.508	5.546	10.054	-1.038
ECO	4.980	5.315	10.295	-0.335
EOL	5.358	5.026	10.384	0.332
GITS Sub-Factors				
GITS1	6.949	6.838	13.787	0.111
GITS2	8.196	7.485	15.681	0.710
GITS3	7.017	7.807	14.824	-0.790
GITS4	8.187	7.154	15.341	1.033
GITS5	6.213	7.277	13.491	-1.064
SSP Sub-Factors				
SSP1	11.543	11.187	22.730	0.355
SSP2	10.816	10.641	21.457	0.175
SSP3	10.559	11.099	21.657	-0.540
SSP4	10.756	10.369	21.126	0.387
SSP5	10.740	10.822	21.562	-0.082
SSP6	9.875	10.170	20.045	-0.295
OLI Sub-Factors				
OLI1	15.793	16.272	32.065	-0.479
OLI2	16.208	16.448	32.656	-0.240
OLI3	13.310	13.073	26.383	0.237
OLI4	16.059	15.577	31.636	0.483
IEM Sub-Factors				
IEM1	25.255	26.270	51.525	-1.016
IEM2	25.444	25.448	50.892	-0.004
IEM3	25.017	26.457	51.474	-1.440
IEM4	24.855	22.740	47.595	2.115
IEM5	24.846	24.252	49.098	0.594
IEM6	21.927	22.178	44.105	-0.250
ECO Sub-Factors				
ECO1	17.539	17.282	34.821	0.258
ECO2	16.798	18.043	34.841	-1.246
ECO3	18.310	17.552	35.863	0.758
ECO4	17.529	17.299	34.827	0.230
EOL Sub-Factors				
EOL1	6.899	7.212	14.111	-0.312
EOL2	7.212	6.913	14.125	0.299
EOL3	6.605	7.088	13.693	-0.482
EOL4	4.267	5.090	9.357	-0.823
EOL5	5.401	4.081	9.482	1.319

Table 7: Aggregated weights of the AHP methodology for the major and sub-factors for all managers

Managers Factors	M'ger-1 Weights	M'ger-2 Weights	M'ger-3 Weights	M'ger-4 Weights	M'ger-5 Weights	M'ger-6 weights	Mean
Major factors on the goal for all managers							
GITS	0.315	0.213	0.508	0.553	0.360	0.145	**0.3490**
SSP	0.255	0.137	0.227	0.233	0.151	0.427	**0.2383**
OLI	0.163	0.030	0.125	0.102	0.097	0.033	**0.0917**
IEM	0.064	0.255	0.061	0.058	0.085	0.174	**0.1162**
ECO	0.094	0.199	0.036	0.032	0.125	0.023	**0.0848**
EOL	0.109	0.166	0.043	0.022	0.182	0.198	**0.1200**
GITS sub-factors on the GITS major factors for all managers							
GITS1	0.247	0.239	0.399	0.603	0.591	0.376	**0.4092**
GITS2	0.267	0.310	0.218	0.216	0.182	0.086	**0.2132**
GITS3	0.085	0.137	0.114	0.113	0.118	0.128	**0.1158**
GITS4	0.165	0.137	0.091	0.044	0.071	0.030	**0.0897**
GITS5	0.236	0.177	0.178	0.024	0.038	0.380	**0.1722**
SSP sub-factors on the SSP major factors for all managers							
SSP1	0.393	0.327	0.323	0.544	0.122	0.293	**0.3337**
SSP2	0.289	0.147	0.118	0.242	0.161	0.175	**0.1887**
SSP3	0.169	0.214	0.048	0.104	0.049	0.202	**0.1310**
SSP4	0.064	0.205	0.170	0.058	0.057	0.157	**0.1185**
SSP5	0.044	0.080	0.208	0.035	0.184	0.045	**0.0993**
SSP6	0.041	0.027	0.133	0.017	0.427	0.128	**0.1288**
OLI sub-factors on the OLI major factors for all managers							
OLI1	0.230	0.404	0.363	0.645	0.234	0.682	**0.4263**
OLI2	0.230	0.085	0.259	0.237	0.101	0.166	**0.1797**
OLI3	0.378	0.135	0.275	0.081	0.058	0.039	**0.1610**
OLI4	0.162	0.376	0.103	0.037	0.607	0.113	**0.2330**
IEM sub-factors on the IEM major factors for all managers							
IEM1	0.333	0.538	0.193	0.522	0.589	0.472	**0.4412**
IEM2	0.300	0.205	0.199	0.240	0.208	0.154	**0.2177**
IEM3	0.177	0.116	0.179	0.120	0.066	0.035	**0.1155**
IEM4	0.057	0.075	0.268	0.065	0.059	0.169	**0.1154**
IEM5	0.084	0.031	0.112	0.035	0.042	0.032	**0.0560**
IEM6	0.049	0.035	0.049	0.018	0.036	0.138	**0.0542**
ECO sub-factors on the ECO major factors for all managers							
ECO1	0.449	0.645	0.588	0.700	0.414	0.422	**0.5363**
ECO2	0.313	0.205	0.267	0.100	0.212	0.082	**0.1965**
ECO3	0.090	0.111	0.113	0.100	0.100	0.382	**0.1493**
ECO4	0.148	0.039	0.032	0.100	0.274	0.114	**0.1178**
EOL sub-factors on the EOL major factors for all managers							
EOL1	0.217	0.323	0.308	0.594	0.329	0.144	**0.3192**
EOL2	0.062	0.023	0.110	0.153	0.227	0.270	**0.1408**
EOL3	0.095	0.015	0.115	0.153	0.119	0.506	**0.1672**
EOL4	0.313	0.325	0.146	0.066	0.149	0.060	**0.1765**
EOL5	0.313	0.314	0.321	0.034	0.176	0.020	**0.1963**

Table 8: The Comparative Analysis of Local and Global Weights of SSCM Implementation Factors and Sub-Factors in the Mining Industry

Dimensions /Major Factors	Local Weights - Major Factors DEMATEL	Ranking DEMATEL	Local Weights - Major Factors AHP	Ranking AHP	Sub-Factors	Local Weights - Sub-Factors DEMATEL	Global Weights- Sub-Factors DEMATEL	Ranking DEMATEL	Local Weights - Sub-Factors AHP	Global Weights- Sub-Factors AHP	Ranking AHP
GITS	0.1558	**6**	0.3490	**1**	**GITS1**	0.1885	0.0294	**20**	0.4092	0.1428	**1**
					GITS2	0.2144	0.0334	**12**	0.2132	0.0744	**3**
					GITS3	0.2027	0.0316	**15**	0.1158	0.0404	**8**
					GITS4	0.2098	0.0327	**13**	0.0897	0.0313	**11**
					GITS5	0.1845	0.0287	**23**	0.1722	0.0601	**4**
SSP	0.1804	**1**	0.2383	**2**	**SSP1**	0.1768	0.0319	**14**	0.3337	0.0795	**2**
					SSP2	0.1669	0.0301	**18**	0.1887	0.0450	**7**
					SSP3	0.1684	0.0304	**16**	0.1310	0.0312	**12**
					SSP4	0.1643	0.0296	**19**	0.1185	0.0282	**14**
					SSP5	0.1677	0.0302	**17**	0.0993	0.0237	**16**
					SSP6	0.1559	0.0281	**25**	0.1288	0.0307	**13**
OLI	0.1559	**5**	0.0917	**5**	**OLI1**	0.2612	0.0407	**6**	0.4263	0.0391	**9**
					OLI2	0.2661	0.0415	**5**	0.1797	0.0165	**23**
					OLI3	0.2150	0.0335	**11**	0.1610	0.0148	**24**
					OLI4	0.2577	0.0402	**7**	0.2330	0.0214	**18**
IEM	0.1661	**4**	0.1162	**4**	**IEM1**	0.1748	0.0291	**21**	0.4412	0.0513	**5**
					IEM2	0.1727	0.0287	**24**	0.2177	0.0253	**15**
					IEM3	0.1747	0.0290	**22**	0.1155	0.0134	**25**
					IEM4	0.1615	0.0268	**27**	0.1154	0.0134	**26**
					IEM5	0.1666	0.0277	**26**	0.0560	0.0065	**29**
					IEM6	0.1497	0.0249	**30**	0.0542	0.0063	**30**
ECO	0.1701	**3**	0.0848	**6**	**ECO1**	0.2481	0.0422	**4**	0.5363	0.0455	**6**
					ECO2	0.2482	0.0422	**2**	0.1965	0.0167	**22**
					ECO3	0.2555	0.0435	**1**	0.1493	0.0127	**27**
					ECO4	0.2481	0.0422	**3**	0.1178	0.0100	**28**
EOL	0.1716	**2**	0.1200	**3**	**EOL1**	0.2322	0.0399	**9**	0.3192	0.0383	**10**
					EOL2	0.2324	0.0399	**8**	0.1408	0.0169	**21**
					EOL3	0.2253	0.0387	**10**	0.1672	0.0201	**20**
					EOL4	0.1540	0.0264	**29**	0.1765	0.0212	**19**
					EOL5	0.1560	0.0268	**28**	0.1963	0.0236	**17**