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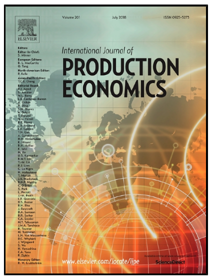

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Philipp C. Sauer, Stefan Seuring

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Extending the reach of multi-tier sustainable supply chain management – insights from mineral supply chains

Authors:
Philipp C. Sauer [a] (corresponding author: philipp.sauer@uni-kassel.de)
Stefan Seuring [a] (seuring@uni-kassel.de)

Affiliations and postal address:

[a] University of Kassel, Faculty of Business and Economics, Chair of Supply Chain Management, Nora-Platiel-Str. 4, 34109 Kassel, Germany

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Abstract

Triadic or tetradic multi-tier sustainable supply chain management (MT-SSCM) research emerged recently to reach out towards raw material suppliers and to address their often severe sustainability impacts. This is especially relevant in mineral supply chains (SCs) which consist of a commodity chain upstream and an end-product chain downstream. To comprehensively investigate the reach of MT-SSCM in mineral SCs, the extant Delphi study brought together 44 global authors on sustainability in mineral SCs. They contributed their professional knowledge in three questionnaire rounds, which systematically identify, evaluate and contrast the sustainability challenges in mineral SCs. As a result, a generic mineral SC structure is derived and 17 major sustainability issues are identified. Moreover, the findings reveal that all but two sustainability issues need to be addressed in the upstream SC. As mineral SCs might comprise up to nine tiers, the most impactful tiers lie outside the reach of current MT-SSCM concepts, which are limited to triads or tetrads by the visible horizon or lacking power of the focal firm. We thus propose a cascaded MT-SSCM approach which links the up- and downstream SC parts. Moreover, individual focal firms for each SC part are defined, which build a direct strategic link. This link enables that tailored managerial responses can be cascaded into the respective SC parts, where the individual sustainability issues can best be addressed. This cascaded design represents a novel approach in MT-SSCM which multiplies existing concepts. Moreover, the challenges and opportunities, which the cascaded approach raises for MT-SSCM research are discussed and outlined.

Keywords: Delphi study, Multi-tier supply chain management, Sub-supplier management, Sustainability, Mineral resources, Cascaded approach

1. Introduction

Today's supply chains (SC) connect a wide range of contexts, actors and industries in order to provide a competitive end-product. A firm's knowledge about the participants of a SC decreases with the physical and cultural distance as well as with the number of tiers between a focal firm and a certain supplier (Carter et al., 2015; Kembro et al., 2017). This is especially relevant for businesses which are sensitive to sustainability, which is typically heavily impacted by the raw material suppliers at the upstream end of the SC (Mena et al., 2013; Schmidt et al., 2017).

However, many industries rely on commodity supplies which are produced in considerably different contexts regarding production processes and regulatory frameworks. These commodity supplies often remain outside the visible horizon, i.e., the n-tier suppliers known by the focal firm (Carter et al., 2015). Moreover, one commodity might function as raw material for more than one industry (Schmidt et al., 2017). Mineral commodities, for example, are used by construction, automotive, aviation, jewlry, electronics and packaging industries (Hofmann et al., 2018; Young, 2015). Such industry spanning SCs call for joint concepts in order to implement an effective management of sustainability issues (Seuring & Gold, 2013).

Multi-tier sustainable supply chain management (MT-SSCM) thus aims to "reach deeper into the supply chain" (Mena et al., 2013, p. 59) and consequently started to evaluate triadic SCs as the next step upstream (Choi & Wu, 2009). While Mena et al. (2013) proposed ideal structures for triadic SCs, Tachizawa & Wong (2014, p. 651) extended their propositions to "any lower-tier supplier", thereby moving beyond the second tier. These concepts are currently dominating MT-SSCM research with most studies investigating cases from the food industry (Mena et al., 2013; Grimm et al., 2014) or multiple cases integrating different industries such as electronics, retailing and food (Grimm et al., 2016; Wilhelm et al., 2016a; 2016b). The just outlined MT-SSCM concepts by Mena et al. (2013) as well as Tachizawa and Wong (2014) thus prove applicable for studying entire industries.

In the case of mineral commodities, the associated SCs are conceptualized by a distinction between upstream and downstream SC segments (Young, 2015). This distinction is natural to all SCs, but investigating the mineral SC segments promises to be especially fruitful as the segments differ substantially in terms of production processes and sustainability challenges. These challenges range from the formalization of artisanal mining in developing countries to the optimization of high-tech processing and recycling facilities in industrial contexts (Sauer & Seuring, 2017). Traditionally, both segments of the mineral SC are economically highly connected, but the recently rising stakeholder pressure for sustainability (Schmidt et al., 2017) has also revealed the segments' mutual dependence in the social and ecological domain (Hofmann et al., 2018).

This study is thus designed as a three-round Delphi study to collect the expertise of the global authors on sustainability of mineral SCs. Delphi studies are especially suitable to comprehensively map a field and use this basis for exploratory theory building (Akkermans et al., 2003). The method has furthermore proved fruitful for driving the research on multi-tier SCs (Kembro et al., 2017). To take full advantage of the method, we investigated the following research questions (RQs):

RQ 1) How can the up- and downstream SC segments of a generic mineral SCs be defined to structure the SC?

RQ 2) Which major sustainability issues can be identified in the mineral SC?

These rather broad questions, which could also be answered by a literature review, represent the "brainstorming" phase of the study, which yields a comprehensive map of the two objectives, which is more valid than a literature review as it was validated in the second and third round of the Delphi study (Okoli & Pawlowski, 2004). Moreover, we coupled the round 1 results in the following question, which aims at the systematic identification of the SC segments in which the sustainability issues in a multi-tier mineral SC can best be addressed:

RQ 3) Where in the identified SC structure have the identified sustainability issues to be addressed to best enhance the sustainability of the SC?

This holistic investigation is again far more valid than a literature based approach and moves beyond the currently available empirical studies on MT-SSCM which investigate triadic (Mena et al., 2013; Grimm et al., 2014; 2016; DeYong & Pun, 2015; Kembro et al., 2017) or tetradic SCs (Wilhelm et al., 2016a). We thus adopted the lens of MT-SSCM, which has only marginally been used in the context of minerals (Hofmann et al., 2018) to investigate the final question:

RQ 4) How can MT-SSCM approaches be used to address the sustainability issues in the respective SC parts?

To our best knowledge, this study is the first to empirically complement the fragmented literature on sustainability in minerals SCs by comprehensively mapping the field and outlining future solutions and research opportunities. The study results identify 17 major sustainability issues in mineral SCs and the experts suggest to address the majority of them in the upstream SC segment. However, this part of the SC is mostly out of reach for the focal firm which is traditionally located in the downstream SC segment. This study thus develops a cascaded MT-SSCM approach which combines the up- and downstream SC parts and defines individual focal firms for each SC part. A direct strategic link among these focal firms is proposed, from which tailored responses to the sustainability issues can cascade into the individual SC parts, where the issues can be addresses best. This cascaded design represents a novel approach in MT-SSCM which multiplies existing approaches and raises new challenges and opportunities for MT-SSCM research.

The article is structured as follows: First, the literature on the MT-SSCM and mineral SCs is reviewed. Second, the method is outlined with regard to its suitability to conceptualize the complex interplay of sustainability issues and their implications for the management of the mineral SC. Third, the findings are presented and synthesized into the cascaded MT-SSCM approach. Fourth, the contribution of this approach and the study in general are discussed and research directions and limitations are outlined. Finally, we conclude the paper with a short section summarizing the study.

2. Literature review and conceptualization of key terms

2.1. Characterization of the mineral supply chain

Mineral SCs are regularly divided in an upstream and downstream segment. These differ substantially in their relevant regulations, operational processes and routines (Young, 2015). However, their boundaries are blurry and a clarification of the SC structure is required for a sound analysis of a multi-tier SC (Carter et al., 2015; Choi & Wu, 2009). This study thus investigates the mineral SC structure, which represents an extreme case for MT-SSCM with up to nine tiers (Young, 2015) and a high complexity in ensuring sustainable operations (Giurco & Petrie, 2007). To enable an easy understanding of the analysis and the design of the study, the structure of the mineral SC will be presented first. The following definitions of the upstream and downstream SC have been developed and validated during the Delphi study. They answer RQ 1) and are used throughout the study to structure the SC and enable the systematic comparison of a) the sustainability issues along the SC as requested in RQ 3) and b) the suitability of MT-SSCM approaches for managing such a complex multi-tier SC requested in RQ 4):

The *upstream mineral SC* comprises all stages up to the production and sale of concentrated and refined minerals or cut/polished (gem-)stones. It especially entails the extraction and beneficiation, smelting or refining of minerals and support processes such as trading and transportation.

The *downstream mineral SC* comprises all stages using concentrated and refined minerals or cut/polished (gem-)stones. It especially entails the use of the mineral products for manufacturing pre- and end-products as well as retail, use, recycling and disposition of end-products. Support processes such as trading and transportation are also included in the SC concept.

These definitions indicate the high number of actors involved in a mineral SC and mirror Young's (2015) findings of long and complex mineral SCs. Moreover, it contrasts the labour and energy intensive production of a commodity in the upstream SC with the rather diversified and value adding manufacturing of end-products and value recovery in the downstream SC.

Addressing the differences of the SC segments in all three dimensions of sustainability, i.e., social, environmental, and economic issues (Elkington, 1997) goes beyond the scope of the traditional dyadic SSCM focus and requires a broadened focus on more actors in the SC (Seuring & Gold, 2013; Schmidt et al., 2017). This is taken up by MT-SSCM research, which is introduced subsequently.

2.2. Current status on multi-tier sustainable supply chain management

Based on the understanding of a generic mineral SC and its actors provided in Figure 1, we apply the definition of SSCM by Ahi & Searcy (2013). Throughout the study, the issues of interest are related to “The creation of coordinated supply chains through the voluntary integration of economic, environmental, and social considerations with key inter-organizational business systems designed to efficiently and effectively manage the material, information, and capital flows associated with the procurement, production, and distribution of products or services…” (Ahi & Searcy, 2013, p. 339). From the remaining part of the definition we extracted the three core objectives in SSCM, which are “… to (1) meet stakeholder requirements, (2) improve the profitability [and] competitiveness and (3) [improving] resilience of the organization over the short- and long-term.” (Ahi & Searcy, 2013, p. 339; numbering added). These three objectives were used throughout the study to evaluate the effects and benefits of the investigated issues for SSCM for minerals.

As mentioned in the introduction, extending SSCM to MT-SSCM implies the investigation of firm relations beyond dyadic relationships (Mena et al., 2013; Tachizawa & Wong, 2014). However, extending the scope of SSCM is found to decrease management efficiency dramatically due to increasing difficulties in information sharing (Kembro et al., 2017) as well as limited visibility of SC partners (Carter et al., 2015) and their performance (Schmidt et al., 2017; Maestrini et al., 2017). These challenges of MT-SSCM have been addressed by two major contributions recently:

1) Mena et al. (2013) introduced a set of three typical SC structures in buyer – supplier – sub-supplier triads. These encompass a) the open structure with no direct connection between buyer and sub-supplier, b) the closed structure with direct management of the sub-supplier by the buyer and c) the transitional SC in which buyer and sub-supplier are in the process of building a direct relation.

2) Tachizawa & Wong (2014) extended the prior concepts by addressing "any lower-tier supplier (i.e., so not only the second tier)" (Tachizawa & Wong, 2014, p. 651). Changing the focus from structure to practices, Tachizawa & Wong (2014) re-labelled the open structure as the "indirect" approach in which only the tier-1 supplier manages lower-tiers and the closed structure as the "direct" approach. Moreover, the "work with third parties" approach adds the reliance on NGOs, or other non-traditional SC members for managing sustainability in lower-tiers. Finally, the "don't bother" approach applies if the buyer does not or cannot manage lower-tier suppliers. These two papers present the core of current MT-SSCM concepts and the starting point for the extant research.

The majority of extant MT-SSCM research focusses on triadic SCs and covers a variety of industries or issues such as the food sector (Grimm et al., 2014; Autry et al., 2014), automotive SCs (Thomé et al., 2014), manufacturing triads (DeYong & Pun, 2015), information sharing in triads (Kembro et al., 2017), SC risk management (Tse & Tan, 2012), conflict minerals (Hofmann et al., 2018), information technology and retailing (Grimm et al., 2016) or multi-industry studies (Wilhelm et al., 2016a; 2016b). The evaluation of SCs with more than three connected tiers is scarce (see Wilhelm et al. (2016a) for an investigation up to tier-4) and comes to limits with regard to the complexity of data collection (Choi & Liker, 2002; Autry et al., 2014; Thomé et al., 2014). However, the sustainability challenges of particularly long and complex SCs, like the mineral SC, require an even wider scope. Additionally, the use of multi-tier SC concepts is still limited and requires further exploratory theory building (Maestrini et al., 2017; Kembro et al., 2017). Therefore, we subsequently integrate the current MT-SSCM approaches and the upstream-downstream division in mineral SCs to develop a cascaded SC structure as the basis for our arguments on extending the reach of MT-SSCM.

2.3. *Integrating multi-tier sustainable supply chain management and the upstream-downstream division in mineral supply chains*

Mineral SCs represent an extreme case for MT-SSCM as they are long and complex and have their biggest sustainability challenges at the raw materials stage, which is often out of reach for the focal firm (Mena et al., 2013; Young, 2015). We thus adopt the cascaded structure of the generic minerals SC model by Sauer & Seuring (2017, p. 235), "which complements the traditional downstream buyer-supplier concept in SSCM by adding a second buyer-supplier relationship led by an upstream focal firm for enhanced sustainability management." The notion of a cascade, i.e., passing (something) on to a succession of others, captures this interplay of two buyer-supplier relationships, which comprise of interactions internal to the single SC parts as well as interactions of the SC parts at large. Figure 1 displays this cascaded structure in which each focal firm manages either the upstream or downstream SC segment by means of the just reviewed MT-SSCM strategies and practices while coordinating the main sustainability and management goals of the SC with the other focal firm. Building on the MT-SSCM approaches outlined above, both the upstream and downstream SC consist of a buyer or focal firm and the respective tier-1 and lower-tier suppliers.

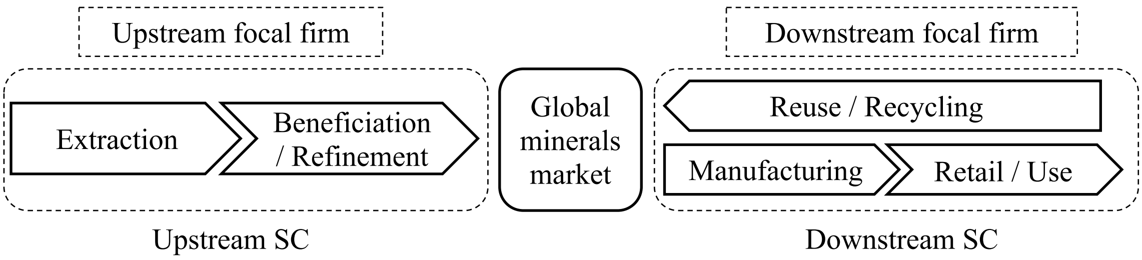

Figure 1: Generic Mineral SC Model (Sauer & Seuring, 2017)

Based on this model, our study concept applies a systematic comparison of the up- and downstream SC to contrast their characteristics relevant to SSCM. The obtained results are then synthesized against the just outlined cascaded MT-SSCM approach. The study's design follows the argument that "it is certainly easier to get data on dyadic relationships, but the more challenging and perhaps more interesting questions involve longer supply chains. This is where key systems dynamics will be revealed" (Choi & Liker, 2002, p. 202). To do so, we collected experts' opinions on the topic in the course of a Delphi study, which is explained in more detail in the following chapter.

3. Methodology

This chapter introduces the Delphi technique as the main method and the content analysis and hierarchical cluster analysis as the used consolidation tools.

3.1. Delphi technique

Delphi studies represent "a structured group communication […] to deal with a complex problem" (Linstone & Turoff, 1975, p. 3). The method is particularly suitable for exploratory theory building on under-researched, complex and interdisciplinary topics (Akkermans et al., 2003) such as the sustainability in multi-tier SCs and mineral SCs.

Recent applications of the Delphi technique in (S)SCM research encompass SC performance under uncertainty (Tseng et al., 2016), driving research in green (Jayaram & Avittathur, 2015) or sustainable SCM (Seuring & Müller, 2008; Reefke & Sundaram, 2017), or information sharing in multi-tier SCM (Kembro et al., 2017).

Historically, Delphi studies evolved as a contrast to committees and discussion formats in which participants directly interact and to one-off surveys by combining elements of both techniques (Linstone & Turoff, 1975; Goodman, 1987). A Delphi study is conducted by a monitoring team that designs and moderates the entire study during which the participants stay anonymous to each other and interact with the monitoring team only (Linstone & Turoff, 1975). Contrasting committees, this avoids opinion leadership and ensures individual responses that represent the actual opinion of the respondent (Goodman, 1987). Furthermore, a Delphi study is structured in multiple rounds in order to obtain, structure and aggregate information on the researched problem (e.g. Häder, 2014; Linstone & Turoff, 1975). These features contrast one-off surveys and enhances construct validity, as the experts comment on their previous answers (Okoli & Pawlowski, 2004). Reliability is ensured by rigorous study design and documentation as well as pre-testing the single questionnaires (Häder, 2014; Okoli & Pawlowski, 2004). These drivers of validity and reliability were an integral part of both designing and conducting our study in order to ensure high quality results.

Häder (2014) distinguishes four main aims of Delphi studies, which determine their core design principles: 1) the aggregation of ideas, 2) the exact definition or determination of an uncertain object or event, 3) the aggregation and qualification of experts‘ opinions and 4) building consensus. Looking at the research objectives, this study aims to compile a list of major issues and their relations due to a lack of comprehensive studies on the topic of sustainability in mineral SCs. Therefore, this research fits the third group covering the aggregation and qualification of expert opinion on the topic.

3.1.1. Study design

The extant study adopts the three-round design proposed by Okoli & Pawlowski (2004). Table 1 presents the design choices taken with regard to the first three research questions, which were addressed in the three questionnaire rounds. It furthermore includes the intermediate steps, which aim to operationalize the problem, to narrow it down and to rank the solutions by processing the individual expert contributions into a group opinion (Okoli & Pawlowski, 2004).

	Structure of mineral SC	Major issues in SSCM for minerals	Location of issues in mineral SC
Round 1 Questionnaire	Open question on SC structure	Open questions about challenges and opportunities of SSCM for minerals	-
Operationalization	Content analysis to build definitions	Content analysis to build consolidated list of issues	-
Round 2 Questionnaire	Validation of definitions via agreement or disagreement with comments	Rating the contributions of consolidated issues to SSCM objectives on ordinal scale	Locating issues in either upstream, downstream or whole SC
Narrowing down	-	Hierarchical clustering of issues in 4 clusters	Frequency analysis to calculate group opinion
Round 3 Questionnaire	-	Re-rating the contribution of clusters on 5-point Likert scale based on previous results	Re-locating the issues in either upstream, downstream or whole SC based on previous results
Ranking	-	Calculating group mean and variance	Frequency analysis to calculate group opinion

Table 1: Study design of the individual rounds with regard to the research questions

Concerning the data collection process, the first questionnaire was directly e-mailed to the experts without prior contact. Round 1 was conducted by means of an e-mail and an attached editable PDF questionnaire. Rounds 2 and 3 were designed and run as online questionnaires preceded by e-mail invitations. The questionnaires were programmed and administered via the “SoSci Survey” online tool, which is public and free for scientific use (Leiner, 2014). Each round consisted of an invitation and three reminders in two week intervals. The data collection lasted 13 months, i.e., form April 2016 to May 2017. To ensure the validity of the results over this time span, each question was evaluated in two rounds at least (see also Table 1) including the opportunity to comment on different opinions or other concerns regarding the questions (Okoli & Pawlowski, 2004). During the second evaluation of the individual questions, the prior group opinion was displayed to enable a re-evaluation by the experts. In effect, no concerns were raised.

3.1.2. Round 1

As shown in Table 1, round 1 encompassed an operationalization of the addressed problem by asking two open questions. First, the experts were asked to operationalize the structure of the mineral SC by listing and explaining the individual stages of it.

Second, the experts were asked to operationalize the major issues for a successful SSCM for minerals. A generic SSCM definition was provided for the experts and they were asked to list risks and challenges as well as opportunities and benefits for SSCM for minerals. The instructions asked for at least three items concerning the upstream, downstream and whole SC (i.e., both up- and downstream simultaneously) each as well as comments on the items.

The answers in round 1 had to be filled in a text box, without further instructions or space limitations. The responses came in full text or keywords and the content was analyzed as described in chapter 3.2 in order to consolidate the individual contribution into a group opinion as suggested by Okoli & Pawlowski (2004). This consolidation delivered the definitions of a generic structure of mineral SCs presented in section 2.1 as well as a consolidated list of sustainability issues in mineral SCs as a basis for round 2.

3.1.3. Round 2

In round 2, the definition of the mineral SC structure derived from round 1 results was presented and participants were asked to either agree or disagree and comment on the reasons for their disagreement. The intention was to validate the compiled definition by having the experts revision, a particular strength of the Delphi technique (Okoli & Pawlowski, 2004).

Moreover, the experts were asked to rate the contributions of the consolidated issues to the three objectives in SSCM outlined in section 2.2, which are: (1) to meet stakeholder requirements, (2) to improve the profitability and competitiveness, (3) improving resilience. This rating was conducted on an ordinal scale indicating whether or not the issue was important to the mentioned objectives in the up- and downstream SC. In effect, the experts rated all three objectives for each of the 17 issues with regard to the upstream and the downstream SC. The obtained results were then fed into a cluster analysis as described in section 3.3 to narrow down the number of issues.

A third question in round 2 investigated the location of the issue in the SC, i.e., in which segment of the SC do the experts see the biggest potential to enhance or reduce the issue. Possible answers were upstream, or downstream, or the whole SC if both SC segments were seen as equally important. The results of this question were collected and the frequencies of the single SC segments were counted.

The round 2 questionnaire thus represented a standardized questionnaire which was sent to the entire panel. This standardization formalized the open answers from round 1 in order to build a defined scheme for the further investigation of the researched problem (Okoli & Pawlowski, 2004). The individual results received from the experts were processed to calculate the group opinion as the basis for round 3.

3.1.4. Round 3

The round 3 questionnaire repeats or refines round 2 questions combined with information on the group opinion, the so-called feedback, in order to encourage the experts to re-evaluate their opinion (Goodman, 1987). As shown in Table 1, a re-ranking of issues was conducted on a 5-point Likert scale for the single clusters, which added more depth to the ranking than the ordinal scales in round 2. Furthermore, the locations of issues were validated by repeating the third question from round 2 including feedback, i.e., providing the previous results to enable a re-evaluation by the experts.

3.1.5. Expert selection

Following the design suggestions by Häder (2014), the relevant expert panel needs to encompass either all experts in the field or a purposeful selection of them. Hence, the expert selection in Delphi studies does not require a random and representative sample like a survey (Goodman, 1987). Instead, the expert selection needs to be adapted to the research aims and the available resources (Häder, 2014). In general, the study quality rises with the number of participants and a minimum of 20 participants should be realized to avoid biases caused by single responses (Akkermans et al., 2003).

As the study aims at bridging the current gap between up- and downstream SC, there is a strong need for a comprehensive coverage of the field of sustainability in mineral SCs by the panelists. Moreover, the panelists should have a broad knowledge on the topic and should be able to reflect on the consequences of the actions of one SC part on the other part. We thus decided to aim for experts, who published on the topic and who thus fulfill the just outlined requirements and can take an external expert view on the entire SC and its complexity.

According to these requirements a single panel was built. Panelists were identified based on a systematic literature review on the topic (Sauer and Seuring, 2017). This review as well as the study by Young (2015) found the critical interdependence of the up- and downstream mineral SC, while the research on the single SC parts is poorly connected. We thus build on Sauer and Seuring's (2017) paper sample, which delivers a timely and comprehensive list of experts in the field of mineral SCs. The exact identification of papers is displayed in the review paper. In total, 67 peer-reviewed, English-language journal papers published anytime before 2016 and listed in the Web of Science database were used to identify a total of 147 authors around the globe. The applied keyword search for SC-, mineral- and mining-specific terms ensured that experts worked in the relevant field and scientific peer-review processes are assumed as a valid tool for ensuring sufficient expertise. Complementing the ex-ante expert identification, participants were asked to nominate further experts. Their fit according to the expert criteria was checked to determine their eligibility. Using this snowball method, four additional experts were invited of which two participated in the study. Eventually, the panel covered participants from all continents, experts on all major minerals and a balanced expertise on the up- and downstream SC. The comprehensive coverage of the field of sustainability in mineral SCs by the panelists enabled the investigation of the research questions which require an external or expert view on the entire SC due its complexity.

All panelist were invited to each round in order to address all experts in the field as suggested by Häder (2014). Round 3 responses were checked for inconsistencies of participants which took part in round 2 and those who did not. As the results were consistent among the two groups we included all round 3 responses into the findings.

In total, 44 experts participated across all rounds of the study. On average (median) they published nine papers, had an H-Index of four and had been cited 103 times. In total the panel had 831 publications, which are cited more than 16,700 times. These numbers show the expertise covered by the panel and underlines the experts' capability to reflect on the research questions. This data was taken from the Web of Science database which was also the source of the papers for expert identification. The database includes more than 20,000 journals from all major publishers, and thus represents the most comprehensive database in the field (Sauer & Seuring, 2017).

3.1.6. Validation workshop

The study was part of a research project on sustainability in mineral SCs which initiated a number of a multi-stakeholder workshops, which unites a diverse group of researchers and practitioners. A validation of the study results in these workshops was part of the study design. This design allowed for a more researcher dominated expert panel in order to complement and contrast the practitioner dominated workshop. In effect, the study results were discussed, validated and complemented by both practitioners and academics.

	Industry	(N)GOs	Academia	Sum	Experts invited	Response rate
Round 1	5	2	27	34	147	23.1%
Round 2	5	1	23	29	151	19.2%
Round 3	5	1	24	30	151	19.9%
Workshop	16	8	9	33	-	-

Table 2 – Participants of Delphi study and validation workshop

Table 2 presents the composition of the study and workshop participants across the different stakeholder groups. In effect, the Delphi study's participants were mainly academics (79%) whereas the validation workshop was dominated by practitioners (73%) which validated and complemented the results from a practitioner's perspective.

In the course of the study, the expert answers had to go through two main processing steps which are outlined in the following sections.

3.2. Content analysis

We adopted the content analysis method proposed by Mayring (2000) which aims at a rule-governed and inter-subjectively replicable process of categorizing text material. In order to do so, first there is the need "to formulate a criterion of definition, derived from theoretical background and research question" (Mayring, 2000, p. 4). In our case this was the consolidation of a) the structural elements of a mineral SC and b) of the major issues in SSCM for minerals, i.e., management aims and practices. In order to reach this level of abstraction, the answers were first broken down into discrete items, i.e., individual items were identified, differences in spelling were consolidated and the items were assigned to a segment of the SCs according to the expert's nomination. Second, the meaning of the items was checked in relevant literature and synonyms as well as closely related items were grouped together inductively, as proposed by Mayring (2000). This process was conducted by the two authors individually before the results were discussed and refined in a "discursive alignment of interpretation" (Seuring & Gold, 2012, p. 547). This is especially beneficial when interpreting "soft" criteria (Duriau et al., 2007), such as the open answers in round 1, which need to be condensed to their core. In contrast to an interpretation by one researcher, this design substantially enhances the validity and reliability of the consolidation (Duriau et al., 2007) and has been widely applied in SSCM research (Seuring & Gold, 2012).

3.3. Cluster analysis

Cluster analysis reveals hidden patterns in data by grouping the issues into clusters, which should be internally homogeneous and heterogeneous among each other. Following Backhaus et al. (2016) the issues were clustered in SPSS after round 2 based on the obtained frequency distributions. This enabled the "narrowing-down" of issues (Okoli & Pawlowski, 2004, p. 25) by bundling them into clusters in order to aggregate the results.

Since this Delphi study deals with relatively low sample sizes compared to other cluster analyses, special attention had to be paid to the selection of the correct clustering procedure and its quality tests. In general, there is no minimum sample size for running a cluster analysis, but larger samples yield more stable results (Sarstedt & Mooi, 2014).

When conducting cluster analysis with small samples, more attention needs to be given to logical consistency checks, in which the researchers evaluate the fit of a clustered object to its cluster based on their contents and meanings (Backhaus et al., 2016).

As suggested for small sample sizes without prior knowledge of the number of clusters, we adopted a hierarchical clustering procedure and followed the best practice recommendations by Backhaus et al. (2016), Bacher et al. (2010) as well as Sarstedt and Mooi (2014). Following these references, we performed multiple tests for each design decision, which are outlined below, with complementing test results indicated in brackets.

As suggested in the literature, frequency data can best be clustered using a chi-square-measure (phi-square-measures delivered no significant differences) and the Ward-algorithm (tests of single-linkage- and complete-linkage-algorithms supported the choice (Bacher et al., 2010; Sarstedt & Mooi, 2014; Backhaus et al., 2016)). Four clusters were built based on Elbow-criteria and Mojena test, logical consistency checks and tests for highly correlated variables (correlation factor > 0.9) of which none were detected. The last test ensured that the evaluated variables, i.e., the contribution to up- and downstream SSCM objectives, were sufficiently discriminant for individual investigation (Sarstedt & Mooi, 2014; Backhaus et al., 2016).

Backhaus et al. (2016) moreover suggest to calculate F-Values for each cluster variable in all clusters. The F-Value is defined as the quotient of (1) the variance of the variable in a cluster over (2) the variance of the variable over all clusters. F-Values below one indicate a fully homogenous cluster, while values above one should be avoided or logically consistent (Backhaus et al., 2016).

4. Findings

4.1. Structuring the mineral supply chain

The content analysis of the 34 answers in round 1 yielded a total of 51 structural items for the mineral SC structure. Apart from the upstream and downstream SC, which have been focused in the questionnaire, five respondents also included an additional midstream SC. The experts' comments identified this stage as focused on adding value to the mineral itself by "chemical processing" or "alloying" as well as producing semi-finished commodity products as "tubes" or "sheet metal" (Respondent 1.18). These five answers proposing a midstream SC substantially overlapped with the remaining 29 ones. In order to reach a clear operationalization, we compiled the definitions for the upstream and downstream SC presented in section 2.1.

Round 2 validated the proposed definitions as 28 of the 29 respondents agreed to each of the definitions. The rejection of the upstream definition by one expert was explained by the missing "midstream" segment, while the respondent agreed that the two definitions can serve for a "broad differentiation" (Respondent 2.11). The expert's rejection of the downstream definition pointed to the diamonds' SC, where "downstream […] usually only includes selling diamonds to end customers" (Respondent 2.24). As this is covered in the proposed downstream definition and in order to cover a possible use of diamonds for producing jewelry, we decided to accept both definitions based on the 97% agreement of experts. In effect, the two definitions presented in the literature section answer the first part of RQ 2) by defining a generic mineral SC structure. This structure also serves as an integral part of the remaining questions, which are outlined below.

4.2. Identifying the major sustainability issues in the mineral supply chain

The content analysis of the 34 answers to the open question on the operationalization of the sustainability issues in round 1 yielded a total of 152 items for risks and challenges as well as 113 items describing opportunities and benefits. Following Mayring's (2000) inductive category development outlined in chapter 3.2, these items were grouped by the authors according to their content. A comparison of the first groupings revealed individual groups on complementing challenges and opportunities, which focussed common issues. The most obvious was the challenge of environmental degradation and the opportunity of reducing the environmental impact by means of SSCM for minerals. Thus, a second inductive consolidation step was conducted, which integrated related risks and benefits as well as related challenges and opportunities along the common issues. The issues were then sorted in two groups. First the adverse issues, which need to be reduced to achieve the objectives of SSCM outlined in section 2.2. Second the beneficial issues, which need to be enhanced to achieve the SSCM objectives. This consolidation yielded the 17 major issues and their sub-issues displayed in Table 3. These represented the basis for round 2 in which they were validated by the experts. The 17 issues further answer RQ 2).

In round 2 the perceived potential impacts of the 17 individual issues on the three objectives in SSCM shown in top row of Table 4 were investigated. In order to do so, a nominal scale was used, i.e., a contribution to the three SSCM objectives could be indicated by the experts for each SC segment. Appendix 1 displays the results of this investigation, which were subsequently processed in a hierarchical cluster analysis as outlined in chapter 3.3. which yielded the four clusters shown in Table 3. Each cluster covered three to six major issues that had been grouped in the cluster analysis based on the homogeneity of their contribution to the SSCM objectives.

Appendix 2 displays the F-Values for the clusters and enables a check for homogeneity as proposed by Backhaus et al. (2016). The results show, that all clusters but Cluster 4 can be considered fully homogeneous. Cluster 4 however, is the largest cluster and has a F-Value of 1.58 for the variable “Enhancing profitability & competitiveness upstream”. This is caused by the extraordinary high rating of issue C 4.5 “Enhancing company capabilities and resources", which has the highest rating in the entire data set in the mentioned variable (see Appendix 1). Performing a test for logical consistency as suggested by Backhaus et al. (2016), it becomes clear, that the issue is a natural driver of the variable "Enhancing profitability & competitiveness". The rating can thus be seen as uncritical. Moreover, Cluster 4 and the issue have the best fit with regard to the content. Finally, Cluster 4 has the highest rating in the variable of all clusters (see Table 4), which justifies the inclusion of the issue in the cluster. Based on this test for logical consistency, we consider all clusters as homogeneous and all issues as correctly assigned. In the following round 3, this assignment was again displayed and the experts were asked to comment if they disagree. In the end, no objections were raised.

No	Major issue	Sub-issues
C 1	Creating demand and supply for sustainable minerals	
C 1.1	Enhancing the traceability of minerals and products	using certification, tracking production conditions, mapping the SC, demonstrating and documenting legality and sustainability of operations, establishing financial transparency
C 1.2	Enhancing the demand for sustainably produced products	paying price premiums for cleaner products, raising customer loyalty and customer awareness
C 1.3	Enhancing the perception of sustainability efforts	safeguarding / enhancing brand reputation, acquiring investment capital for upgrading processes, reducing negative publicity for unsustainable behavior
C 1.4	Enhancing recycling	enhanced recycling technologies, moving towards a circular economy, raising material recovery, design for recycling
C 2	State and private governance	
C 2.1	Enhancing industry governance structure	establishing consistent sustainability concepts, (governmental) incentives, consistent decision making, industry and government dialogs
C 2.2	Reducing political risk	changing legislation and rising requirements, lack of (local) enforcement capabilities, dissimilar regulations among countries, property rights
C 2.3	Enhancing waste management	minimizing waste, enhancing disposition and treatment of tailings and wastes
C 3	Enhancing socio-environmental sustainability	
C 3.1	Reducing human rights violations	avoiding slave or forced labor, child labor, financing of conflict
C 3.2	Enhancing working conditions	paying fair wages, lowering health and safety risks, strengthening labor rights
C 3.3	Securing the social license to operate	achieving / exceeding a ratio of (local) development and socio-environmental burden, which is accepted by local stakeholders
C 3.4	Reducing environmental damage	reducing change of landscape, emissions, damaging ecosystems, deforestation

C 4	Decommoditization: Cooperation for a more sustainable mineral supply	
C 4.1	Enhancing cooperation among partners and organizations	reducing fragmentation of SC and resource hoarding, enhancing communication and integration
C 4.2	Enhancing the availability of mineral resources	ensuring long-term availability of minerals / access to minerals or alternative resources, reducing supply risks
C 4.3	Reducing the "by-product character" of minerals without specific production infrastructure	minerals whose provision is dependent on production of a "main mineral" and its market conditions such as gallium from bauxite mining, germanium or indium from zinc and lead mining
C 4.4	Reducing resource consumption	decreasing ore grades, inefficient design of products and processes (incl. transport), lack of recycling, use of energy and water, overconsumption / depletion, supply risks
C 4.5	Enhancing company capabilities and resources	raising the availability of technology, capital, expertise and skills
C 4.6	Enhancing the balance and stability of market conditions	stabilizing prices, controlling power of international companies

Table 3 – List of major issues (serially numbered in their clusters C1 to C4)

The contribution of the four clusters was then re-evaluated in round 3 on a 5-point Likert scale (1 = I fully disagree; 5= I fully agree to a potential contribution of the clustered issues to the respective SSCM objective) to add more depth to the analysis. The related results of rounds 2 and 3 are displayed in Table 4. The frequencies obtained in round 2 and the mean values from round 3 show that throughout both rounds the tendencies stayed consistent for the clusters.

			Meeting stakeholder requirements		Enhancing profitability and competitiveness		Enhancing resilience	
			Up-stream	Down-stream	Up-stream	Down-stream	Up-stream	Down-stream
Round 2	Cluster 1		15	21	13	21	11	17
	Cluster 2		21	20	15	13	20	16
	Cluster 3		24	20	11	9	15	12
	Cluster 4		10	12	17	18	18	18
Round 3	Cluster 1	Mean	3.59	4.03	3.86	4.10	3.79	4.07
		SD	1.15	0.82	1.06	0.86	1.05	0.80
	Cluster 2	Mean	4.10	3.83	4.00	3.72	4.17	3.79
		SD	0.86	1.00	0.76	1.00	0.80	0.98
	Cluster 3	Mean	4.52	3.97	3.28	3.07	4.07	3.62
		SD	0.69	0.98	1.19	0.84	0.84	0.98
	Cluster 4	Mean	3.76	3.62	4.17	4.10	4.31	4.07
		SD	0.99	0.90	0.89	0.82	0.76	1.00
	Mean (all cluster)		3.99	3.86	3.83	3.75	4.09	3.89

Table 4 – Contribution of Clusters to SSCM objectives
(Round 2 (n=29) frequency distribution showing positive responses;

Round 3 (n = 30) values for 5-point Likert scale; SD = standard deviation)

As shown in Table 4, the mean of all clusters is above the central value of the scale, i.e., three. Nevertheless, Table 4 shows that each cluster has its own strengths. Cluster 1 "Creating demand and supply for sustainable minerals" is clearly seen as a major contributor to downstream SSCM success. All downstream values are exceeding the mean values over all clusters and reach into the top range of the scale above 4. The same holds for the contribution of Cluster 2 "State and private governance" in the upstream SC. This clearly underlines the need for more governance efforts in the upstream SC and their positive effect on the entire SC.

Cluster 3 "Enhancing socio-environmental sustainability" is the most important driver for meeting stakeholder requirements in both parts of the SC. In contrast, the cluster is weak in the domain of enhancing profitability and competitiveness. Still, we do not see this as a general denial of economic benefits of sustainable minerals. Combining Cluster 1 results, i.e., above-average profitability impacts of enhanced demand and supply for sustainable minerals, and the below-average impact of Cluster 3 on profitability, show the required actions. These actions are to build a market via issue C 1.2 which includes raising customer awareness as well as paying price premiums and thus building demand for sustainable minerals. Furthermore, Cluster 3 has a substantial resilience impact on the upstream SC which reflects the undeniable business risks of being associated to socially or environmentally irresponsible operations in any segment of the SC (Hartmann & Moeller, 2014; Wilhelm et al., 2016a).

Finally, Cluster 4 "Decommoditization: Cooperation for a more sustainable mineral supply" has been rated remarkably high for the up- and downstream profitability and competitiveness as well as resilience. This underlines the need for more interaction among the SC segments in order to enable synergies and realize the potential regarding the three

SSCM objectives indicated by the experts in this study. The following question thus investigates in which SC segment the issues have to be addressed.

4.3. Where have the issues to be addressed in the mineral SC?

The third questions aimed to identify the origin of the major issues in SSCM for minerals targeted in RQ 2). Consequently, the experts were asked to assign each issue to one or both segments of the SC that offered in their opinion the biggest potential to enhance the beneficial or reduce the adverse issues. Experts were advised to choose "whole SC" in case they see both SC segments as equally relevant. These results are shown in Table 5 for round 2 and 3. Here, we see the typical convergence of results in Delphi studies towards the prevailing answer of the previous round and an increasing emphasis on the whole SC.

		Question 3: SC segments to address issues (Round 2 (n = 29) / Round 3 (n = 30))		
Issues		Upstream	Whole SC	Downstream
C 1.1	Enhancing the traceability of minerals and products	41% / 29%	45% / 71%	14% / 0%
C 1.2	Enhancing the demand for sustainably produced products	10% / 4%	31% / 32%	59% / 64%
C 1.3	Enhancing the perception of sustainability efforts	17% / 7%	62% / 89%	21% / 4%
C 1.4	Enhancing recycling	3% / 4%	45% / 57%	52% / 39%
C 2.1	Enhancing industry governance structure	24% / 26%	76% / 70%	0% / 4%
C 2.2	Reducing political risk	45% / 33%	52% / 63%	3% / 4%
C 2.3	Enhancing waste management	55% / 41%	31% / 56%	14% / 4%
C 3.1	Reducing human rights violations	62% / 58%	38% / 38%	0% / 4%
C 3.2	Enhancing working conditions	62% / 50%	38% / 46%	0% / 4%
C 3.3	Securing the social license to operate	59% / 50%	41% / 46%	0% / 4%
C 3.4	Reducing environmental damage	76% / 46%	24% / 54%	0% / 0%
C 4.1	Enhancing cooperation among partners and organisations	14% / 0%	79% / 96%	7% / 4%
C 4.2	Enhancing the availability of mineral resources	52% / 69%	34% / 31%	14% / 0%
C 4.3	Reducing the "by-product character" of minerals without specific production infrastructure	55% / 77%	24% / 23%	21% / 0%

C 4.4	Reducing resource consumption	10% / 4%	66% / 81%	24% / 15%
C 4.5	Enhancing company capabilities and resources	21% / 0%	66% / 100%	14% / 0%
C 4.6	Enhancing the balance and stability of market conditions	17% / 0%	62% / 96%	21% / 4%

Table 5 – Round 2 and 3 answers regarding the SC segments with biggest potential to address the single issues

Figure 2 visualizes the results of Table 5 and shows the striking emphasis on the cooperation in the whole SC. Moreover, the upstream SC is seen as the SC segement to address the majority of issues. The downstream SC is always involved (at least via the whole SC), but it is directly assigned by more than one expert only concerning the demand for more sustainable products (C 1.2), recycling (C 1.4) and reduced resource consumption (C 4.4). This underlines the need for cooperative solutions and the finding that sustainability issues in mineral SCs cannot be solved by one of the SC segments alone.

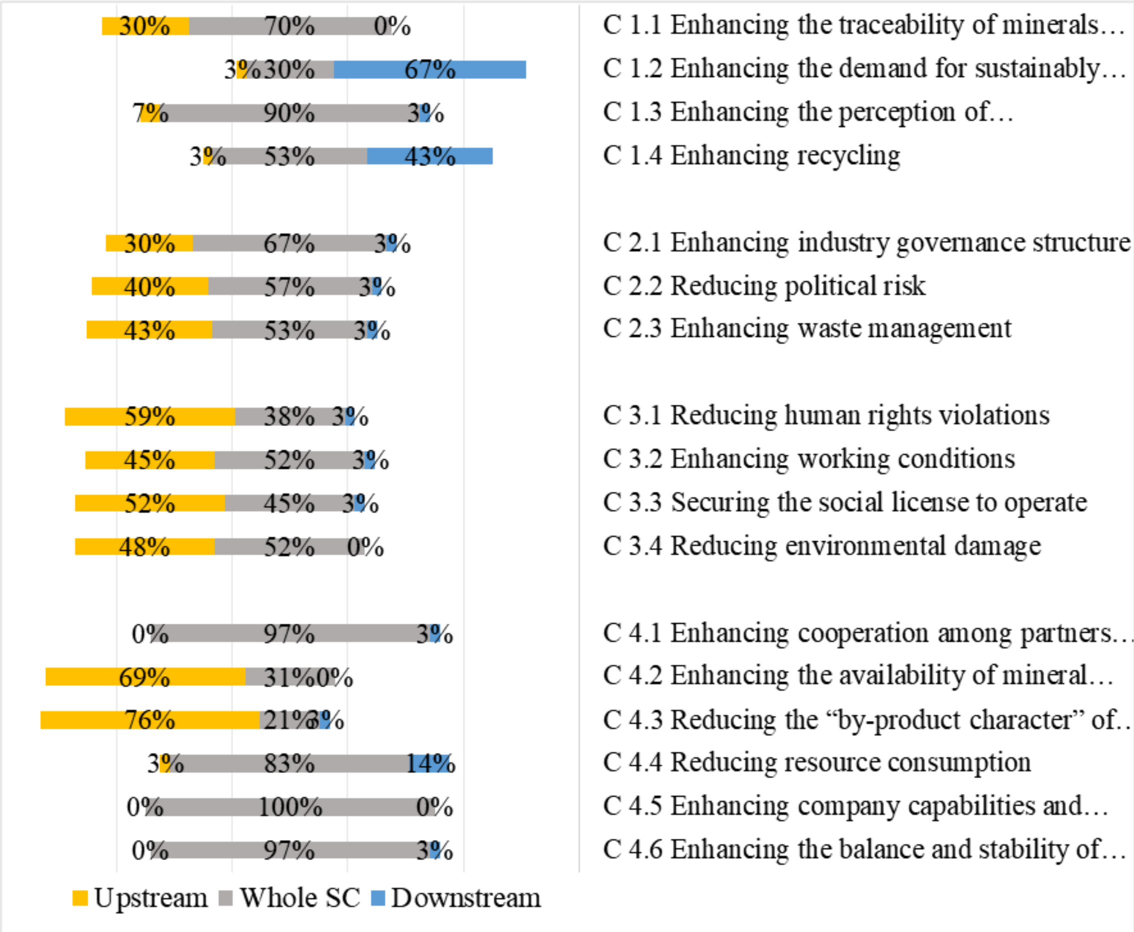

Figure 2 - SC segments offering the biggest potential to address the single issues

Considering the individual clusters, we see that Cluster 1 is attributed to the downstream SC. Contrastingly, the biggest potentials for Cluster 2 and even more for Cluster 3 are seen upstream. Cluster 4 however does not show a clear tendency. In summary, the issues represent a complex interplay along the SC which is delineated in the subsequent sections.

4.4. Conceptual synthesis

Contrasting the up- and downstream segments of the mineral SC revealed the heterogeneity of sustainability issues, their impact on SSCM objectives and their distribution across the SC.

Building on these results, we will now synthesize the issues and current MT-SSCM approaches to answer RQ 3.

4.4.1. Clarifying the relation among the identified issues

The study results underlined the substantial sustainability impact of the raw material stages of a SC (Mena et al., 2013) and the supply side in general (Pagell & Wu, 2009). All social as well as environmental issues showed a clear upstream focus or upstream tendency regarding the biggest resolution potential. Still, such a resolution is dependent on the availability of a) information on the issue and b) resources (capital, skills and technology) for its realization (Pagell & Wu, 2009; Tachizawa & Wong, 2014; Young, 2015). Furthermore, the ability to invest in such measures is dependent on the market stability, which has been low in recent years in the case of minerals (Luthra et al., 2015). This instability hinders an upgrading of the processes in the investment intensive mining industry (Petrie, 2007). However, the issues which enable the upgrading of the upstream SC have clearly been assigned to the whole SC. Especially the issues on enhanced traceability (C 1.1), cooperation (C 4.1) and market stability (C 4.4) are relevant in this regard. These enablers are crucial to enhance the performance and sustainability in mineral SCs (see also Brix-Asala et al., 2018; Hofmann et al., 2018). Therefore, we labelled the issues assigned to the whole SC as “strategic issues”. These issues require long-term actions for their realization and affect the entire SC. In contrast, the issues assigned to one of the SC segments are labelled as “operational issues”, which can and have to be addressed on a smaller scale and in the short term. This structure follows the assumption that “the interdependence of companies refers to both strategic management and to day-to-day operations.” (Seuring & Gold, 2013, p. 1).

Besides the social and environmental issues, two further sets of issues have been assigned to the upstream SC. First, the availability and by-product character of (some) minerals represent technical risks for a stable supply for the downstream SC (Bell et al., 2012). Second, political risks and lacking governance in the upstream SC are unpredictable threats as they open the path for irresponsible business practices (Hofmann et al., 2018). These can impact on the reputation of the entire SC and thus require attention by the whole SC (Hartmann & Moeller, 2014; Wilhelm et al., 2016a).

Again, addressing those issues requires the implementation of strategic issues first. Especially, enhanced traceability is essential to track the supply routes and identify possible bottlenecks (Pagell & Wu, 2009; Young, 2015) as "the heterogeneity, scarcity, and risks associated with mineral supply chains are much more complex than many realize" (Participant 1.12). After these bottlenecks are identified, cooperation and capacity building become important strategic issues to mitigate the mentioned risks. SSCM research suggests a variety of strategies and practices for such cooperation as well as supplier development and underlines their importance (Pagell & Wu, 2009; Beske & Seuring, 2014; Brix-Asala et al., 2018). However, their realization depends on the design of MT-SSCM approaches as shown in the following section.

4.4.2. Evaluating the reach of current multi-tier sustainable supply chain management with regard to mineral supply chains

Following the SC concept outlined in section 2.3, Figure 3 sums up the results of the study in its three parts. The two upper SC concepts display a) the currently available MT-SSCM approach and b) the proposed cascaded approach to address sustainability in mineral SCs. The bottom level c) displays the issues separated in operational and strategic issues.

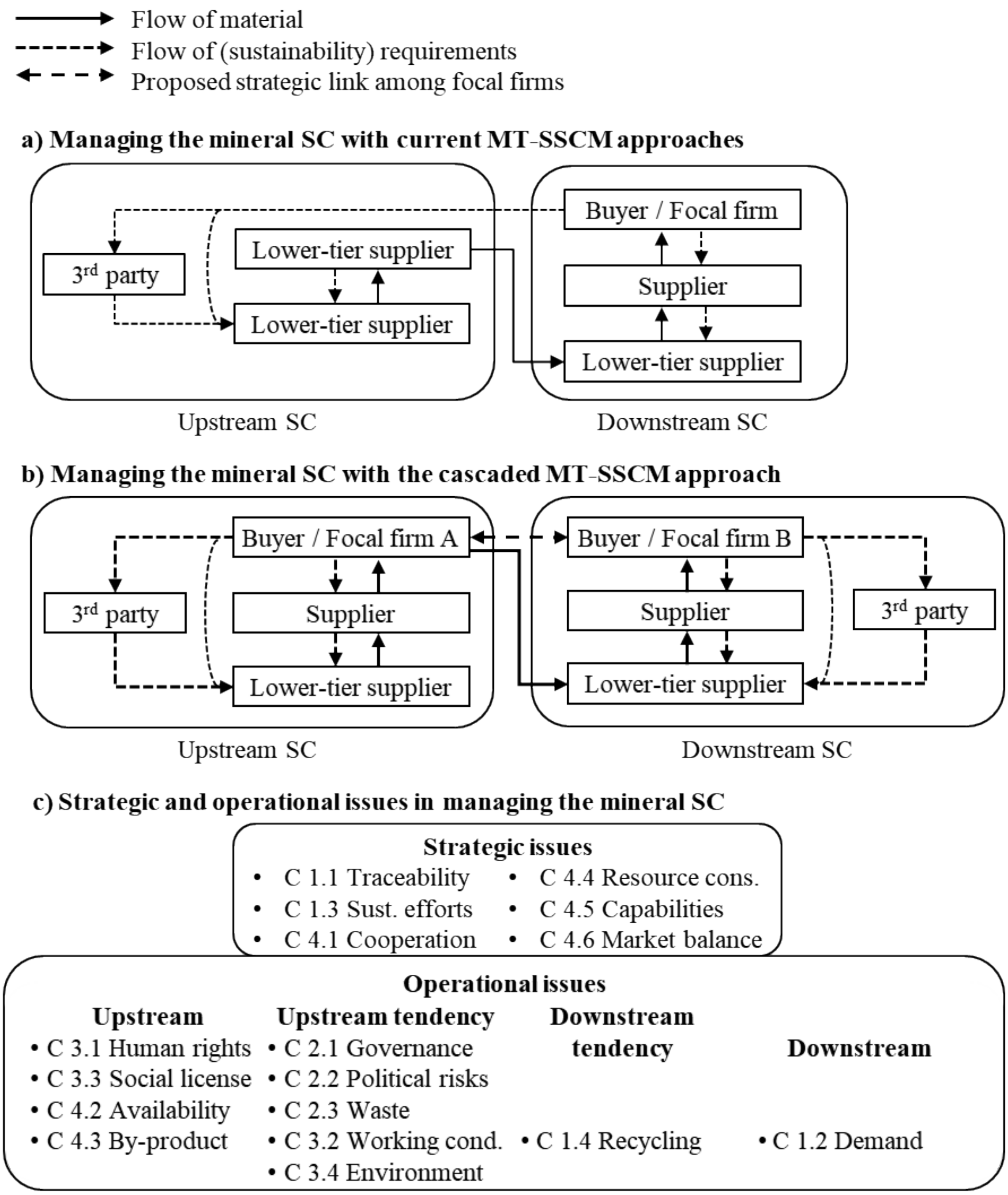

Figure 3 – Linking (a) current and (b) proposed MT-SSCM approaches to (c) strategic and operational issues in the mineral SC (based on Tachizawa and Wong (2014); Sauer and Seuring (2017) and study results)

As outlined in section 2.2 and in Figure 3a, current MT-SSCM approaches propose the leadership of the SC by one focal firm in the downstream SC which needs to manage the chain either directly or with the support of tier-1 suppliers or third parties (Mena et al., 2013; Tachizawa & Wong, 2014; Grimm et al., 2014). However, the reach of the focal firm and its ability to realize the identified issues decreases with each tier it has to manage (Carter et al., 2015).

In comparison, the proposed cascaded MT-SSCM approach follows the division of mineral SC in two distinct segments. These segments build a cascade in which one SC part can pass its challenges and opportunities for solving sustainability issues in the SC on to the other SC part. It thus encompasses two focal firms which need to directly interact to ensure the alignment and implementation of the strategic issues. Based on the strategic alignment, the individual focal firms can taylor the management of their SC segment according to the specific sustainability issues, which are easiest to solve in their SC segment. The management approaches in the single SC segments can then be designed according to the existing MT-SSCM approaches. This is expected to be substantially more efficient, as the SC segments are supposed to be within the visible horizon of the respective focal firm. Moreover, the direct interaction among the two focal firms streamlines information sharing processes which are crucial to achieve high performance in the chain (Kembro et al., 2017).

Which of the MT-SSCM approaches defined by Tachizawa and Wong (2014) can be seen as the most suitable for the individual issues is discussed in the subsequent section.

4.4.3. Grounding the management of the supply chain segments on existing multi-tier sustainable supply chain management approaches

There are four groups of issues across the SC segments, which need to be addressed by applying different MT-SSCM approaches. These groups are organized by combining the results of the two major questions in the study, i.e., the contribution of clusters to SSCM objectives displayed in Table 4 and the identification of SC segments offering the biggest potential to address the single issues shown in Table 5.

First, there are the operational issues contributing to the social and environmental sustainability. These represent reputational risks in the SC (Schmidt et al., 2017; Hofmann et al., 2018) and impact on the SSCM objective of meeting stakeholder requirements (Table 4). In contrast, their impact on profitability and competitiveness is rated below average. Thus, we suggest to implement the "work with third parties" approach by Tachizawa & Wong (2014) which enables a sector wide cooperation and saves resources due to standardization and the avoidance of multiple audits.

Second, the strategic issues can also be implemented via this approach allowing cost savings. However, they are part of Cluster 1 and 4 which rank particularly high in terms of profitability, competitiveness and resilience (see also Hofmann et al., 2018). We thus see their pro-active implementation as a potential path to a competitive advantage. This implies the adoption of an (in-)direct approach, which offers more impact and internalization of knowledge and relations (Tachizawa & Wong, 2014).

Third, both the mentioned sets of technical (Cluster 4) as well as political issues (Cluster 2) represent supply risks. The experts see the resolution of the technical risks as drivers for profitability, competitiveness and resilience. This calls for the use of (in-)direct approaches in order to differentiate themselves from competition (Tachizawa & Wong, 2014). Addressing the political risks in Cluster 2 has been identified as contributor to meeting stakeholder requirements. Furthermore, these issues require an industry wide consensus. We thus propose the "work with third parties" approach, which explicitly includes industry alliances to gain momentum on a common issue (Tachizawa & Wong, 2014).

Finally, only two operational issues have been assigned to the downstream SC. These encompass recycling activities, which provide secondary supplies to the downstream SC and creating demand for sustainably produced minerals and related products. The latter issue moreover encompasses the payment of price premiums for more sustainable supplies, which reduces the cost pressure on actors in upstream SC part, i.e., the commodity SCs. These should ideally "not only survive but thrive" (Pagell & Wu, 2009, p. 52). Thus, both issues contribute to stabilized markets and require the mobilization or concerting of large supply volumes for recycling as well as demand volumes for the sustainably produced minerals. This mobilization and concerting is best achieved with a "work with third parties" approach, which enables to join forces across the entire sector. Implementing these issues could also reduce the current lack of economic resources in the upstream SC, which hinders process upgrading and the implementation of strategic as well as operational issues. However, the high amount of tiers between downstream focal firm and upstream sustainability hotspots requires the proposed cascaded approach to implement an effective SSCM.

The remarkably low number of downstream issues underlines the imbalance of sustainability impacts along the SC and support the SC position paradox outlined by Schmidt et al. (2017). It furthermore shows the relevance of extending the current MT-SSCM focus on triads towards an even wider perspective, as suggested in this study and the following discussion chapter.

5. Discussion

The study combined a renowned method and a novel MT-SSCM approach to crack open the current research silos of sustainability in minerals and mining SCs as well as (multi-tier) SSCM (Sauer & Seuring, 2017). Consequently, we see our study as the first, which addresses the intersection of MT-SSCM and sustainably produced minerals. It yielded a number of observations and research directions which contribute to the praxis as well as to the academic debate in the field. These contributions as well as research directions and limitations will be outlined in the following sections.

5.1. Contributions to the field of sustainability in minerals and mining supply chains

The study covers many issues currently discussed in research on mineral resources. Especially the social, environmental and political issues are well linked and discussed in the field (Petrie, 2007; Young, 2015).

Moreover, mineral SCs feature an upstream commodity segment and a substantially different downstream segment. This study provides a step towards a more comprehensive investigation of mineral SCs by providing definitions concerning their structure. These definitions respond to calls for the incorporation of all major tiers of the chain (Choi & Liker, 2002; Seuring & Gold, 2013), especially the supply side (Pagell & Wu, 2009) as well as the support SC, i.e., actors outside the material flow (Carter et al., 2015).

The main contribution of this study is the explicit link of the identified issues to the management objectives in both the upstream and downstream SC segments. The integration of the buyer perspective, i.e., the contribution of the issues and clusters to the downstream SSCM objectives (see Table 4) is novel. This integration reveals the benefits for the downstream SC when helping to resolve upstream issues. Such benefits have been identified for socially orientied buyers (Brix-Asala et al., 2018), but the study at hand extends this insight to minerals in general. Therefore, this integration of the downstream perspective is the missing link in the current discussion on the economic viability of more sustainably produced minerals, which shows "a need for better understanding institutional behaviour in the context of multilateral partnerships and sophisticated business networks" (Fleury & Davies, 2012, p. 97). This essential influence of market pull has been identified for conflict mineral SCs in which "it appears that markets, not government regulation, are the dominant governance mechanism […], particularly when metals are traced upstream" (Young, 2015, p. 14). Based on the collected expert opinion, we suggest that this holds for a wider set of minerals and contributes to MT-SSCM as well, as outlined below.

5.2. Contributions to multi-tier sustainable supply chain management

The current conceptualization of MT-SSCM is suitable for triads with clear power relations (Mena et al., 2013). This study takes a radical approach towards extending the reach of MT-SSCM by systematically revealing and aligning the upstream and downstream sustainability requirements as called for by Seuring & Gold (2013). The emphasis on sustainability challenges at the upstream end and the focus on the economic benefits at the opposite end of the SC supports current research on the relevance of upstream actors (Pagell & Wu, 2009; Mena et al., 2013) as well as the SC position paradox (Schmidt et al., 2017). Moreover, it showcases the need for taking an enlarged perspective on the SC. This is supported by Kembro et al. (2017), who found a lack of trust, benefit sharing and information quality in multi-tier SCs in general and especially at the intersection of two industries in one SC.

Another contribution with regard to the archetypes of multi-tier SC structures by Mena et al. (2013) and the inclusion of "any lower tier supplier" by Tachizawa & Wong (2014, p. 651) is the cascaded SC displayed in Figure 3. Contrasting their concepts building on a single focal firm, the proposed cascaded design entails multiple focal firms which interact with each other. In this novel design, each SC segment addresses the sustainability challenges which it can best handle. At the same time, the focal firms of each SC segment coordinate the mutual SC goals and the overarching strategy. This strategic link of the focal firm mirrors the direct approach according to Tachizawa & Wong (2014). Within the individual SC segments, all MT-SSCM approaches by

Tachizawa & Wong (2014) can be applied as necessary. This enables the pursuit of an effective MT-SSCM across different actors in day-to-day operations. At the same time the realization of the SSCM strategy and its goals can be tailored to the individual industry in the single SC segments. This combination of concerted strategic SSCM goals on the ultimate SC level (Mentzer et al., 2001) and tailored SSCM operations in the single SC segments contributes to an effective alignment of SC actors and efficient operations in the single SC segments (Seuring & Gold, 2013). This combination of existing MT-SSCM approaches among multiple focal firms in one SC addresses the challenges of MT-SSCM far better than the current MT-SSCM concepts centred around a single focal firm. Especially MT-SSCM challenges such as the visible horizon, which limits the reach of a single focal firm (Carter et al., 2015) as well as the lacking power and knowledge of a single focal firm related to a distant supplier (Tachizawa & Wong, 2014) can be mitigated in the proposed cascaded design. This study thus answers the calls for further exploratory theory development on multi-tier SCs (Kembro et al., 2017; Maestrini et al., 2017).

The proposed cascaded SC structure essentially multiplies previously proposed structures, but adds to the researchable scope, which offers a set of research directions, that will be outlined below.

5.3. Research directions

The outlined cascaded SC design brings up implications for further MT-SSCM research. First, future research could dive deeper into the single sustainability issues identified in this study and investigate appropriate solution approaches. These solution approaches can moreover take the outlined interdependencies of the SC segments into account. Folllowing Autry et al. (2014), a particularly fruitful path might be the investigation of how the two SC segments can first establish stable inter-firm relationships and then move into shared SC processes, which are crucial for enhancing SC performance.

Moreover, the study provides a structure for analysing and modelling SC sustainability and its management on a more holistic level. As performed in this study, relevant sustainability issues, their drivers and resolution approaches can be evaluated in the individual SC segments systematically. This enables a localization of hotspots in the ultimate or extended SC (Mentzer et al., 2001) to guide in depth (multi-tier) SSCM research to determine the most suitable resolution approaches.

Using expert opinion or panel data for the first localization has proven to be an appropriate method (see also Kembro et al., 2017), due to challenges in researching multi-tier SCs (Choi & Liker, 2002; Carter et al., 2015). Building on the suggested cascaded SC structure, expert interviews or focus groups could localize issues in any complex multi-tier SC and build hypotheses on interrelations relevant to sustainability, SC risk or performance. These hypotheses could then be tested in a second more detailed step, such as modelling and empirical research which can gather real life data on the issues and test the hypotheses to determine the most suitable MT-SSCM approaches. Especially, the research on formal SSCM models, SC risk management as well SC performance measurement could benefit from a wider SC coverage, as there is a paucity of models on SSCM, SC risk management and multi-tier SC performance measurement with a comprehensive SC concept (Tse & Tan, 2012; Brandenburg & Rebs, 2015; Maestrini et al., 2017).

In terms of theory, contingency research is gaining traction in MT-SSCM, that investigates in which contexts certain approaches and strategies are successful (Grimm et al., 2014; 2016; Tachizawa & Wong, 2014; Wilhelm et al., 2016a; 2016b). The cascaded SC structure offers a comprehensive multi-tier SC concept to systematically contrast the contexts along the SC. This could deepen the research set ups and enrich the generated data.

Another theoretical aspect in SCM which might profit from the proposed structure is institutional theory. It builds on the concept of an institutional field as its unit of analysis. The results of this study show the substantial differences of SC segments. Thus, we propose to conceive the segments of a SC as different institutional fields or at least sub-fields. Developing related definitions further might enrich SCM and especially MT-SSCM concepts and enhance its theoretical grounding.

5.4. Limitations

The applied SC structure enables a comprehensive "helicopter perspective" on the SC but leads to a lack of details. This is thought provoking and inspiring (Choi & Liker, 2002), but also one of the major limitations of the study. A variety of relative heterogeneous minerals, issues, actors and contexts are evaluated in a common frame. This required a very technical and neutral formulation of issues which inevitably leads to a loss of specificity and details. It furthermore limits the generalizability of the results both in the field of mineral resources and with regard to MT-SSCM.

Furthermore, the expert panel is dominated by academics. Although the results were validated in a practitioner dominated workshop, a bias towards normative results might occur. Still, this calls for a wider evaluation of results with experts from industry, non-govermental and governmental organizations as well as empirical data from cases studies.

6. Conclusion

This Delphi study sheds light on the complexity of sustainability issues in mineral SCs and how MT-SSCM can address them. By building on the expertise of 44 global authors on sustainability in mineral SCs, we suggest a generic structure to research and discuss mineral SCs. It covers all actors from mine to end-customer and reverse SC. Providing such a generalized structure opens up the path for a more comprehensive investigation and understanding of the SC, its actors and challenges (Carter et al., 2015). Moreover, the experts systematically identified, evaluated and re-evaluated a generic set of 17 issues aiming for an enhanced sustainability performance of mineral SCs. This set of issues represents a generic orientation concerning a) sustainability challenges and opportunities in mineral SCs, b) establishing the benefits of resolving the challenges for the individual segments of the SC and c) in which SC segment they need to be addressed. However, this localization revealed that the current triadic or tetradic MT-SSCM research lacks reach to comprehensively address the issues. The study's major contribution thus is the proposition of a cascaded approach which helps to drive MT-SSCM further and enlarge its impact for practice and research. On the minerals' side, the study helps reducing the "lack of awareness of what happens in the stages from mining to the smelters [… of] most businesses and managers" in the mineral SC (Respondent 1.12). The study results can be useful for researchers and practitioners alike as they link the relevant issues across all dimensions of sustainability to the core objectives of SSCM. This reveals the potential economic benefits of enhanced sustainability performance in the mineral SC, which is especially relevant for industrial applications. The explicit identification of leverage potentials that can only be realized by SC wide cooperation, contrasts the currently widely applied price driven commodity logic in mineral SCs and provides support for a decommoditization of resources as put forward by Pagell & Wu (2009).

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Appendix

	Issue	Meeting stakeholder requirements		Enhancing profitability & competitiveness		Enhancing resilience	
		Up-stream	Down-stream	Up-stream	Down-stream	Up-stream	Down-stream
C 1.1	Enhancing the traceability of minerals and products	19	26	14	20	15	17
C 1.2	Enhancing the demand for sustainably produced products	11	16	13	23	7	14
C 1.3	Enhancing the perception of sustainability efforts	19	22	13	20	13	16
C 1.4	Enhancing recycling	9	19	10	22	10	19
C 2.1	Enhancing industry governance structure	21	20	15	14	20	18
C 2.2	Reducing political risk	21	19	14	11	21	17
C 2.3	Enhancing waste management	21	21	16	15	18	14
C 3.1	Reducing human rights violations	22	22	9	9	15	14
C 3.2	Enhancing working conditions	21	16	9	9	15	12
C 3.3	Securing the social license to operate	28	20	11	6	19	14
C 3.4	Reducing environmental damage	25	20	15	10	9	9
C 4.1	Enhancing cooperation among partners and organizations	13	14	17	18	20	21
C 4.2	Enhancing the availability of mineral resources	11	13	16	16	21	22
C 4.3	Reducing the “by-product cha-racter” of minerals without specific production infrastructure	9	8	13	12	15	15
C 4.4	Reducing resource consumption	9	14	15	16	16	17
C 4.5	Enhancing company capabilities and resources	14	12	28	24	20	19
C 4.6	Enhancing the balance and stability of market conditions	6	10	15	19	18	16

Appendix 1 – Round 2 results: positive answers of the contribution of individual issues to SSCM objectives (n=29)

	Meeting stakeholder requirements		Enhancing profitability & competitiveness		Enhancing resilience	
	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
Cluster 1	0.65	0.78	0.16	0.08	0.67	0.41
Cluster 2	0.00	0.04	0.05	0.15	0.13	0.41
Cluster 3	0.23	0.27	0.44	0.10	0.93	0.53
Cluster 4	0.20	0.25	1.58	0.54	0.32	0.75

Appendix 2 – F-Values of all four clusters and all six cluster variables