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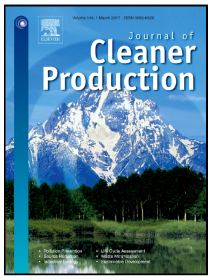

Sustainable supply chain management for minerals

Philipp Christopher Sauer, Stefan Seuring

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Sustainable supply chain management for minerals

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

[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

As inputs to virtually all supply chains (SCs), mineral resources drive the modern economy. However, despite the substantial sustainability impact of the initial stages of mineral SCs, these remain largely outside the scope of sustainable supply chain management (SSCM). This paper aims to map the intersection of the literature on sustainability in mineral SCs and SSCM, thus bridging the current gap, and to propose research directions for future work. The paper presents a structured content-analysis based literature review of 67 peer-reviewed, English-language journal papers listed in the Web of Science database. These have been identified via a keyword search for SC-, mineral- and mining-specific terms. The content analysis is based on the work of Beske and Seuring (2014), which is abductively complemented with mineral SC-specific practices to build a comprehensive SSCM for minerals framework. Furthermore a contingency analysis is conducted to reveal association patterns between the used constructs. As main contribution, we propose the addition of a Government interventions category as well as mineral-specific practices to the Risk and Pro-activity management categories of the framework. These are identified as essential practices for improving the sustainability in mineral SCs. Moreover, a cascaded mineral SC design is proposed adopting literature based propositions. It 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. This design integrates mineral extraction and refinement into a comprehensive SSCM approach and proposes practices for its realization. The resulting approach thus offers the potential for supreme sustainability performance in mineral SCs. Finally, research directions for future studies on this issue are formulated.

Highlights

- First systematic literature review on sustainability in mineral supply chains
- Practices for sustainable supply chain management for minerals are proposed
- The use of these practices is analyzed across the mineral supply chain
- Contingencies among the practices are calculated and discussed
- Research directions for the future development of the field are derived

Keywords

Supply chain management; Mineral resources; Sustainability; Literature review; Content analysis; Contingency analysis

1 Introduction

Sustainability in mineral supply chains (SCs) is a contentious topic: Some say that sustainability is already a reality in mineral SCs, while others consider the phrase an oxymoron. Both the positive effects of mineral SCs on employment and revenue generation and their severe environmental and social impacts have been widely discussed in the field (Laurence, 2011).

However, the implementation of sustainable development "that meets the basic needs of all people without compromising the ability of future generations to meet their own life-sustaining needs" (WCED, 1987) requires the inclusion of all three dimensions — economic, environmental, and social — of the triple bottom line (TBL) (Elkington, 1997). In the case of non-renewable resources, like minerals, this task implies a double responsibility of the current generation. First, this generation has to use the minerals to meet its own needs. Second, it has to sustain and enhance its other resources or develop new ones, which future generations can rely on. This encompasses especially preserving the fertility of farmlands, building mineral processing capabilities, or developing businesses and industries which do not rely on mineral resources (Ebert and La Menza, 2015; Morris et al., 2012; Solomon, 2011). However, balancing these tasks is highly challenging, as it is a trade into the future with an uncertain outcome. Giurco and Cooper (2012) demonstrate that discussions related to this trade-off mainly focus on the mines themselves, and they call for the adoption of a more integrated view.

Drawing from the research on supply chain management (SCM), we suggest that the SC offers a useful perspective on the issue. Giurco and Petrie (2007, p. 843) summarize the applicability of SCs in the challenging context of minerals by stating: "Notwithstanding the complexity of connected metal cycles, the value chain perspective provides a helpful starting point from which to consider the sustainability of metal cycles at large, with explicit consideration of conflicting objectives, values and perspectives." These conflicting sustainability perceptions and issues along the SC impact the ability of the current generation to use the minerals in their own interests and need to be addressed to enhance the sustainability in mineral SC (Fleury and Davies, 2012; McLellan et al., 2009).

Especially sustainable SCM (SSCM) offers valuable approaches for this task by integrating the TBL into SCM (Seuring and Müller, 2008). However, applying SSCM to mineral-specific challenges, such as human rights violations and civil wars (Bleischwitz et al., 2012; OECD, 2013), toxic and radioactive wastes in multiple SC stages (Edraki et al., 2014; Golev et al., 2014), and the opaque material and capital flows undermining current transparency efforts (Rotter et al., 2014; Scheijgrond, 2011), requires an adaption of available concepts. Despite this need, no comprehensive concept for the introduction of sustainability practices into the highly specific context of mineral SCs has yet been identified (Pimentel et al., 2016). It is the aim of this paper to address this gap by answering the following research questions:

RQ 1) What is the current state of research on SSCM and sustainability in mineral SCs, and what overlaps and gaps are evident?

RQ 2) Which future research directions can be identified for the field?

To answer these questions, we conducted the first structured review of scientific literature at the intersection of SCM, sustainability, and mining and minerals. Systematic literature reviews are the method of choice for mapping the state of knowledge in a field, and they offer the potential for theory development through the identification of knowledge gaps, related research avenues, and possible links among previously isolated research topics (Seuring and Gold, 2012; Tranfield et al., 2003).

This paper contributes to the fields of mining and sustainability as well as SSCM by 1) bridging the gaps that exist across the dispersed research areas of sustainability in mineral SCs and SSCM by outlining the current state of the related academic discussion and 2) offering promising directions for further research efforts towards more sustainable mineral SCs.

To achieve these objectives, we will begin by laying a basic terminological groundwork in the upcoming section. Next, in chapter three, we will introduce the applied method. This is followed by the findings and a discussion of the issue. Finally, we will identify the limitations of our research and develop our research proposition. The conclusion summarizes the paper.

2 The sustainability discussion in mineral supply chains

During the analysis, a variety of SC understandings became evident within the mineral SC literature. Thus, in Figure 1, we provide a generic concept of a mineral SC as a basis for the upcoming analysis. The defined SC stages are used for both the descriptive analysis and the contingency analysis to excavate the relations among SC stages and SSCM practices. The concept represents an ultimate SC, including "all the organizations involved in all the upstream and downstream flows of products, services, finances, and information from the ultimate supplier to the ultimate customer" (Mentzer et al., 2001, p. 4). Furthermore, it incorporates generic mineral SC stages (which vary in their characteristics for different minerals) and the diversion into upstream and downstream SC that often exist in mineral SC literature (e.g. Ortiz and Viana Júnior, 2014; Giurco et al., 2014; Rauer and Kaufmann, 2015). The concept furthermore encompasses individual focal firms for the SC parts, as proposed by Young (2015). These firms shape the management of the individual SC tiers against the aim of enhanced sustainability performance (Seuring and Müller, 2008). Finally, recycling and reuse operations, which supply secondary inputs within the downstream SC, are also covered (e.g. Geyer and Blass, 2010; Prior et al., 2013).

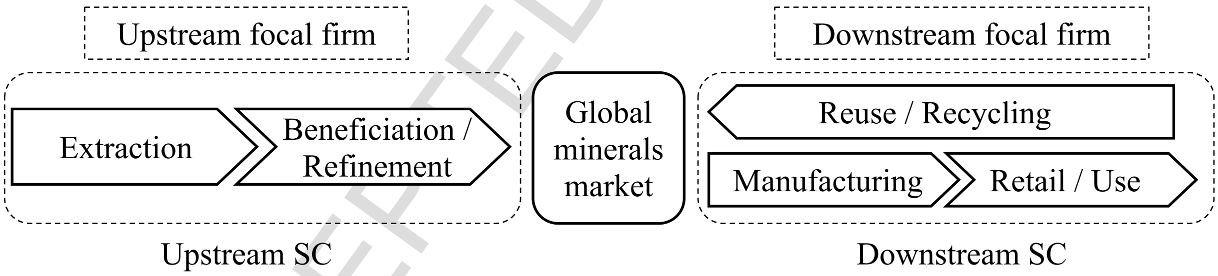

Figure 1: Mineral SC concept

Onto this generic mineral SC, we apply the concept of SSCM, as defined by Ahi and Searcy (2013, p. 339):

> "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 in order to meet stakeholder requirements and improve the profitability, competitiveness, and resilience of the organization over the short- and long-term."

In particular, the described translation of stakeholder requirements into sourcing decisions (Koplin et al., 2007) makes SSCM a fruitful lens through which to enhance the sustainability in mineral SCs. Previous research has identified several SSCM concepts (Carter and Easton, 2011; Pagell and Wu, 2009; Seuring and Müller, 2008; Beske and Seuring, 2014), on which we will draw in this paper. Based on these concepts, we apply an abductive research process (Spens and Kovács, 2006), which adapts Beske and Seuring's (2014) concept to the mineral context by adding mineral SC-specific practices identified in the reviewed literature. This particular framework is chosen because it provides a generic list of practices that enable SSCM and, thus, serves as a sound starting point. Figure 2 shows the resulting SSCM for minerals framework, which is separated into three parts: Strategic values, SC structure, and SSCM processes of mineral SCs. These three areas encompass several categories and practices. A category is "an umbrella term to group and sort the different practices and link them to relevant issues" (Beske and Seuring, 2014, p. 323). By contrast, a practice is "the customary, habitual or expected procedure or way of doing something" (Beske and Seuring, 2014, p. 323). The arrows in Figure 2 further show the relations among the categories, illustrating which categories impact others. For clarity, both categories and practices are written in italics and start with capital letters in the upcoming chapters of the paper.

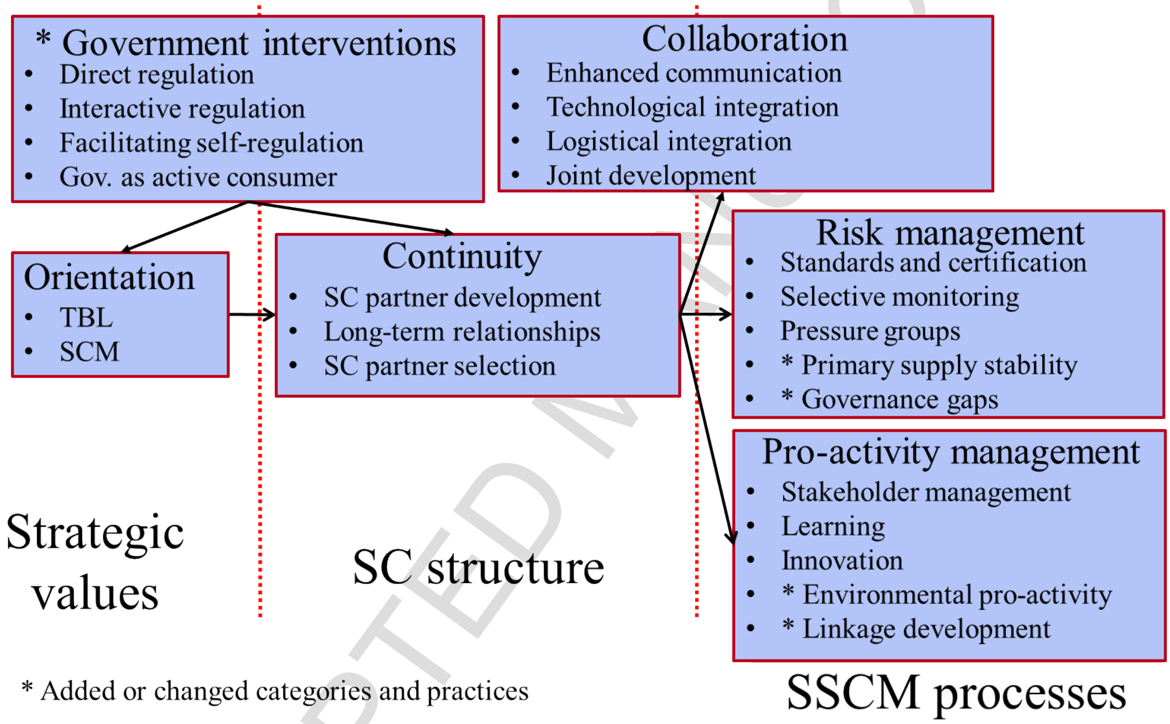

Figure 2: Abductively complemented SSCM for minerals framework (based on Beske and Seuring, 2014)

For building Figure 2, we kept the basic framework by Beske and Seuring (2014) as the main structure into which we integrate a pre-defined and thus deductive *Government interventions* category based on Vermeulen and Kok (2012). It adds to the understanding of sustainable supply chains as private and largely self-regulating governance systems. It operationalizes the way in which "governments support, facilitate or even monitor and assure success of these 'self-regulated' initiatives" via four practices (Vermeulen and Kok, 2012, p. 185). These are shown in Figure 2 and are described in more detail with regard to mineral SCs in section 4.2.1. As a result, this category analyses the institutional context in which the actors of the evaluated SC operate. Institutional contexts differ significantly across the countries in a mineral SC and set the frame for the strategic and operational characteristics (Seuring and Müller, 2008; Vermeulen and Kok, 2012). Thus, the *Government interventions* span both the Strategic values and the SC structure portions of the concept. In addition, we have identified three practices in the analyzed literature, which are relevant in research on the sustainability in mineral SCs but not represented in the deductive frameworks we used. These three practices emerged from the analyzed material and are thus inductively defined and then added to the SSCM processes by Beske and Seuring (2014). Finally, we re-defined the original practice of "Life cycle assessment" into the more general "Environmental pro-activity" encompassing any environmental beneficial practice. This is necessary to fully capture the wide range of environmentally beneficial practices in mineral SCs (e.g. Kusi-Sarpong et al., 2015).

Categories and related practices	Description
*** Government interventions** 1) Direct regulation 2) Interactive regulation 3) Facilitating self-regulation 4) Government as active consumer	**Governments intervene** in SC governance and operations by imposing legally binding **direct regulations**, **interacting** with and financing social society actors, and providing information and guidance to **facilitate self-regulation**. In addition, they can act as **active consumers** to build markets for more sustainable products and services.
Orientation 5) Dedication to TBL 6) Dedication to SCM	**Orientation** centers on the strategic decisions of SC members to adopt the **TBL** and **SCM** practices to realize competitive advantages.
Continuity 7) SC partner development 8) Long-term relationships 9) SC partner selection	**Continuity** draws on the SC structure and focuses on building **long-term relationships** with **selected SC partners**. Subsequent **development of** weak **partners** enhances overall SC performance.
Collaboration 10) Enhanced communication 11) Technological integration 12) Logistical integration 13) Joint development	Operational practices, such as **enhanced communication** and **joint development**, strengthen the **collaboration** among SC members, which is further facilitated by integrating **logistical** and **technological** structures.
Risk management 14) Standards and certification 15) Selective monitoring 16) Pressure groups 17) * Primary supply stability 18) * Governance gaps	**Pressure groups** targeting unsustainable operations in the SC represent major SC **risks**, which can be mitigated by **monitoring** suppliers and relying on **standards and certification**. Mineral SCs have to develop governance structures, since they often include weak **governance** contexts. In addition, it is important to **stabilize primary mineral supplies,** which have recently been subjected to substantial volatility and represent a supply risk.
Pro-activity management 19) Stakeholder management 20) Learning 21) Innovation 22) * Environmental pro-activity 23) * Linkage development	Being **pro-active** in mineral SCs starts with **developing linkages** at the mine to share revenues with often-exploited local **stakeholders**. Managing **stakeholder** requirements enables **learning** effects, which stimulate SC **innovation**. **Environmental pro-activity** represents a further means to diversify from competitors and gain competitive advantages in mineral SCs.

Table 1: Category overview, frequencies, and descriptions of related practices
*(own illustration based on Vermeulen and Kok (2012) and Beske and Seuring (2014); abductive or re-defined categories and practices are marked with *)*

The widened as well as the three added practices have been marked with asterisks (*) in Figure 2 and Table 1, which depict and operationalize the categories and practices used and illustrate our framework. The single constructs are defined and coded discriminant to one another (i.e. to allow clear differentiation, neither the categories nor the practices overlap in scope). Additionally, the items are sufficiently operational, so they allow the coding of respective publications.

The added practices are: (1) ensuring *Primary supply stability*, (2) filling *Governance gaps*, and (3) *Linkage development*. While the first two are self-explanatory, a short definition is required for the last one. *Linkage development* describes commodity-based economic growth as a three-level creation of economic linkages among related actors (Hirschman, 1981; Morris et al., 2012). These levels include fiscal (taxes and royalties), consumption (domestic demand driven by miners' income), and production linkages (provision of supplies for mines and processors). The more such linkages exist in a mining region, the higher the degree of value addition and, thus, the higher the mine's economic and social development impact.

3 Methodology

3.1 Literature review

This review applies a systematic, content-analysis based literature review approach (Seuring and Gold, 2012). It encompasses the analysis of a set of systematically identified literature by means of content analysis and allows a rule-governed combination of quantitative and qualitative arguments (Mayring, 2010) and reproducibility (Fink, 2010). The empirical social sciences define content analysis as "any methodological measurement applied to text (or other symbolic materials) for social science purposes" (Shapiro and Markoff, 1997, p. 14). This definition can be broken down into two main foci of analysis: recording text statistics to evaluate manifest content and interpreting latent content to excavate the ideas between the lines. These steps can be conducted either deductively or inductively (Mayring, 2010).

The applied systematic literature review process proposed by Seuring and Gold (2012) integrates the four-step content analysis by Mayring (2010). It consists of (1) *material collection*, (2) *descriptive analysis*, (3) *category selection*, and (4) *material evaluation*, which are briefly specified for our research in the upcoming paragraphs. This approach encompasses widely accepted literature review process steps (e.g. Tranfield et al., 2003; Fink, 2010) in its steps (1), (2), and (4). Step (3), the *category selection*, encompasses the core of the approach. It builds on content analysis techniques for a rule governed, transparent, and replicable definition of a category system (Mayring, 2010). This system is built and refined in an iterative way during the analysis and is used to synthesize the material against the research questions (Seuring and Gold, 2012; Mayring, 2010). Seuring and Gold (2012) adapted the generic approach by Mayring (2010) to the field of SCM. We prefer this more detailed approach for our field against other well-known but more generic approaches such as the ones by Tranfield et al. (2003) or Fink (2010).

As a result, the *material collection* phase encompassed the study design including the formulation of research questions, definition of search parameters as well as databases, and obtaining the material. The latter is based on a keyword search in the titles, keywords, and abstracts of peer-reviewed English articles in the Web of Science (WOS) database. The choice of this database in uncommon in SCM research. However, the WOS is in our eyes the most suitable database for our research. It matches the two core quality criteria for literature databases requested in leading literature review approaches such as the ones by Tranfield et al. (2003) and Fink (2010). (1) The scope of the database fits our research design and questions. The WOS offers more than 22,000 journals across all major publishers. This is the probably widest range of high quality scientific journals of all databases. Furthermore, our two main review topics of sustainability in mineral SCs and mining as well as (S)SCM are well represented. The related Social Science and the Science Citation Index alone provide 3245 and 8864 journals respectively. (2) These are compiled in one database and can be searched in a unified process using Boolean operators to build a tailored search string. This enables us to deliver a consistent set of literature spanning both topics reviewed in this paper. Including all WOS sub-databases and publication dates before 2016 yielded a comprehensive coverage of all topics associated with the research objective. The search terms formed two groups: (1) The SC dimension included the term itself and its synonyms. Including SC synonyms is uncommon in recent SCM literature reviews (Ahi and Searcy, 2013; Yawar and Seuring, 2015; Ashby et al., 2012), but excluding them reduces the number of articles by more than a third. (2) The mining- and mineral-related keywords were extracted from the glossary of Directive 2006/21/EC on Extractive Industries by the European Commission (2015). The applied search steps and their outcomes are listed in Table 2, which documents our *material collection* process.

Search and reduction steps	**Found/remaining articles**
Initial search using the search string: ("supply chain*" OR "value chain*" OR "demand chain*" OR "value network*" OR "value stream*" OR "chain of custod*") AND (*metal* OR mine* OR mining* OR quarr* OR ore* OR "open pit*" OR "rare earth*" OR *rock* OR *stone*)	654 articles using the required key words regardless of the relation of mineral and SC related terms
Automatic exclusion of irrelevant articles using the following search string: NOT ("data mining*" OR "text mining*" OR earthquake OR "process mining" OR oregon OR milestone OR cornerstone OR keystone)	508 articles using the required key words while not using the excluded words regardless of the relation of mineral and SC related terms
Manual screening of abstracts against the relation of mineral and SC terms to identify articles on mineral SCs	191 articles addressing mineral SCs
Manual screening of abstracts to identify articles directly addressing sustainability or one of its dimensions in mineral SCs	67 articles at the intersection of sustainability in mineral SCs and supply chain management

Table 2: Search and reduction steps during the material collection

These articles were then reduced in multiple steps as shown in Table 2. This reduction encompassed both an automatic and manual screening of abstracts in order to identify articles addressing mineral SCs and their sustainability or one of its dimensions. Regarding the economic dimension a clear development impact on the stakeholders of the relevant actors had to be evident to be selected for further analysis. Optimization papers were excluded, since these models focus on individual issues without incorporating the complex but often decisive interdependencies among the field's “conflicting objectives, values and perspectives” (Giurco and Petrie, 2007, p. 843). Neither sustainability nor its dimensions were represented in the search terms; this choice represented an attempt to broaden the search results and, thus, the potential insights of the review. Finally, a sample of 67 papers was selected for further analysis, which are numbered in squared brackets in the reference section.

The *descriptive analysis* delineates the formal characteristics of the papers, such as the years and journals in which the papers were published, the regional and SC foci, and the applied research methodologies.

The subsequent *category selection* follows "the default two-steps approach" of category building by Seuring and Gold (2012, p. 552). It starts with the adoption of the deductive categories derived from Vermeulen and Kok (2012) and Beske and Seuring (2014) based on the definition of the review topic of SSCM and sustainability in mineral SCs. This set of categories is then complemented by defining additional practices to capture emergent issues identified in the reviewed literature. The applied process of iteratively adding inductive categories identified in the analyzed material to pre-defined deductive frameworks represents an abductive research approach as proposed by Spens and Kovács (2006). Its results have already been displayed in Table 1 and Figure 2.

The final *material evaluation* is conducted by coding the papers against the defined categories and then analyzing and drawing conclusions from these results. Following the research foci of content analysis discussed above, the evaluation of the coding results is twofold. First, the distribution of frequencies among the specific practices is discussed to identify prevailing ones. Second, the specific topics in the individual papers are reviewed to provide insights into the practices and reveal the underlying discussions in the field.

This research design inherently raises the questions of validity and reliability, which are discussed in chapter 5. While the outcomes of the literature search and the *category selection* are covered by this chapter and in Table 1, respectively, the findings of the *descriptive analysis* and the *material evaluation* are presented in the upcoming chapters.

3.2 Contingency analysis

In order to complement the more qualitative work related to the content analysis, we also performed a contingency analysis. It excavates "association patterns between categories, i.e. […] pairs of categories which occur relatively more [or less] frequently together in one paper than the product of their single probabilities would suggest" (Gold et al., 2010, p. 235). This is done based on the coding frequencies compiled in the *material evaluation* and the strength of these patterns is evaluated based on the phi-coefficient (φ). It is calculated using a chi-square test. Thus, two quality requirements must be met to identify valid and significant relations. None of the expected counts in the contingency table may be below 5, and φ must be above 0.3 (Fleiss et al., 2003).

However, the identified patterns do not reveal any underlying causality. Even the use of both categories in a single paper could be unintentional. Still, the positive associations among the categories point towards a connection that must be justified against the related literature. Adding the contingencies offer insights into the use of practices within the individual papers. This contrasts with the content analysis, which focusses on similar contents across different articles. Combining both methods offers substantial value by enabling a second level of analysis and interpretation. This is especially interesting as we review a highly heterogeneous field. The contingencies can excavate statistically significant gaps as well as links within the literature sample and are thus essential to answer our research questions. This is done in the upcoming findings and discussion chapters.

4 Findings
4.1 Descriptive analysis

The formal characteristics of the review sample reveal its relative infancy. The distribution of papers over time in Figure 3 shows the growing scientific interest in the topic. Since the publication of the first articles in 2007, the issue has continuously gained traction.

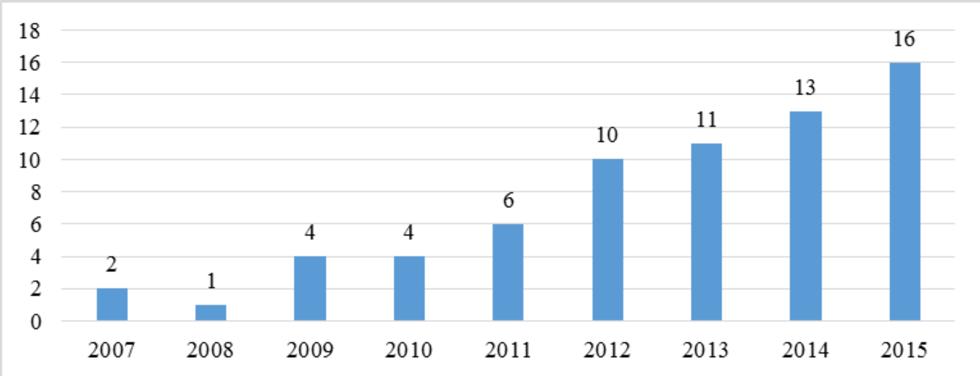

Figure 3: Distribution of reviewed publications over time (n = 67)

While the positive trend is not surprising due to the growing interest in sustainability and SCM research (e.g. Ahi and Searcy, 2013; Ashby et al., 2012; Seuring and Müller, 2008), the appearance of the first articles in 2007 is. This indicates a late integration of SCM and sustainability into mineral SCs. Both SCM and sustainability emerged during the 1980s (Bichueti et al., 2014), and other literature reviews on sustainability and SCM identified their first papers in the 1980s (Ashby et al., 2012) or the mid-1990s (Seuring and Müller, 2008). This underscores the argument for a developing field at the intersection of sustainability, mining and minerals, and SCM (Fessehaie, 2012; Govindan et al., 2014).

The rising publication numbers are also driven by special issues in *Resources Policy* in 2012 and 2015, the *Journal of Cleaner Production* in 2014, and *Waste Management & Research* in 2011, which accounted for five, seven, four and two papers, respectively. The first two journals also provide the most papers in the sample (17 and 7, respectively). In total, 36 journals are identified, covering multiple research domains. The majority of the journals (11 journals, accounting for 33 papers) focus on resources, including energy, recycling, and minerals. The nine sustainability-oriented journals contribute 18 publications, and the 8 business, 4 manufacturing and production, and 4 cultural studies journals contribute one paper each. This wide distribution of journals reveals the relevance and interdisciplinary scope of the topic.

A similarly dispersed picture is evident in the regional focus. The coding logic used seeks to exclusively assign papers to either a single continent or — if multiple continents are discussed — the *Generic* subcategory. This results in 30 *Generic* articles, 12 each focusing on *Africa* and *Asia*, 5 on *Latin America*, 4 on *Oceania*, 3 on *Europe*, and only 1 on *North America*. The fact that *Generic* articles represent the majority illustrates the topic's global interdependencies. The high frequencies for *Africa*, *Asia,* and *Latin America* underscore the impact and importance of developing economies for sustainability in mineral SCs (see also Giurco and Petrie, 2007). This observation is further supported by the low counts for the developed economies.

The coding against the SC focus follows an analogue logic. Papers drawing on more than one of the SC elements depicted in Figure 1 are coded as *Overarching*. In sum, 28 papers were categorized as *Extraction*, 1 as *Refinement*, 3 as *Manufacturing*, 0 as *Retail*, 13 as *Recycling*, and 22 as *Overarching*. This implies a clear focus of the mineral SC literature on primary and secondary resources, while intermediate processes are less commonly discussed or focused on at an aggregated level.

The applied research methods displayed in Table 3 reveal a predominance of *Case studies*, while *Theory* papers, *Models*, *Surveys*, and *Reviews* are substantially less common. Although 8 theoretical papers out of 67 total articles seems to represent a sound theoretical basis, a deeper look into these publications reveals their diverse foci. 2 papers draw on closed-loop SCs (Sahamie et al., 2013) and metal recycling (Wilts et al., 2011). 5 papers build on SCM; however, subfields, such as scarce minerals as SC risk (Bell et al., 2012; Slowinski et al., 2013), green SCM (Rauer and Kaufmann, 2015; Xu et al., 2013), and market access restrictions as pressure towards sustainable SC operations (Fleury and Davies, 2012), are discussed separately. Finally Morris et al. (2012) examine *Linkage development* and economic diversification. This dispersed picture underlines the need for a comprehensive conceptualization to build a sound basis for further research in the field. This observation is supported by the low frequencies for *Reviews*, *Models*, and *Surveys*, as well as by the dominance of *Case studies*, which are "one of the best (if not the best) of the bridges from rich qualitative evidence to mainstream deductive research" (Eisenhardt and Graebner, 2007, p. 25).

Applied research method	**Case study**	**Model**	**Theory**	**Review**	**Survey**
No. of publications (n = 67)	45	10	8	2	2

Table 3: Applied research methods of reviewed publications

Moreover, the two identified *Reviews* are of interest with regard to possible overlaps with the given paper. The first evaluates the sustainability of rare earth minerals against the TBL dimensions and techno-scientific aspects (McLellan et al., 2013). The second draws on mine tailings and reviews the technological approaches available for optimizing their sustainability impacts (Edraki et al., 2014). Both publications have a technical focus on specific minerals and the often-toxic byproducts of the initial SC stages. These findings further underscore the need for a broad review in order to conceptualize the interdependencies that arise in the complex circumstances and properties of mineral SCs (Giurco and Petrie, 2007; OECD, 2013). The use of *Models* is substantially driven by a special issue in *Resources Policy* published in 2015. It is titled "Application of multi-criteria decision making/operations research techniques for sustainable management in mining and minerals" and accounts for six *Models* and one *Case study*.

4.2 Material evaluation

This step of the review process covers the analysis of the selected publications and the coding against the previously defined categories. Its findings are presented according to the structure outlined in the Tables 1 and 4. Table 4 presents the individual papers assigned to each of the practices. The frequencies given in the table represent the number of papers drawing on both the individual practices and the entire category. Since papers can be assigned to more than one practice per category, the sum on the category level is usually lower than the sum of the frequencies for the related practices.

Categories and practices	Reference number of assigned paper	Sum
*** Government interventions**	**see individual practices**	**55**
1) Direct regulation	2, 4, 5, 6, 7, 8, 11, 13, 14, 15, 19, 20, 21, 26, 27, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 42, 43, 44, 46, 48, 50, 51, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66	47
2) Interactive regulation	4, 5, 6, 9, 11, 13, 14, 16, 18, 19, 21, 22, 24, 28, 30, 34, 35, 37, 38, 39, 40, 41, 44, 45, 46, 48, 50, 51, 53, 56, 57, 58, 59, 60, 61, 63, 64	37
3) Facilitating self-regulation	6, 21, 22, 24, 30, 39, 51, 56	8
4) Government as active consumer	none	0
Orientation	**see individual practices**	**44**
5) Dedication to TBL	2, 4, 7, 8, 12, 15, 17, 21, 22, 25, 26, 30, 31, 32, 35, 38, 42, 45, 46, 48, 54, 56, 60, 63, 66	25
6) Dedication to SCM	1, 2, 6, 11, 13, 14, 15, 17, 23, 25, 26, 28, 30, 31, 33, 34, 35, 36, 40, 42, 43, 50, 51, 54, 55, 57, 61, 62, 65	29
Continuity	**see individual practices**	**31**
7) SC partner development	2, 11, 13, 14, 17, 22, 28, 31, 34, 36, 40, 50, 51, 65	14
8) Long-term relationships	6, 7, 11, 13, 14, 21, 23, 26, 28, 30, 31, 33, 34, 36, 40, 48, 50, 51, 55, 57, 58, 61, 62, 65	24
9) SC partner selection	3, 13, 14, 15, 22, 25, 30, 31, 33, 34, 40, 46, 50	13
Collaboration	**see individual practices**	**29**
10) Enhanced communication	2, 6, 7, 13, 17, 21, 23, 28, 29, 33, 34, 35, 36, 40, 44, 45, 46, 48, 50, 51, 54, 55, 60, 64	24
11) Technological integration	6, 33, 34, 50, 55	5
12) Logistical integration	1, 13, 31, 33, 55, 63	6
13) Joint development	13, 14, 23, 29, 31, 33, 35, 36, 50, 57, 60	11
Risk management	**see individual practices**	**60**
14) Standards and certification	4, 10, 14, 15, 17, 22, 25, 26, 28, 30, 31, 35, 37, 39, 46, 47, 50, 51, 53, 56, 64, 65, 66	23
15) Selective monitoring	2, 14, 17, 28, 30, 33, 34, 61	8
16) Pressure groups	2, 3, 5, 6, 7, 8, 10, 12, 15, 17, 19, 20, 22, 25, 26, 30, 31, 33, 34, 36, 37, 39, 42, 43, 45, 46, 47, 50, 51, 52, 54, 55, 56, 58, 60, 61, 62, 65	38
17) * Primary supply stability	1, 8, 14, 18, 22, 24, 34, 38, 41, 44, 50, 57, 59, 60	14
18) * Governance gaps	4, 7, 10, 16, 19, 20, 27, 32, 39, 40, 43, 47, 48, 49, 50, 51, 56, 58, 63, 64	20
Pro-activity management	**see individual practices**	**58**
19) Stakeholder management	2, 6, 8, 17, 25, 26, 30, 34, 36, 37, 38, 42, 45, 46, 49, 50, 51, 54, 56, 62, 65, 67	22
20) Learning	8, 14, 17, 28, 34, 40, 42, 55, 58, 62, 65	11
21) Innovation	11, 13, 14, 17, 21, 28, 30, 33, 34, 35, 38, 40, 42, 46, 50, 55, 56, 61, 64, 65	20
22) * Environmental pro-activity	1, 2, 4, 6, 8, 9, 12, 15, 17, 20, 21, 22, 23, 24, 25, 26, 27, 31, 33, 34, 36, 38, 45, 46, 48, 50, 52, 53,	38

	54, 55, 57, 58, 59, 62, 63, 64, 65, 67	
23) * Linkage development	5, 8, 10, 11, 13, 14, 16, 17, 18, 19, 28, 29, 35, 38, 40, 43, 48, 49, 54, 56, 58, 63	22

Table 4: Referenced papers for each practice
*(n = 67; abductive or re-defined categories and practices are marked with *)*

4.2.1 Government interventions

Governments intervene in mineral SCs mainly by applying *Direct* (47) and *Interactive* (37) *regulations*. The practice of *Facilitating self-regulation* is less commonly used (8), and the practice of *Governments as active consumers* was not mentioned in the reviewed papers. This is not surprising, since the literature focuses on raw materials and end-of-life products, while governments typically procure end products or services. Nevertheless, it might become a relevant topic if governmental actors include mineral certifications in their procurement processes.

The discussed *Direct regulations* in mineral SCs comprise local content, investment, and recruitment requirements (e.g. Bloch and Owusu, 2012; Fessehaie and Morris, 2013), which are closely related to the practice of *Linkage development*. Moreover, environmental requirements are imposed on rare earth mining and tailings handling (Rauer and Kaufmann, 2015; Ortiz and Viana Júnior, 2014). Chinese export restrictions on rare earths heavily impacted global supplies and lead to substantial discussions on the issue; these effects are also captured in the practice of *Primary supply stability*. Furthermore, the U.S. Dodd-Frank Act, Section 1502, imposes reporting requirements on conflict minerals in SCs (e.g. Bleischwitz et al., 2012; Young et al., 2014).

Interactive regulation refers to the cooperation with target groups or the financing of cooperative programs. Its main aims in mineral SCs are supporting *Linkage development* (e.g. Fold et al., 2014; Hanlin and Hanlin, 2012) and mitigating resource criticality (e.g. Moss et al., 2013; Stegen, 2015). Here, we see a clear link to the final two categories on *Risk* and *Pro-activity management.*

Facilitating self-regulation focuses on strategic decisions and resilience, but it is less commonly discussed. Related papers focus on the provision of information and guidance on resource criticality (Golev et al., 2014), as well as regional industry development roadmaps (Giurco et al., 2011; Hilson, 2014).

In total, 44 articles draw on at least one of the identified practices. This finding underlines the paramount importance of *Government interventions* in mineral SCs. The bulk of the discussed interventions concerned the environmental dimension, while social issues were less commonly discussed, with relevant articles focusing on linkages and conflict minerals. Furthermore, direct approaches clearly dominate cooperative approaches. This trend is in line with Govindan et al.'s (2014) findings on drivers of green SCM implementation in mining. It is further supported by the mineral industry's relative inertia to change (Petrie, 2007) and often reactive attitude towards the sustainability discussion (Muduli et al., 2013). A means to change this inertia of upstream SC partners is the pressure exerted by the SC itself, which is analyzed in the following sections.

4.2.2 Orientation

Orientation, the first of the categories derived from Beske and Seuring (2014), refers to a clear commitment to the use of SCM approaches and the TBL as essential precursors of SSCM implementation. Therefore, the unit of analysis originally was a single SC. As this review focuses on single papers as its unit of analysis, we cannot fully adopt the definition given above. Contrastingly, our approach aims at revealing the foci of the single papers in SCM and among the three dimensions of the TBL. As a result, 29 papers show a *Dedication to SCM* by explicitly integrating SCM approaches into their considerations. Additionally, 25 articles build on the *Dedication to TBL*. These relatively high frequencies should be considered in the context of the literature search, which focused on both topics. Nevertheless, it is surprising that, although all papers include the term SC or synonyms in their titles, keywords, or abstracts, only 29 draw on SCM practices. Additionally, we see that the discussion occurs at an aggregated level. Authors prefer to discuss at SC, national, or stakeholder group levels than to identify specific actors and the practices they apply. SCM, as our theoretical lens, is further cannibalized by other concepts, such as Industrial Ecology, which has certain overlaps with SSCM (Seuring, 2004). Combined with the wide distribution of the reviewed literature across journals and research streams, these results imply a lack of awareness of SCM in fields related to sustainable mining.

The *Dedication to TBL* suggests a clear trend towards adopting all dimensions. More than two thirds of the papers dedicated to the TBL were published in the last three years of the review period. In addition to the 25 papers dedicated to the TBL, a total of 17 publications focus on the intersection of the environmental and economic dimensions, while 14 address the nexus of social and economic issues. This underlines the centrality of economically viable solutions for SC sustainability (Seuring and Müller, 2008) and the impact of mineral SCs on both environment and society, especially in developing economies (Govindan et al., 2014). In contrast to the general SCM literature, which largely bypasses social issues (Yawar and Seuring, 2015), a significant body of literature dedicated to this dimension is available for mineral SCs. This primarily comprises the *Linkage development* literature, which focuses particularly on the population dependent on mineral extraction (Morris et al., 2012) and, thus, the upstream SC. Mining is estimated to support more than 150 million lives globally (Hruschka and Echavarria, 2011), which underscores the paramount importance of including it in SSCM frameworks. This reality has also driven the integration of *Linkage development* into the *Pro-activity management* category.

4.2.3 Continuity

The relationships in mineral SCs are shaped by *SC partner selection* (13), *Long-term relationships* (24), and *SC partner development* (14). However, the frequencies of these individual practices are relatively low. Altogether, 31 articles are assigned to this category. This underscores the general lack of dedication to SCM practices.

When a supplier has been selected for further relations, SSCM authors suggest investing in *Long-term relationships* to build trust with central partners and enhance performance along the SC (Pagell and Wu, 2009; Carter and Easton, 2011). Contrary to transaction cost economics (TCE) (Williamson, 1979, 2008), which suggests sourcing commodities from the spot market, Pagell and Wu (2009) propose building continuous relations with commodity suppliers. This approach enables suppliers to invest in enhanced sustainability performance, thus driving the performance of the entire chain. China's rare earth export restrictions are major drivers for *SC partner selection* in mineral SCs, since suppliers outside the country are at risk of raw material shortages (Giurco et al., 2014) and SCs must adapt to this. The practices focused on *Continuity* have special relevance in mineral SCs, since the sector is characterized by a need for large infrastructures, high investment and maintenance costs, and long lead times (Petrie, 2007). All of these factors favor *Long-term relationships* with suppliers that have proven their reliability (Hanlin and Hanlin, 2012). This process can be further driven by *SC partner development*. These efforts "to assess, train or assist their suppliers" (Bichueti et al., 2014, p. 64) in relevant fields involve in minerals SCs especially reducing water usage (Bichueti et al., 2014) and upgrading local suppliers for mine inputs (Ebert and La Menza, 2015; Fessehaie, 2012; Morris et al., 2012).

4.2.4 Collaboration

Collaboration practices are dominated by *Enhanced communication* (24). By contrast, only eleven publications refer to *Joint development*, and *Logistical integration* (6) and *Technological integration* (5) are largely overlooked. Again, relatively low frequencies for important SCM practices are evident, underlining the underdeveloped link between sustainable mining and SSCM. Nevertheless, *Collaboration* practices offer great potential for enhancing sustainability performance. The reviewed articles emphasize this by drawing on information and skill spillovers due to *Enhanced communication* and *Joint development* (e.g. Henn, 2012; Rauer and Kaufmann, 2015). Two other studies apply these practices to mitigate risks in critical mineral supply and recycling (Ting and Seaman, 2013; van der Wiel et al., 2012). Simpson (2010) calls for the application of the entire set of *Collaboration* practices to achieve economically viable advanced recycling operations. As a result, *Collaboration* practices are applied to enhance performance in all dimensions of the TBL and can, thus, be seen as central elements in SSCM for minerals.

Linking this category back to the practice of *Interactive regulation* offers another path for collaboration beyond the business-driven practices discussed here. Discriminant coding significantly impacted the frequency of *Enhanced communication*. The very low frequencies for the remaining practices could be caused by the complexity of the processes in the field and the current commodity nature of minerals. Both *Technological* and *Logistical integration* have been hindered by TCE scholars' recommendations to not engage deeper with commodity suppliers (e.g. Williamson, 2008). Furthermore, these issues are discussed primarily in quantitative optimization approaches (see also Pimentel et al., 2016), which have largely been excluded in the literature search.

4.2.5 Risk management

Risk management is critically important to the field. Overall, only seven articles do not mention its practices. The most important *Risk management* practice is the management of *Pressure groups* (38), followed by the use of *Standards and certification* (23) and the filling of *Governance gaps* (20). Another issue is ensuring *Primary supply stability* (14). *Selective monitoring* (4) is largely overlooked. The identification of *Pressure groups* as the most prominent driver is fully in line with SSCM literature (e.g. Seuring and Müller, 2008). Furthermore, 35 of the 38 publications in the *Pressure groups* practice mention stakeholder pressure (e.g. Garrett and Lintzer, 2010; Quastel, 2011; Rotter et al., 2014), and 17 draw on customer pressure (e.g. Govindan et al., 2014; Hilson, 2014; Xu et al., 2013). Keeping in mind the 55 papers on *Government interventions*, we see that governmental influences prevail over those of stakeholders and customers in mineral SCs. This supports previous findings that customers "often are overlooked in mining sectors" (Govindan et al., 2014, p. 217) and that mining stakeholders are largely without power in developing economies (Quastel, 2011).

However, the management of *Pressure groups* is one of the primary drivers for SSCM implementation in general (Yawar and Seuring, 2015; Seuring and Müller, 2008).

The practices of using *Standards and certification*, filling *Governance gaps*, and *Selective monitoring* are applied to avoid and detect misconduct related to sustainability issues. The use of SC or industry-wide standards, in particular, has recently gained attention as means to build transparency in mineral SCs (Young et al., 2014). In the sample, 20 papers identified *Governance gaps* that need to be filled to safeguard the SC's reputation. Issues addressed most often included (a) a lack of enforcement capabilities among state institutions (e.g. Bleischwitz et al., 2012), which lead to (b) illegal rent-seeking activities by armed groups or even policemen raising informal taxes (e.g. Garrett and Lintzer, 2010) and (c) informal recycling (e.g. Raghupathy and Chaturvedi, 2013) and mining operations (e.g. Fold et al., 2014). This third issue, in particular, has severe environmental and health impacts (Muduli et al., 2013; Williams et al., 2008). *Selective monitoring* is closely related to the *Continuity* category. In particular, *SC partner selection* is based on information gathered by monitoring activities and compliance with standards and codes of conduct (Beske and Seuring, 2014). Discriminately coding these practices has led to relatively low individual frequencies.

Another major risk concerns the recent price fluctuations for minerals, which have resulted in supply volatility and even disruptions (Slowinski et al., 2013). China accounts for 95% of global rare earth production (Rauer and Kaufmann, 2015); thus, in addition to free market developments, China's export restrictions have triggered substantial supply risks for SC actors outside the country. These restrictions were withdrawn in January 2015 after a lost lawsuit at the World Trade Organization, but the supply concentration is still evident (Stegen, 2015). Since 12 papers draw on *Primary supply stability*, and since this is not captured by the practices identified by Beske and Seuring (2014), we added it as an abductive practice closely related to SC risk management literature (Bell et al., 2012).

4.2.6 Pro-activity management

The *Pro-activity management* category is the second most commonly applied. Only nine articles do not mention this category. The reasons for this trend are the severe impacts of mineral SC operations (OECD, 2013), which offer potential for deviating from competitors through enhanced sustainability and, thus, decommoditization (Pagell and Wu, 2009). To achieve this, the reviewed literature builds mainly on *Environmental pro-activity* (38), which reflect the potential in the environmental dimension. On the social side, *Linkage development* for enhanced value addition in the mining region (22) was also frequently addressed, followed by the wider oriented *Stakeholder management* (22) and search for *Innovation* (20). *Learning* in the sense of information spillovers from stakeholder interactions remains rarely discussed (11).

The *Environmental pro-activity* practice is largely driven by discussions on using secondary supplies and reducing environmental impacts of primary production as well as the processing of materials. The latter especially encompasses pollution prevention practices (Govindan et al., 2014) and symbiotic approaches, which aim at integrating wastes and by-products of nearby companies as inputs to others (Corder et al., 2015). The articles on secondary supplies center on increasing secondary material streams (Simpson, 2010), and design for recycling approaches, which lower specific recycling costs (Giurco et al., 2014; Hagelueken and Corti, 2009). Secondary supply further mitigates primary supply risks (Bell et al., 2012; Giurco et al., 2014), brings reputational benefits related to the positive image, and substantially lowers the environmental burden of recycled inputs (Sahamie et al., 2013). This, in turn, implies that economic and environmental gains can be achieved through the integration of recycling operations in mineral SCs.

Suggested strategies for *Linkage development* include local sourcing (Fessehaie and Morris, 2013; Garrett and Lintzer, 2010), building a local supplier base for specific supplies, and providing infrastructure for industry diversification (Rajak, 2012; Solomon, 2011; Hanlin and Hanlin, 2012). Each of these measures improves local supplier capabilities, resulting in shorter lead times, higher flexibility, and loyalty to the focal firm. These benefits induce regional development and enhanced resilience for both the mining region and the mine itself. They also impact the social dimension, which benefits from the educational effects of *Joint development* and training practices with local suppliers as well as improved working conditions (e.g. the increased automation of harmful processes).

Innovation focuses on advancing economic and environmental operations through cost reductions and efficiency gains (Ebert and La Menza, 2015; Fessehaie, 2012), as well as advanced processing and recycling operations (Lydall, 2009; Simpson, 2010). In contrast to the practice of managing *Pressure groups*, which aims at avoiding reputational risks, *Stakeholder management* is directed towards actively building reputation (Hilson, 2014; Rauer and Kaufmann, 2015) and providing enhanced customer value. This is a core aim of all SCM activities (Mentzer et al., 2001) and is achieved in mineral SCs by promoting and communicating SC responsibility to the customer (e.g. Gomes et al., 2014; Govindan et al., 2014). However, Hilson (2014) recounts a case of "fair gemstones" in which a mineral SC did not change the sustainability of its production processes, but profited from customers' perceptions of the well-known Fair Trade label. Given cases like this one, he argues that greenwashing activities might harm the credibility of sustainability efforts in the sector.

4.3 Results of the contingency analysis

The contingency analysis represents the second analytical step. It reveals connections among the practices just described and enables the identification of hot topics as well as gaps in the reviewed literature. Here, we distinguish among the contingencies at the level of the six categories and at the level of the 23 practices and the regional as well as SC foci. These have to be seen in conjunction with the literature search which focused on specific issues. However, the maximum numbers of observed frequency of categories and practices occurring together underlines the heterogeneity of the field. This maximum number is 30 on the level of the six categories and 22 on the practice level. This means, the most common pair of categories appears in 45% of the articles. For the practices we only find a rate of 33%.

4.3.1 Contingencies at the category level

At the category level, three contingencies are evident. Table 5 lists the relevant results, which are also presented in Figure 4.

As Table 5 shows, *Orientation*, *Continuity,* and *Collaboration* are all contingent on one another at the category level. This establishes an initial set of closely related practices at the heart of the literature on mineral SCs. It implies that *Orientation* drives both *Continuity* and *Collaboration*. However, the link to *Continuity* shows a substantially higher phi-coefficient and, thus, a stronger relation. The observed frequency of 30 articles underlines the centrality of this link, especially as only 31 papers address *Continuity* at all.

Category pair	**Chi-square significance**	**Phi-coefficient**	**Expected frequency**	**Observed frequency**
Orientation and Continuity	0.000	0.562	21.3	30
Orientation and Collaboration	0.001	0.395	19.9	26
Continuity and Collaboration	0.001	0.398	13.4	20

Table 5: Contingency results at the category level

Based on Table 5, *Continuity* and *Collaboration* are re-enforcing. This finding is in line with the arguments for an active search for reliable and stable buyer-supplier relationships in mineral SCs. Such relationships are often driven by the industry's high investment intensity and the associated costs of changing the SC structure (e.g. Fessehaie and Morris, 2013). Engaging in *Long-term relationships* with suppliers drives *Collaboration*, including integration and communication and vice versa. Observing these contingencies on the category level illustrates the general relevance and connectedness of the issues.

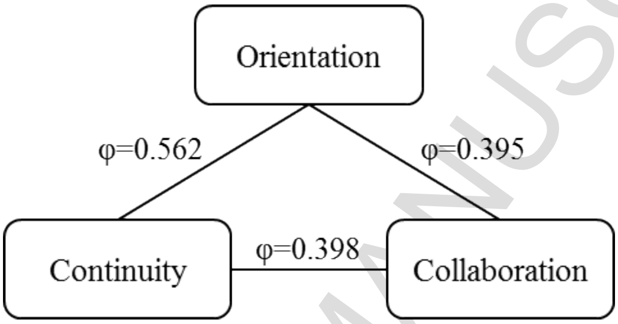

Figure 4: Contingencies at the category level

4.3.2 Contingencies at the level of practices and SC and regional foci

At this level, 19 contingencies are evident. Table 6 lists them ranked by the phi value. While the first 14 contingencies show a significantly high usage of their respective pairs, the bottom five list show a significantly low pair usage.

To discuss the contingencies, we divide them into two groups. First, the easily comprehended contingencies are briefly discussed in the text. Second, we provide a topical arrangement of the more connected positive contingencies in Figure 5. This depicts the correlations among practices, which are discussed in further detail to enable a more integrated comprehension.

In the first group, contingencies no. 12 and 17 (see Table 6) encompass a *Generic* regional focus. These are easily comprehended and, thus, are only briefly described here. First, *Generic* papers, which discuss more than one continent, often have an *Overarching* SC focus covering more than one SC stage. This is unsurprising, but supports the notion of globally dispersed actors within mineral SCs. Second, *Extraction* papers do not have a *Generic* regional focus (i.e. they center on a specific continent). That underlines the high context dependency of mineral extraction and its discussion in academia (Giurco and Cooper, 2012). Furthermore, contingency no. 15 indicates a lack of connections among *Interactive regulation* and *Pressure groups*. This is most likely due to the discriminant coding of these related practices, which reduces their simultaneous use in one paper and, thus, represents a technical issue.

Contingency no. 16 for *Dedication to SCM* and *Governance gaps* is negative, implying a lack of links between these issues. This suggests that SCM papers overlook *Governance gaps*, which are primarily associated with informal and small-scale actors. There is, thus, a need for SCM literature to integrate informal actors, thus fostering their formalization. This is especially relevant as the formalization can drive the reduction of both environmental and social impacts of mining (Cartier, 2009) as well as recycling (Giurco et al., 2014). Including this into SSCM research offers a pathway to strengthen its impact on the social dimension which is still underrepresented (Yawar and Seuring, 2015).

	Pairs of practices and SC and regional foci	Chi-square significance	Phi-coefficient	Expected frequency	Observed frequency
1	Dedication to SCM and Long-term relationships	0.000	0.604	10.4	20
2	Dedication to SCM and SC Partner development	0.000	0.514	6.1	13
3	Long-term relationships and SC Partner development	0.000	0.458	5.0	11
4	Pressure groups and Stakeholder management	0.001	0.418	12.5	19
5	Dedication to SCM and Innovation	0.001	0.418	8.7	15
6	Long-term relationships and Innovation	0.001	0.397	7.2	13
7	Extraction and Linkage development	0.002	0.374	9.2	15
8	Direct regulation and Long-term relationships	0.004	0.351	16.8	22
9	Long-term relationships and Enhanced communication	0.004	0.351	8.6	14
10	Dedication to SCM and SC partner selection	0.006	0.333	5.6	10
11	Enhanced communication and Innovation	0.007	0.329	7.2	12
12	Generic and Overarching	0.007	0.329	9.9	15
13	Interactive regulation and Primary supply stability	0.010	0.315	7.7	12
14	SC Partner development and Enhanced communication	0.013	0.305	5.0	9
15	Interactive regulation and Pressure groups	0.013	0.302	21.0	16
16	Dedication to SCM and Governance gaps	0.012	0.307	8.7	4
17	Generic and Extraction	0.006	0.337	12.5	7
18	Linkage development and Environmental pro-activity	0.004	0.351	12.5	7
19	Extraction and Environmental pro-activity	0.003	0.359	15.9	10

Table 6: Contingency results at the level of practices and SC and regional foci

In Figure 5 and the mining group on the left, a positive relation between *Linkage development* and *Extraction* papers is evident. This emphasizes the importance of linkages as one of the "hot topics" in the literature on extraction and sustainability in mineral SCs (Morris et al., 2012). Contrastingly, both show a lack of links to *Environmental pro-activity* and, thus, a weak environmental focus (see no. 18 and 19 in Table 6). While this is not surprising for the socially oriented linkage papers, it is a major finding that the literature on mineral extraction and the mineral SC largely overlooks environmentally beneficial practices. This indicates a clear social focus of publications on the sustainability of extraction operations in mineral SCs.

The second contingency in the mining group is the link between *Interactive regulation* and *Primary supply stability*. This relation encompassing all but two papers on the *Primary supply stability* points to the major role of governmental mineral strategies in related SCs. These strategies formulated and implemented by, for example, the U.S., the EU, South Korea, and Japan, try to secure mineral resources to mitigate China's monopolistic position, especially in rare earths (Ting and Seaman, 2013). Such actors have the power and resources to implement game-changing regulations like the Dodd-Frank Act, which led to the certification of 95% of Tantalum producers (Young, 2015). This underlines the high importance of governmental actors in mineral SCs.

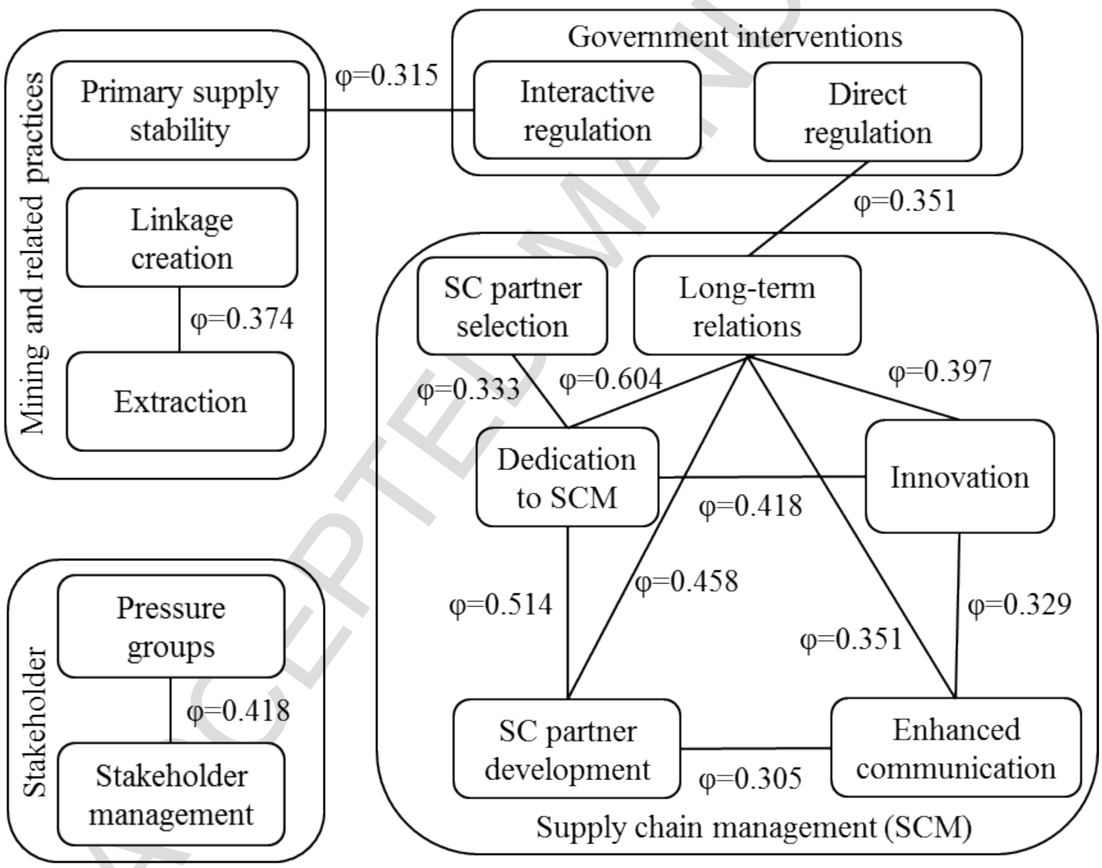

Figure 5: Contingencies at the level of practices and SC and regional foci

In the stakeholder domain, we further see a strong link between *Pressure groups*, with a focus on mitigating negative influences, and *Stakeholder management*, which seeks to foster positive relations. As a result, a close link between these issues is evident in the mineral SC literature, and future studies should apply a unified practice. Such a practice could follow the proposition of "reconceptualizing who is in the SC" put forward by Pagell and Wu (2009), who call for the active integration of NGOs and other stakeholders into the SC. This is especially important as Western societies have shifted the burden of raw material provision abroad (Mena et al., 2013): Sustainability issues related to raw material extraction will be documented and published by *Pressure groups*, and the stakeholders of downstream SC actors and brand leaders will then have to react to this pressure (Hartmann and Moeller, 2014).

The largest and most interesting group of significantly frequently interlinked practices in mineral SCs is the SCM group. This group represents a detailed view of the connections among the *Orientation*, *Continuity,* and *Collaboration* categories discussed above. It centers on the *Dedication to SCM* and *Long-term relationships*, each of which has four links within the group. These two practices also have the strongest link in the entire analysis, with a phi-coefficient above 0.6. Furthermore, all three practices of the *Continuity* category are represented here. While *Long-term relations* and *SC partner development* are directly connected, *SC partner selection* is only linked to *Dedication to SCM*. The latter is central to the three practices of the *Continuity* category and underlines its role as a precursor, as defined by Beske and Seuring (2014). *Dedication to SCM* is also contingent on *Innovation* and can, thus, be seen as an *Innovation* driver. *Enhanced communication* is related to *SC partner development* and *Innovation* and acts as an antecedent to both in mineral SCs. The contingency on *Long-term relationships* underlines the re-enforcing character of such relationships (already mentioned in the category-level analysis above). These results indicate that *Continuity* practices are used primarily in SCM-related publications, further emphasizing the gap between SSCM and sustainable mining. However, within the review sample, *Enhanced communication* is not used more than average in SCM papers, suggesting a second line of interpretation involving the links among *Long-term relations*, *Innovation,* and *Enhanced communication*, with no explicit SCM focus. This indicates the importance of communication in the field of sustainable mineral SCs and related innovations (Simpson, 2010). Finally, the link to *Direct regulation* further identifies governments as major drivers in the field (see also Govindan et al., 2014).

Looking at the SCM contingency group as a whole provides evidence for the coherence of SCM practices in the field of mineral SCs. Although the category system divides these practices according to their links to strategy, structure, and processes (see Figure 2), the data show their connectedness across categories for the field of mineral SCs. However, not all core SCM practices are well established in the literature sample. In particular, the low frequencies for all *Collaboration* practices but *Enhanced communication* suggest further potential for integrating core SCM practices into sustainable mineral SCs. This possibility is addressed in the upcoming discussion.

5 Discussion and research directions

5.1 The practices in SSCM for minerals

This review abductively formed a comprehensive set of practices for SSCM for minerals represented in Figure 2. Both the coding results and the identified contingencies provide evidence of current trends and blind spots in the academic discussion of the issue. Since no comparable review has yet been conducted, the findings of this study contribute to our understanding of sustainability in mineral SCs and its management. Further, the set of SC practices identified in the frequency and contingency analysis offers insights into the topics covered in the current academic debate. These insights will be elaborated in the upcoming paragraphs.

We found that almost all of the deductive categories are addressed in the reviewed literature. However, there is a striking heterogeneity in the literature, which addresses diverse issues ranging from small-scale mining as one extreme to industrialized recycling of metals and minerals as the other extreme. But these in-depth, country and SC stage specific case studies represent only one side of addressing the sustainability in mineral SCs and their management. The analysis of the literature underlines the complex and far-reaching interrelations within the SC. Sticking to the given example, we see the mitigation of upstream sustainability impacts via enhanced recycling and the resulting reduced demand for virgin material (Corder et al., 2015; Giurco and Petrie, 2007). However, this in turn limits the potential development impact of the mines and affects the social sustainability (Wilts et al., 2011). It is this wide array of interwoven sustainability challenges which makes a comprehensive management of mineral SCs so important and from which we derive implications for research and managerial practice in the upcoming paragraphs.

At first, the review revealed the noticeably high context dependency of mineral extraction, which is also underlined by the results of the contingency analysis. This calls for the inclusion of national and supranational governmental bodies in the design of mineral SCs (e.g. Giurco and Cooper, 2012; Ting and Seaman, 2013). Actors engaged in mineral SCs should, thus, carefully map the current and future roles of governmental actions and strategies in their mineral SCs (see also Rauer and Kaufmann, 2015). The heterogeneity of mineral sources and supply is also of major concern in terms of SC risks management (Bell et al., 2012). SCs often only have limited knowledge on their ultimate suppliers. Nevertheless, trends of mineral supply concentration (especially in China) simultaneously drive the need to monitor the reliability and stability of such supply routes (Ting and Seaman, 2013). This issue has already led to substantial governmental efforts in securing mineral supplies and has to be complemented by focal firm actions.

In addition to revealing the potential impacts of governmental actions, the mining literature shows the adverse effects of a lack of regulations or regulatory power (Garrett and Lintzer, 2010; Rotter et al., 2014). In such cases, SSCM literature often points to the use of standards (e.g. Seuring and Müller, 2008; Grimm et al., 2016); however, mineral SCs are highly heterogeneous and sometimes feature more than nine supplier tiers (Young, 2015). This renders the effective implementation of sustainability standards along the SC almost impossible (Tachizawa and Wong, 2014). Thus, we identify minerals as an extreme case for the implementation of SC standards and call for further research to determine and mitigate the challenges of mineral certification. The other solution proposed by the literature on sustainability in mineral SCs is the creation of linkages. This approach of enabling local stakeholders to build a stable economic base and emancipate from a single firm's social contribution in a region is to date underrepresented in SSCM research (Yawar and Seuring, 2015).

As a result, the most important differences between SSCM and sustainable mining addressed in RQ1) were abductively added to the category system by complementing SSCM *Risk management* practices with a) identifying *Governance gaps* and b) ensuring *Primary supply stability*. A third addition was made by integrating *Linkage development* into the *Pro-activity management* category. These mining-specific issues can be considered the blind spots of current SSCM frameworks, which focus mainly on downstream operations (Mena et al., 2013). SSCM has to move up the SC and extend its reach to raw material sources. The recently emerged topic of sub-supplier management (e.g. Grimm et al., 2016; Mena et al., 2013; Tachizawa and Wong, 2014) offers great potential in this regard.

5.2 The benefits of SSCM for minerals

Another interesting point concerns the distribution of TBL dimensions across the sample. While most extraction-related papers adopt a social focus on linkages and conflict minerals (e.g. Upson and Clarke, 2015), the SCM literature primarily integrates environmental issues, such as pollution and recycling (e.g. Simpson, 2010). In linking these topics to the general SSCM debate, including the prevalence of green approaches over social ones (Yawar and Seuring, 2015), there is great potential for SSCM theory to benefit from the integration of mining literature. Our paper can be seen as a first step in helping to strengthen the social dimension of SSCM.

We also see this integration as being valuable for the sustainability in mineral SCs. Few related papers provide evidence on sustainably-produced minerals, i.e. minerals produced and processed according to high sustainability standards, as a viable business model; instead, they address only raw materials for jewelry and high-tech devices (Moss et al., 2013; Young et al., 2014). These cases are in line with the SSCM argument that customer pressure for sustainable products (Seuring and Müller, 2008) and reputational risks associated with suppliers' misconduct in the field of sustainability (Hartmann and Moeller, 2014) are drivers for sustainable operations. However, there are no successful cases for less visible and/or mass minerals, which are currently traded as commodities and experience volatile prices (Slowinski et al., 2013). Integrating SSCM approaches into mineral SCs offers mineral producers price premiums if they can prove that they conduct or are developing sustainable operations (Carter and Easton, 2011). This gives mineral producers the chance to exit the price-driven commodity markets, engage in direct sourcing or selling, and differentiate from their competitors. Such actions encourage decommoditization (Pagell and Wu, 2009) and yield stable revenues.

However, mineral SCs feature both upstream and downstream SC parts, which are highly heterogeneous. Moreover, there is a need for more integrated and consistent sustainability perceptions in the design of the single SC parts, especially upstream (McLellan et al., 2009) as well as along the entire SC. Our literature review excavated the diverse challenges related to the individual SC parts, which call for specific resources to manage the SC. As it is the task of the focal firm to align the SC's structure and practices with stakeholder requirements (Seuring and Müller, 2008), we propose implementing a focal firm in each portion of the SC. This creates an "upstream focal firm" (see also Figure 1 and Young (2015)) that integrates the context-specific challenges of mineral extraction and beneficiation into the management of the upstream SC. In turn, this facilitates the provision of sustainably-produced minerals and, thus, decommoditization (Pagell and Wu, 2009). The downstream focal firm applies "classic" SSCM practices to foster the competitiveness of the downstream SC and to sell products based on sustainably-produced minerals. This could, in turn, drive demand for sustainably-produced minerals, thus, increasing their economic viability (Carter and Easton, 2011). This proposition is in line with that of Young (2015), who identified the smelters in the Conflict Free Smelter Standard as such upstream focal firms. Our research broadens the basis for this call by complementing Young's (2015) focus on responsible sourcing of conflict minerals (asking "where" to source (Young, 2015)) with an explicit evaluation of mining SCs against the TBL oriented set of categories and practices of our SSCM for minerals framework (asking "how" to source (Young, 2015)). The introduction of upstream focal firms further offers a chance to extend the reach of SSCM, as just requested. The integration of mineral SCs has several benefits for both upstream and downstream actors; thus, we call for comprehensive efforts in both research and practice.

5.3 Limitations, research directions and research quality

Literature reviews typically face three limitations. First, the literature search is limited (in this case, to academic journal publications). However, alongside the academic discussion, there is a substantially larger practitioner community in the field (Young et al. 2014). Though these sources have been excluded from this review, they would certainly yield valuable insights and implications for further research in fields like sub-supplier management, sustainable operations, sustainability reporting, governance, and stakeholder management.

Second, the literature analysis — which is, in our case, conducted against only one framework — can create limitations. Although the concept used is enriched by abductive means (Spens and Kovács, 2006), it still limits the analysis to SSCM-related issues. Furthermore, abductive propositions must be empirically verified. Doing so could provide further information on the correlations between mineral SC complexity and the importance of the upstream focal firm. Combining this with our finding of substantially different regulatory environments within the SC points to an analysis of the topic against institutional theory (DiMaggio and Powell, 1983). Another interesting path is the analysis of the specific characteristics of the distinct SC parts, the current state of operation practices, and their evaluation against the structuration theory (Giddens, 1984). In this context, the influences of NGOs and mineral certification schemes as drivers for the adoption of sustainable practices are of interest.

The third limitation involves the review's focus on comprehensively conceptualizing mineral SCs and the practices constituting SSCM for minerals. Thus, it delivers context-dependent findings, which limits the generalizability of the results to this sector. Furthermore, the study is bound to a relatively high level of analysis in order to map the entire field. This limits the potential of the given study to dive into details. However, this map is meant to be the starting point for further research in the field of sustainability in mineral SCs. A valuable next step would be the search for contingency variables enabling and driving the implementation of the identified and described practices in the various contexts relevant in the field.

Moreover, the use of partially overlapping concepts is evident in the reviewed literature. In particular, Industrial Ecology approaches have been found alongside (but not mixed with) SCM. The different fields' exclusive usage of theories with related contents and aims limits the impact of the single concepts due to cannibalization. This calls for an integration of the different communities to foster the common goal of enhancing the sustainability of current and future operations. This can be achieved through reviews, which systematically reveal the differences and commonalities among concepts, follow-up discussions, and conceptualizations, which incorporate these different aspects into more holistic approaches. Such reviews have already been conducted (Seuring, 2004), but the rapid development of SCM into SSCM implies a need to revisit these publications.

Furthermore, the validity and reliability of the literature analysis must be evaluated (Fink, 2010). In our case, validity was ensured by building on the deductive categories of well-established business literature and adding abductive categories through subjects discussed extensively in minerals literature. Moreover, the authors conducted a discursive alignment of interpretation (Seuring and Gold, 2012), which fostered the valid addition of particular categories and ensured coding reliability. The latter was achieved primarily through two coding runs. The first involved the coding of 30 papers by one author before the coding was discussed in detail between both authors. This practice clarifies the common understanding of categories and practices, thus allowing enhanced inter-coder reliability. Conducting the second coding run encompassing all 67 papers based on the consolidated category understanding further enhanced the intra-coder reliability (Seuring and Gold, 2012).

6 Conclusion

This review identified a gap in the extant research on sustainability in mineral SCs and SSCM in general. While the former traditionally focuses on the upstream SC, the latter focuses on the downstream part. However, to achieve enhanced sustainability performance — and, thus, competitive advantage — both need to be comprehensively aligned and managed. This paper offers implications for both sides to enable such efforts. Based on the SSCM framework developed by Beske and Seuring (2014), which is applicable to downstream SC, we introduce further practices to tackle the mineral-specific challenges of SCs. Furthermore, an upstream focal firm specifically managing the upstream SC is suggested. This will facilitate SSCM for minerals and enhance its impact on the initial SC stages, which incur the highest sustainability risks in mineral SCs. Moreover, the provided research directions identify future paths for empirical and theoretical developments in pursuit of the further integration of both SC portions — and, thus, the research fields of both sustainability in mineral SCs and SSCM.

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The 67 papers contained in the review sample are numbered in squared brackets.

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