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Sustainability in mining, minerals and energy: new processes, pathways and human interactions for a cautiously optimistic future

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ABSTRACT

The supply of minerals and energy is critical to global society. However, this supply is associated with social and environmental impacts, leading to concerns of generational and intergenerational equity. In light of these concerns, a call for papers for a special volume on the mining industry was issued with the view that such academic work could assist in reducing the negative impacts associated with this industry. This paper introduces the Special Volume "The sustainability agenda of the minerals and energy supply and demand network: an integrative analysis of ecological, ethical, economic, and technological dimensions". The Special Volume contains 84 articles, divided into several themes; sustainability accounting and reporting, corporate social responsibility, future mining challenges, integrative frameworks for sustainability, management aspects, mining in a developing context and new frontiers in the oil and gas industry. The Special Volume also includes two letters on contemporary issues with commentaries on these from experts in the fields, viz., community conflict and land rehabilitation. Insights obtained across these themes are summarized and recommendations are made of what is needed to build upon the findings of this Special volume. A research agenda is proposed for the future from the gaps and synergies identified. The overall contribution of this Special Volume is that it renews the debate on the sustainability challenges for the mining industry and provides transdisciplinary insights into resolving some of these challenges.

1. Introduction

The mining industry plays a crucial role in ensuring an acceptable quality of life is, or will be, available to billions of people across the globe. The demand for minerals and energy is anticipated to rise, ore quality is decreasing and costs to access it are increasing, as are community expectations of the performance of mining companies and those associated with them. In this context, addressing the sustainability agenda of the mining industry is a 21st century challenge of global significance.

The extraction of natural resources has created legacies of unacceptable long-term social and environmental impacts in many parts of the world. These impacts range from the geographic and cultural displacement of indigenous communities to contamination of water, air and land with toxic by-products of extraction and processing that have not been sufficiently well contained and/or treated. To avoid these impacts in future, business as usual must change, even taking into account the substantial efforts to improve performance made in recent decades by responsible companies and diligent regulators. It is not possible for human society and the ecosystems of this planet to meet the growing demand for minerals and energy if developing economies follow the same inefficient and destructive material and energy trajectories that the high GDP countries took to achieve their current status. This is as relevant for commodity supply impacts as the effects associated with commodity use.

Technological discoveries are needed to radically improve the minerals and energy demand and supply processes and networks, from the extraction of resources to their use and reuse. However, while this will be necessary it is not sufficient. Management systems, company decision-making, governmental policies, educational and research priorities, societal attitudes and empowerment in charting and achieving sustainable societal futures must be

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envisioned and implemented. Implementing this transition is at the heart of equitable, sustainable societal development.

The Call for Papers (CfPs) for this Special Volume (SV) of the Journal of Cleaner Production, (JCLP) was written very broadly to solicit inputs from the international research community on topics, data and approaches that could be used to provide insights into our evolving capability for addressing the immense challenges posed by the projected increases in demands for metals, building materials and energy. This CfPs was published in November 2012, several months after the United Nation Conference on Sustainable Development in Rio De Janiero, in June 2012 (Rio +20 conference), and thus it was released at a pivotal time in renewed global efforts towards Sustainable Development (SD).

Mining's contribution to SD was a critical issue discussed at Rio +20. Building upon the achievements of earlier major events such as the Rio World Summit in 1992 and the World Earth Summit in Johannesburg in 2002 (Rio+10), this conference reiterated the vital role for the mining industry in SD. The International Council on Mining and Metals (ICMM) was at the forefront of these discussions. They issued the following papers at the conference on mining's contributions to SD:

- Mining's contribution to Sustainable Development
- Human rights, social development and the mining and metals industry
- The role of minerals and metals in a low carbon economy

The emphases of these papers by ICMM represented a shift in focus from analysis and mitigation of impacts to the potential of a more comprehensive analysis of the wider contributions of this sector and its products to the transition to truly sustainable societies (ICMM, 2012). Essentially, the focus was not on how mining can be sustainable but on how mining, minerals and metals can contribute to SD (ICMM, 2012, p. 4).

The Rio +20 outcome document, "The Future we Want" includes two paragraphs devoted to the role of mining. In line with the ICMM, the document acknowledged the critical importance of minerals and metals, and highlights a need for mining companies to maximize social and economic benefits, and to effectively address negative social and environmental impacts (UN, 2012, paragraph 227, P. 44). A strong regulatory and legal framework for mining accompanied by improvements in accountability and transparency was also recommended (UN, 2012 p.44).

This SV includes 82 papers and seven commentaries (on two topics) and, as such, is likely the largest published set of fully peer-reviewed work on sustainability in the resources sector. This introductory article places all the contributions into context with one another in terms of the theme they most clearly address but also taking into account the connections between papers and interpretations of threads of issues and opportunities that emerge from the collection rather than just the individual papers. Many papers are cited several times in an attempt to draw connections and lead to conclusions and research issues. Readers are encouraged to focus on the introductory lead—in sentences in each of the descriptive citation sections so that the thread of connection can be discerned. The authors recognize that this is a challenging task given the large number of papers and sections. As a result, it is expected that readers may have to "consume" this introduction in a number of sequential and iterative readings rather than as a single pass. Many SV introductions create a framework for interpretation that can be used to synthesize the overall content of the contributions. In this case, the size of the SV and breadth of the content of the papers made this task too difficult to achieve as well as introduce the individual papers. Consequentially, two of the authors undertook to write a second paper that focused solely on an interpretative overview and not on citation of the individual contributions. That paper (Moran and Kunz, 2014) follows immediately after this introduction in the SV.

The introduction to this SV contains:

- A broad overview of literature on sustainability in the mining industry;
- Brief scoping of the SV, based upon the CfPs;
- Summary of the papers accepted for this SV;
- Discussion of emerging trends, themes and issues;
- Recommendations for future research questions and challenges.

2. Literature on sustainability in the mining industry

To set the scene for this SV, the team conducted a broad literature search to evaluate the extent to which mining and minerals are incorporated into current and historical academic dialogue.

A search on "Sustainable development" within Google Scholar (16 July 2014) returned approximately 1.37 million articles. An analysis was undertaken using the Thomson Reuters ISI Web of Science and Scopus, which found 14,699 and 41,378 articles, respectively to a search on "sustainable development" that was restricted to "articles" from 1987 to 16 July 2014. When the search was refined to only include papers with "mining or mineral*", the results for Web of Science was 537 and Scopus was 3547. Scopus found a significantly greater number of papers than ISI in this domain, possibly because it covers a wider array of social science journals (Markard et al., 2012). Only four institutions appear in all search lists, i.e., the broad SD search and the refined "mining or mineral*" search, viz., the Chinese Academy of Sciences, The University of Queensland, Beijing Normal University and The University of British Columbia. The *Journal of Cleaner Production* (Scopus) was the leading journal by numbers of papers for both the general "sustainable development" search and the constrained "mining and mineral*" search.

A time series analysis of the Scopus data from 1987 to 16 July 2014 found that the literature on sustainable development is increasing (Fig. 1). The first jump in numbers of papers published, occurred in 1996 followed by a surge in 2006–2008. This trend has continued and at an increased rate (note the data for 2014 are incomplete due to the date of the search). In overall numbers, the literature specific to sustainable development in mining and minerals is small by comparison. This is notable given the importance of mining and minerals in global terms. However, the time series

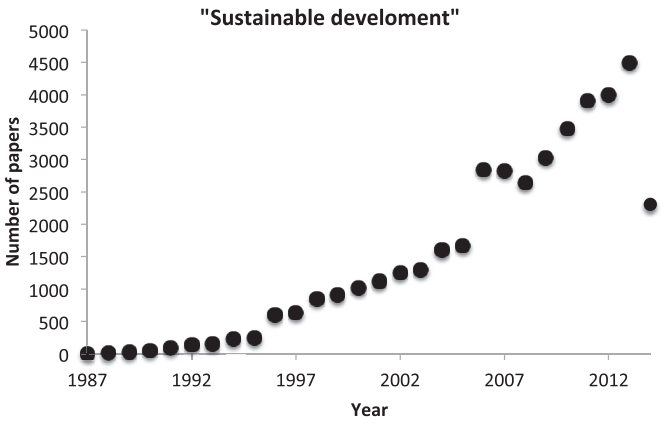

Fig. 1. Number of publications (Scopus) from a search on "Sustainable development" since 1987 (2014 incomplete year).

revealed that this is being addressed. The number of papers on topics, including "mining and mineral*" increased in the same manner as the number that addressed "sustainable development" with the jumps appearing in the same years (Fig. 2). However, "mining and mineral*" showed an increasing trend in terms of percentage of the total, with considerable scatter prior to 1996, and a much clearer upward trend recently (Fig. 3). The strong response to this SV's CfPs is consistent with increased research activity in this area.

3. Summary of SV contributions

The original CfPs (Lodhia et al., 2013) invited submissions on the following seven topics:

- Sustainability accounting and reporting in the mining industry: Environmental and sustainability management and accounting, sustainability and integrated reporting through various media, climate change accounting, water accounting, human rights management and/or reporting, ethical investment in the mining industry.
- Corporate social responsibility (CSR) in the mining industry: CSR practices, Corporate Community partnerships, NGO perceptions of reality of CSR in the mining industry, regulatory issues, e.g., mandatory versus voluntary initiatives, the role of social media in CSR communication and practice, ethical behaviour with regard to workers and inhabitants in the vicinity of mining activities.
- Future mining challenges: Cradle-to-cradle management of all materials, urban mining, the implications of declining ore grades, physical constraints imposed by massive scale mining, challenges in the inevitable shift from surface to massive underground mining.
- Integrative models and frameworks for sustainability: beyond the triple bottom line, what frameworks are proving useful in an operational context? Where have models enabled positive policy developments and/or improved on-the-ground practices?
- Management aspect: industrial ecology, innovation systems, multinational mining in developing countries experiences, implications, and real opportunities to make dramatic improvements, innovative supply chain management.
- Mining in a developing context: resource curse/endowment, artisanal/informal mining, effective governance and regulation (concepts, practices and barriers to implementation).
- New frontiers in the oil and gas industries: specific opportunities and challenges for this industry, e.g. hydraulic fracturing, aquifer interactions, mixed surface footprints of multiple resource-using activities, deep energy-intensive extraction techniques requiring significant surface disturbance, e.g., tar sands mining.

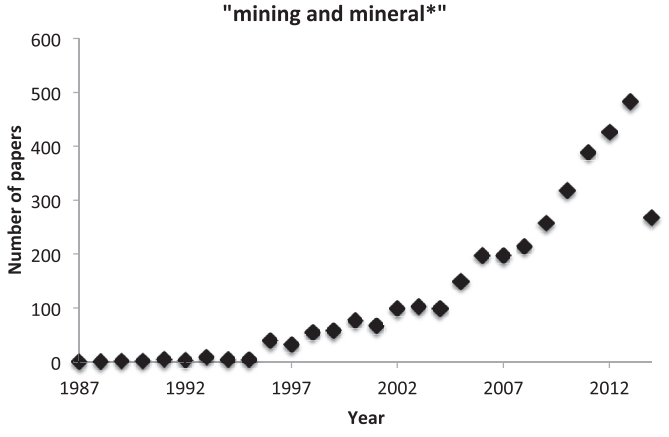

Fig. 2. Number of papers (Scopus) "Sustainable development" AND "mining or mineral*" since 1987 (2014 incomplete year).

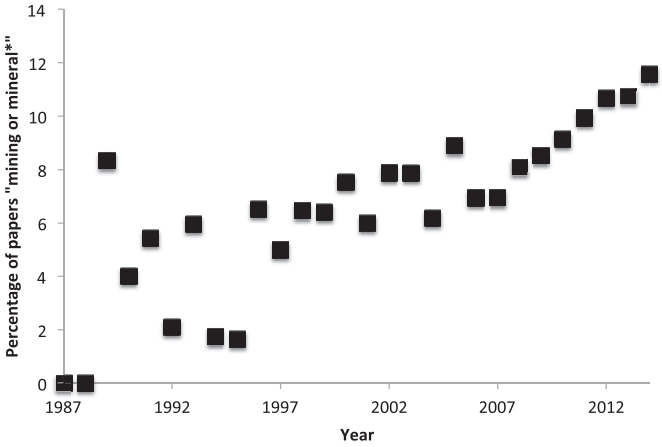

Fig. 3. Percentage of papers including "Sustainable Development" AND "mining and mineral*" of the "Sustainable development" total, published since 1987 (Scopus).

All seven of these themes were addressed by the collection of papers accepted for this SV. While for most papers it was relatively easy to categorise them to a single theme, there were others that touched on several themes. To provide a running order for the SV, each paper was assigned to only one theme (Table 1). The following section provides an overview of the contributions received within each theme, which is elaborated upon by including the discussion of papers that contributed across multiple themes.

Fig. 4 summarises the country of origin of the corresponding author for all papers included in this SV. This does not necessarily reflect the study context of the paper itself, because some authors conducted case studies beyond the country of their institution, nor does it recognise the origin of co-authors. Nonetheless, it provides a rough indication of the main countries represented within this SV. A total of 27 countries are represented, which highlights the international nature of research within the mining and sustainability field. Contributions were from the developing world to more developed countries. Globally based studies were also reported. Australia is the most strongly represented (19), followed by China (9). However despite the diversity of submissions received across countries, the contributions spanned all topical areas. This presented opportunities for lessons to be shared across operating contexts.

3.1. Sustainability accounting and reporting in the mining industry

The papers on sustainability accounting and reporting are wide ranging and make an important contribution to the understanding

Table 1
Summary of the themes used to classify each paper in the special volume.

Theme	Total number of papers
Sustainability accounting and reporting in mining	11
CSR in the mining industry	12
Future mining challenges	9
Integrative models and frameworks for sustainability	11
Management aspects	31
Mining in the context of developing economies	6
New frontiers in oil and gas	4
Total	84

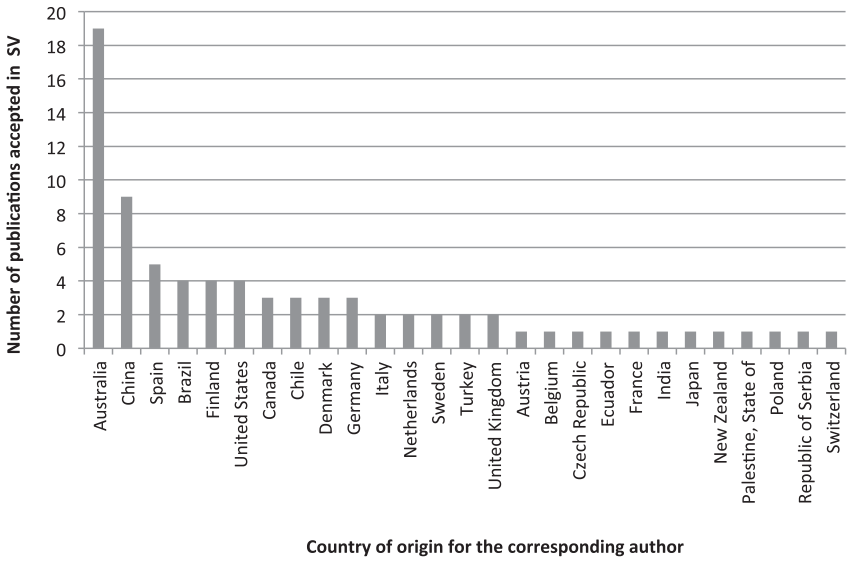

Fig. 4. Country of origin for the corresponding author for all publications accepted in this special volume.

of sustainability issues and challenges in the mining industry. These studies complement the overview of existing mining literature on sustainability accounting and reporting published in *Journal of Cleaner Production* (2004–2013) as discussed by Lodhia and Hess (2014) in this SV.

The authors of these papers highlight that sustainability management can improve business performance in the Brazilian minerals sector (Gomes et al., 2014) but that established management systems do not necessarily lead to effective stakeholder engagement as observed by Ranangen and Zobel (2014a) in the context of Swedish mining and metals companies. The importance given to sustainability management practices in the small to medium sized sector in a developing country, Spain, is encouraging (Vintró et al., 2014).

The papers in this SV also illustrate that environmental disclosure is conforming to a standardised practice in both large and small companies in the case of South African mining companies, thereby, providing evidence of institutionalisation of such disclosures (de Villiers et al., 2014). The urgent need for greater diversity in the salience of stakeholders for the Chinese mining industry (beyond the central government and international consumers) is highlighted (Dong et al., 2014). The effectiveness of mandatory reporting requirements when compared to voluntary initiatives is discussed as well in relation to water related disclosures in the Australian state of New South Wales (Leong et al., 2014). Using Dryzek's 'discursive democracy' theoretical framework, the authors highlighted that the mandatory system was well designed with publicly available information and community consultation, but there was scope for improvement.

Corporate sustainability indicators as a complement to sustainability reporting were studied in relation to a real world case about BHP Billiton, a major global mining company, (Lodhia and Martin, 2014). Differences in the recognition of the sustainability agenda were identified and reflected upon through a focus on sustainability reports and the journal, Resources Policy (Onn and Woodley, 2014). It was found that sustainability reports focussed on the business context and that Resources Policy took a broader view of mining's social and environmental impacts. Lodhia (2014) addressed the role of the medium in communication through an exploration of the factors that influenced the use of the World Wide Web for communication of sustainability issues in the Australian Minerals Industry. The author documented that while the web has communication potential, the use of this potential was influenced by economic, internal organizational and external stakeholder factors. The limitations of the web medium, especially its "double –edged sword" effect, and organizational restructuring, also had an impact on the extent to which the web was used for sustainability communication within the Australian Minerals Industry.

Fonseca et al., (2012) provided a constructive and thoughtful critique of the Global Reporting Index in terms of the mining industry. They cautioned that by continuing to accept limitations inherent in the GRI and, at the same time, promoting communication of GRI results as sufficient, the industry may be creating a medium-term difficulty for itself because eventually communities and governments will require more integrative approaches.

3.2. Corporate social responsibility (CSR) in the mining industry

A significant body of work was compiled in this SV that is related to Corporate Social Responsibility. Additionally, several papers with a focus in other areas also touched upon the importance of social and community benefits as a result of implementation of their methods, processes or approaches (e.g., Kunz and Moran, 2014; Seccatore et al. 2014).

The CSR practices of the mining industry were compared to other environmentally sensitive industries through an analysis of the academic literature (Ranangen and Zobel, 2014b). The authors conceded that despite the growth in the academic literature, an in-depth analysis of how CSR was practised in these industries was lacking.

Critical perspectives on mining resource control and governance in the developing world was given through an exploration of the practices of Argentinian and Ecuadorian companies (Cisneros and Christel, 2014). The authors concluded that economic interests dominated the demand for more democratic decision-making in these countries. On the other hand, Govindan et al. (2014) developed and tested a multi-stakeholder model of Corporate Social Responsibility in the Indian mining industry. Their findings suggested that industries could increase their chances of practising value-added CSR in industrial environments.

Ford et al. (2014) found that an understanding of the factors contributing to innovation should go beyond a mere analysis of Porter's hypothesis in regard to competitive drivers, for example exceeding environmental regulatory compliance can also foster innovation in the Australian Oil and Gas Industry. An analysis of CSR in the global mining and oil and gas industries was provided within a "regulatory scripts" framework (Raufflet et al., 2014). "Regulatory scripts" were described as the practices shared by a group of organizations in an industry in response to international frameworks and standards (termed institutional expectations). The authors also reviewed the frameworks that were used for energy-related reporting in the Canadian mining industry, and compared them against international initiatives (Levesque et al., 2014). They concluded that there is no universally recognised standard, and that this research gap must be addressed in order to allow accurate comparisons to be made across sites and companies. This underscores the urgent need for standardisation using a robust and consistent framework such as what was recently developed for water in the minerals industry (Cote et al., 2012). Danoucaras et al. (2014) documented the robustness of the water accounting framework introduced by Cote et al. (2012) by applying it to a number of commodities and operating environments. This kind of testing is important and in some senses can be compared to pilot scale-up of cleaner production processes developed in the laboratory. Until robustness to wide use beyond the initial development environment is demonstrated it will be difficult to encourage industry to take up standardisation of measurement and reporting and therefore, to provide the necessary solid basis for comparisons among operations, locations and introductions of new processes and technologies to document improvements in performance.

Weldegiorgis and Franks (2013) examined the implications of a shift from coal to biomass in steel production in Australia. They found that social performance would not be optimised by full replacement of coal with biomass. Advantages and uncertainties were found with regard to increased workforce exposure to safety risks and the large spatial extent of land use changes that would be caused by a full transition from coal to bio-mass based energy sources. In a thoughtful provoking document, Bond (2014) introduced a very old concept with a new angle, i.e., the potential to employ knowledge about peace processes and peacemaking to support sustainable development goals in mining communities and regions. She made a cogent case for the inclusion of what she termed "positive peace" in the approaches adopted to achieve triple bottom line goals. Perhaps, Bond (2014) stretched the possibility by asserting that positive peace can transcend triple bottom line considerations; it will be very interesting what future empirical case studies reveal in this realm. On the other hand, Dougherty and Olsen (2014), who also examined an old concept, namely, truth, based their work in an empirical study on gold mining in Guatemala. Dougherty and Olsen (2014) utilized a number of conventional paradigms as they examined how individuals make decisions regarding their objections (or not) to mining. Such an understanding is critical if we are to achieve the possibility of sustainable positive peace as espoused by Bond (2014) because the framework proposed by Bond requires trust building at its core. Dougherty and Olsen (2014) observed that involving and building upon the local culture is critical. This is consistent with the observations of Akiwumi (2014) who described the situation of Sierra Leone where local people view the arrival and rights of "strangers" in a different way from the formal rights that the government of the country bestows upon those who would develop the mineral rights. Failure to understand such fundamentals can clearly compromise the ability to build trust and therefore, to develop and maintain positive peace. As such, these three papers individually and together articulated compelling and admirable objectives but also highlighted the challenges involved.

There was a wide diversity of research contexts for the papers, which addressed CSR impacts. This underscored the extent to which these issues are being faced at a global scale. While there were several papers, which focussed upon a developing economy context (Kuijpers et al. 2014; Dougherty and Olsen, 2014; Akiwumi, 2014), CSR concerns were also raised in developed regions with long histories of mining (Weldgeiorgis and Franks, 2014; Wessman et al. 2014; Tuusjärvi et al., 2014). Across these papers, as a generalisation, human rights impacts and cultural issues formed a stronger focus of attention in the developing countries, while environmental impacts received greater attention in the developed countries. Two papers explored the CSR impacts of a mining revival in Finland - Wessman et al. (2014) by assessing the environmental and social performance of the Finnish mining sector in relation to water, while Tuusjärvi et al. (2014) explored the revival of the Finnish mining industry, and described the economic and environmental consequences that may accrue based on three development scenarios (low, med, high expansion). From both of these papers (Wessman et al. 2014; Tuusjärvi et al., 2014), greater attention to CSR was found to be needed for the industry to earn a social license to operate from the Finnish community.

In seeking to 'earn' a social license to operate, practitioners may benefit from reading the paper by Falck and Spangenberg (2014) which proposed a stakeholder-driven process for developing and testing a set of indicators for communicating the social and environmental impacts of a mining project. Through application at three case study sites in diverse operating regions, the authors gained insights into the importance of tailoring indicators to address the concerns of stakeholders at the local level.

3.3. Future mining challenges

Some of the challenges for future mining were clarified through reflections upon the possibilities of future supply constraints of various minerals. Yellishetti (2014) quantified the fluxes and stores of iron ore and steel in Brazil, Australia, China and India. These countries were chosen on the basis of the fact that Brazil and Australia currently supply the majority of the world's iron ore (Brazil produces much steel as well) and China and India account for a large proportion of demand. Yellishetti (2014) provided a discussion of the national and international consequences of rapid resource exploitation in the short term, e.g., rapid unsustainable growth in local wages, and implications of stock depletion in the medium term. Yellishetti (2014) reinforced a long history of this journal of including the transport component of the life cycle by focussing upon the importance of materials transport in the context of a full energy and emissions LCA.

Yellishetti's assessment of risks of iron ore depletion was complemented by studies of similar risks in supplies of copper, lead, zinc and aluminium (Boryczko et al., 2014), rare earths (Habib and Wenzel, 2014) and uranium (Graetz, 2014). Boryczko et al. (2014) built upon the seminal work of Tilton (2003), which emphasized the alarmingly short time periods over which scarcity may impact societies. They did not critically analyse, question or add to the results of Tilton but rather used his results to justify the need for an improved accounting method for efficient conversion of resources into commodities. That is, when scarcity is evident it becomes increasingly important not to waste those resources that otherwise would relieve the scarcity situation. These papers underscored the need to close the loop on metals efficiency. The significant investment by society from the environmental and social impacts of mining and metals recovery, transformations, transport and use and the embedded energy underscore the urgency of radically

increasing the efficiency of metals management once they are within the technosphere.

The paper of Boryczko et al. (2014) applied exergy, a topic that has been extensively addressed in publications in JCLP (e.g., Seager and Theis, 2002), to assess which technology should be best applied for metal refining. For most metals and most of the processing pathways examined, they found very little difference on the basis of the Cumulative Exergy Consumption (CExC); their preferred indicator. However, a significant difference was recorded for different copper processing options with pure copper cathode production by flash smelting being the preferred option. Swart et al. (2014) also quantified cumulative exergy as the basis for examining preferred options. They evaluated a range of metals that could potentially replace lithium for batteries because of the anticipation that lithium will become scarce in the future. They estimated the cumulative exergy for potential replacement metals along the path from their sources to usage in batteries. The important point of this paper was that if the study had have completed at the battery production stage, then all but one of the alternative materials would be similar. However, by including the battery life in the cumulative exergy calculation two of the metals were found to be better options than the others. These papers demonstrate the importance of combining robust accounting methods for appropriate life cycle boundaries to obtain robust sustainability insights for processing pathways or replacement options. Both papers revealed that exergy accounting was superior to other options; they were also built upon a large body of literature increasingly showing that value of well-constructed exergy measurements. Graetz (2014) provided a very different view of potential supply constraints in the context of uranium. He contended that because most uranium reserves are on traditional lands of indigenous people and many indigenous people have opposed uranium mining in the past, this is likely to escalate into an overall supply constraint in the future unless there is a significant improvement in the relationships between uranium companies and the indigenous landholders. Or of course unless we realize the unacceptable short and long-term societal risks of the entire supply chain and user chain, and decide to dramatically improve on materials and energy efficiency and upon a vast array of renewable energy sources.

Habib and Wenzel (2014) focused on two critical rare earths, neodymium (Nd) and dysprosium (Dy) because of the very interesting feature that renewable energy infrastructure, and hence our capability to install renewable energy at scale rapidly globally, is heavily dependent upon their availability. While they concluded that there is no overall supply constraint in terms of resources of the elements, they made a clear case for short-term mining/processing rates and potential geopolitical threats to supply. They also forecasted that a significant source of these elements from recycling is unlikely to become available until around 2100. It may well be that in the future geopolitical supply threats can be mitigated by material substitution. However, the paper by Swart et al. (2014) on such a strategy for lithium, documented that additional complications such as the performance of the functional commodity into which the metals are embedded, as well as their cost. Further, long-term supply of alternative metals must be considered because a shift to an equally scarce material may not be a sensible long-term option, particularly if that substitute is being sought for multiple substitution options. Finally, substitution options do not necessarily have the same waste consequences as materials they are to potentially replace; this result underscores the need to include the waste management pathways in a fully-accounted systems view, which is becoming increasingly well understood through publications led by seminal work in the JCLP.

Giurco et al. (2014) argued that greater attention on the minerals-energy nexus is needed. Through an extended review of academic and grey literature, the authors concluded that the minerals sector adopts a shorter-term view of supply-demand projections than that of the energy sector. They also found that research exploring the minerals-energy nexus is in its infancy. Following case studies at three nexuses (rare-earths-renewables; coal-steel; and uranium-nuclear) the authors concluded that future research should be expanded on the notion of responsible minerals to incorporate the minerals-energy nexus.

Another theme, explored within the topic of "management aspects" that was addressed in several papers was the importance of improved waste utilization and recycling (and reuse) as forms of "new mining". Lederer et al. (2014) explored, in detail, the stocks and flows of phosphorous in Austria to quantify the extent to which it can be recovered for use in an economically effective manner. They extended current mining concepts of resources and reserves to the anthropogenic sources, e.g., waste dumps, and added the concept of non-utilizable materials. Unfortunately, Lederer et al. (2014) found that only a small amount of the potential P could be recovered. They reported that recovery could have been much higher if the sources rich in P were not mixed with other materials in the landfills. Consequentially, we can conclude that separation at the source would be potentially beneficial if that separation does not introduce other inefficiencies, e.g., transport of materials and energy to those sites which exceed the costs at the landfill. Again, this emphasizes the importance of full system boundary inclusion in robust life cycle analyses when comparing options and alternatives with respect to the use and reuse of metals.

Although mining using *in situ* leaching is not new *per se* it is likely that there will be considerable expansion of application of this technique in coming decades. Too often publication of full impacts of new technologies has lagged far behind their wide implementation. Therefore, the quantification of greenhouse gas footprint for uranium, gold and copper by Haque and Norgate (2014) was very timely. Similarly, Norgate et al. (2014) provided estimations of the greenhouse footprint of nuclear power based upon different uranium ore grades as the feedstocks. They concluded that the effects of the forecasted ore grade decline would significantly close the greenhouse gas gap benefit between uranium and fossil fuel-based systems. They urged caution in their conclusions due to the wide data uncertainties in their estimates in the life cycle analyses.

3.4. Integrative models and frameworks for sustainability

Edraki et al. (2014a) provided a refreshing view of the management of tailings based upon a comprehensive review of existing literature. They proposed a framework, wherein the mining industry would shift from a reactive mode of treating tailings water and geotechnical instability problems to a greater use of ore body information and flexible mineral processing flow sheets to ultimately be in a position to design tailings with far better environmental properties than those that are currently produced. Within the area of rehabilitation, Hou et al. (2014) presented the concept of green and sustainable remediation (GSR), which is not only applicable to mining. Their objective was to determine what creates the conditions conducive for effective use of GSR. They concluded that stakeholder impetus is important but only when combined with institutional promoting (leadership) forces. This is an important finding because, all too often, it is asserted that companies respond primarily to external pressures and without this they would not engage in positive changes in behaviours that result in improved environmental outcomes. Hirons et al. (2014) explored an opportunity for mining companies to improve their land remediation strategies that harnessed carbon finance as an integral element of their sustainability strategies. Given that mining companies

represent significant landholders and reclaimed mine sites can contain large amounts of carbon, the authors contended that there is an opportunity to use decommissioned mines to provide forestry-based legacies. A case study was used to explore the feasibility of including an estimate of carbon stocks as a way forward in this area.

A central element of the sustainability strategy for many companies in the extractives sector is that of improved water usage (Wessman et al. 2014). While previous literature suggested that the principles of *'integrated water resources management'* (IWRM) might provide a guiding framework for companies to reduce their water-related impacts (Kunz et al. 2013a; Romer, 2014), practical frameworks to implement the IWRM principles from theory to practice are in their infancy. Kunz and Moran (2014) outlined a framework to assist in moving towards this goal and introduced the concept of "water benefits" as a pathway for operationalizing IWRM principles at a mine site level. Their research provided a foundation for scholarly debate to link decisions at a mine site level towards IWRM aspirations at regional and global scales.

At the global scale (Kobayashi et al., 2014) proposed an index of biodiversity pressure that is based upon site level data. While the authors acknowledged that their index is only a proxy for biodiversity, the global scale of the data produced is of significance because it provides a basis for consistent reporting of threats at the scale of companies, countries and commodities. Huang et al. (2014) performed a national scale assessment of the flows of nickel. They accounted for locally mined and refined sources as well as imports and quantified various aspects of the supply chain sustainability and derived several indices. Based upon that work, they proposed a number of potential sustainability improvements to the Chinese nickel chain. At the regional scale and following a strong history of the JCLP (e.g, Mirata, 2004), Golev et al. (2014) mapped industrial synergies/symbiosis in Gladstone Australia and illustrated the potential for substantial reductions in resource use and waste burden through the application of future synergy options. Also studying at the regional scale, Yuan et al. (2014) integrated sources, stocks and flows of phosphorus to make a direct link between phosphorus mining and environmental impacts. They traced movement of phosphorus through the Chaou watershed in China. Their framework is an example of integration of the physical, economic and environmental dimensions that were obtained by setting the system boundary to include the watershed boundary, the soil and surface water environments and the lithosphere as well as cycling, use and disposal processes. By tracing phosphorus through the system they were able to provide suggestions for reducing environmental burdens from phosphorus delivery to the surface water environment, thereby, elegantly linking mining to use and environmental outcomes.

Sonter et al. (2014) provided a regional analysis of land use changes in two adjacent regions in Brazil; one with extensive iron ore mining and the other without. They concluded that land uses changes associated with mining are more extensive than one would expect from their physical vegetation clearing impact and that the changes that occur should be considered as specific to mining. Consequently, the impacts of mining on land use changes needs a much broader analysis, including important potential policy considerations (both environmental and social), than has been traditionally undertaken.

Rathod et al. (2014) proposed a more sustainable method for recovering phosphorus than conventional mineral adsorbents through the use of red seaweed (*Kappaphycus alverezii*). In a similar vein but with a more restricted system boundary, Pizzol et al. (2014) examined the impact of a trace component of phosphorus fertilizer, namely, cadmium. Unfortunately, cadmium is not benign and can accumulate up the food chain. Pizzol et al. (2014) showed that the degree of accumulation in humans via food consumption varies depending upon the source of phosphorus, e.g., mineral sources versus manure sources. They quantified the societal, financial costs of the health consequences of cadmium exposure via the food chain. They suggested that diverse economic instruments should be developed to minimize risk of exposure and thereby, to reduce human health impacts and costs. However, their estimates could equally well be used to provide a target cost for beneficiation of the cadmium from the phosphorus downstream from mining. A combination of the thinking of Yuan et al. (2014) and Pizzol et al. (2014) provide an estimate of the value added by phosphorus in the economic and spatial systems, thereby raising the prospect of using the most appropriate place in the system to leverage diverse users to contribute to the alleviation of the negative human impacts of cadmium. This would likely be contentious but it is the sort of policy innovation that could be helpful, based upon the findings of some of the papers in this SV. Supporting policies must address the vexing issue of what might be the meaning of the term, "responsibility boundaries". By this term, we mean that at certain points in a material or energy flow system the responsibility in terms of accounting that is related to regulations, e.g., pollution taxes, passes from one legal entity to another. This is further complicated by the possibility that one or more of the entities might be governmental authorities. There is a reticence in these legal entities to become associated with a liability of another organization. The consequence of such an outcome is that optimization is constrained to local domains, where responsibility is aligned with ownership. Regulations that focused on the overall system optimization would then have to include opportunities to trade up and down the value chain. Without trade, governments could simply mandate responsibilities but this would likely create intense resistance. A third option would be for government to alter tax or levy options at various points along the value chain to create a pool of funds that the government could use to implement optimal solutions. This would be challenging because the requisite skills needed in governments to achieve such outcomes might be difficult to acquire.

3.5. Management aspects

In the CfPs, "management aspects" was a large category that was defined to capture research that would inform changes in management with the aim of improving sustainability outcomes. Perhaps unsurprising for the JCLP, readers given the long-term audience and authors, this was the category for which the largest number of submissions were submitted. Consequentially, a number of sub-themes emerged from those papers. These sub-themes are dealt with in the following order: finding beneficial uses for waste materials, waste sources and distribution in the environment, replacement of undesirable chemicals with benign alternatives, emissions intensity of production processes and the water-energy nexus. In dealing with each sub-theme linkages between papers under this theme are identified and discussed.

A range of waste material and beneficial uses of them have been described. For example, Edraki et al. (2014b) and Park et al. (2014) explored the use of coal combustion by-products for mine site uses, as opposed to the better-developed uses in geopolymers for construction materials (e.g., van Jaarsveld et al., 2002), and concluded that there is potential for this synergy but that research and regulatory support are needed for more extensive consideration of the opportunities. Strong bricks were formed by Zhou et al. (2014) to capture hazardous electrolytic manganese residue. Strength was also a defining feature of the concrete produced from waste marble and aggregates in self-compacting concrete (Uygunoğlu et al., 2014). Aluminium production wastes can be trapped in solids

with interesting insulating properties (Perná and Hanzlícek, 2014). Liu et al. (2014b) examined the prospects for utilisation of the large volumes of red mud from alumina refining in China. They found that using contemporary technologies that it is possible to use 20% of high-iron Bayer red mud and 20% of red mud from sintering to capitalize on its pozollanic properties to produce building and construction materials, dam wall construction and glass ceramics. Clearly, there is a long way to go to achieve full utilization of red mud and low-iron Bayer red mud from these processes and more research is required. These authors called for global collaboration to address this issue.

Ash from mussel shell calcination was combined with sewage sludge and wood ash to create mixtures that retain arsenic, chromium and mercury (Seco-Reigosa et al., 2014). Careddu et al. (2014) demonstrated the potential use of fine calcareous sawdust as a filler substitute for more expensive materials in production of industrial products such as paper, rubber, paint and pharmaceuticals. Pyrite, an undesirable by-product of mineral separation can be used to remove arsenic from aqueous solutions (Bulut et al., 2014). Mattila et al. (2014) documented that replacing limestone with steel production slag to produce calcium carbonate can result in a process that sequesters more carbon than it uses, ie, is carbon negative. They noted that if purification is needed, the additional processing might mean that the emissions, human health and ecosystem advantages of their new method would be reduced or even eliminated. This provides a clear justification for further research into efficient purification processes.

Nunes et al. (2014) demonstrated the potential for waste dust from basalt mining to be used as a source of phosphorus fertilizer. Qiang et al. (2014) developed a sequential process, based on utilization of alkaline media and pulsed current to separate valuable metals from copper smelter flue dust thereby, avoiding disadvantages associated with conventional processes which use distilled water and surfactants that produce undesirable effluents. Not only are wastes from processes being increasingly utilized but spent infrastructure is also being (re)processed to create useful materials. For example, Wang et al. (2014) process old electroless nickel-plating baths to produce nanometer nickel powder.

In addition to finding more economically, ecologically and human health safe ways of using 'wastes,' it is also important to improve our understanding of the relationships between sources of potentially harmful pollutants and their environmental occurrence. Such information is crucial to inform management actions to minimise the impact of pollutants and their potential to impact the entire biosphere, including humans. Towards this end, Dragovic et al. (2014) used a range of methods to determine the distribution of heavy metals in soils in the vicinity of a steel production facility in Serbia. They found that prevailing wind direction was a good explanation of why longitude and latitude with respect to the facility were good predictors of heavy metal concentrations. Equally, cleaner production research has always prioritized the invention of alternative processes that reduce environmental burdens at their sources via preventative approaches. In that context, Liu et al. (2014a) provided an excellent example of this with their new method that applies leaching to a Cr—Fe alloy rather then the conventional chromate ore to reduce pollution that accompanies chromate production. The new method results in zero emissions of residues and waste gases as well as producing hydrogen gas that can be captured and used. Pilot scale testing found that laboratory-scale results could be achieved or even exceeded.

Increasingly, more sustainable materials are being sought to replace existing materials that have undesirable properties. Reyes-Bozo et al. (2014) documented useful applications of organic compounds, i.e., sawdust to ameliorate soil polluted with hydrocarbons, and bio-solids to replace mineral flotation reagents. Similarly, Sarquis et al. (2014) demonstrated that quebracho extract was an effective replacement for conventional chemicals for depression of pyrite during chalcopyrite flotation. Both teams of authors found that the flotation reagent replacement was sufficiently effective to consider replacement of existing reagents, which have undesirable properties, particularly with respect to human health, with the benign natural products. They documented how the individual improvements could be linked to industrial ecology (IE) and synergies within a single mine site thereby, providing a range of sustainability benefits. Another application of site-level IE with an extension that employs formal LCA as a measurement context for assessment of the value of making changes in a processing system was submitted by Mendoza et al. (2014). They introduced a technology change, rainwater harvesting and recovery of sawing granite sludge to quantify overall performance improvements. In another example of applied systems thinking, Swart et al. (2014) examined cathode material supply for lithium ion batteries and the link to cathode performance when other metals, e.g., nickel, cobalt and manganese were used to replace lithium to a greater or lesser degree (see above for summary of their results).

Abu Hanieh et al. (2014) applied similar thinking to examine the process chain for production of stone and marble in Palestine. They developed a formal two-level model that enabled more detailed assessment of each sub-component (quarry, cutting, building) and then they developed a simplified systems view to integrate the three phases. As a result they were able to demonstrate significant savings in energy and water and reductions in the losses of valuable non-renewable stone.

Process innovation was documented by Diaz et al. (2014) who used extremophile bacteria to perform precision etching by controlled removal of pure copper from copper sheets, which is increasingly needed for special applications. Their contribution was to show that their innovative bacterial process could be made sufficiently stable and consistent for industrial applications. Another example of process innovation was documented by, Jia et al. (2014) who used a fuzzy analytical hierarchy process to select the appropriate indicators to compare multiple processing routes for Vanadium extraction. They reported that the process was effective and could provide the basis for a sustainability assessment for the industry in China, where currently there is agreed process/method, on the basis of cleaner production methods. It is interesting to compare their work, albeit in a very different assessment frame, to the comparative assessment of steel production in Germany (Fischedick et al., 2014 (see below for a description of their findings)) in terms of how connected systems thinking and formal approaches are having increasingly wide applications.

A number of papers dealt with the important issue of emissions intensity in metals production. Ciacci et al. (2014) traced the historical carbon emissions from aluminium in Italy. They documented the importance of accounting for the material flows associated with production and importation. Yellishetty and Mudd (2014) highlighted the significance of temporal trends in emissions associated with increasing energy intensity of mining and transport, in part, because of decreasing ore grades mined. This is consistent with forecasts made by Norgate et al. (2014) on the importance to emissions accounting of potential grade declines in uranium ore. Fischedick et al. (2014) developed several scenarios for the future of the German steel industry to 2100. They forecasted that the conventional blast furnace approach with and without carbon capture and storage would become unprofitable by 2050. After that iron ore electrolysis will become more attractive but eventually hydrogen direct reduction will be preferred because decoupling of hydrogen production and steel making allows capitalization during periods of cheap electricity generation.

Brunke et al. (2014) examined barriers to adoption of energy conservation in the Swedish iron and steel industry. They discovered, via interviews and surveys, that while cost effective strategies were important, what was more significant was to emphasise energy management, which requires company leadership to drive that focus within the company. Silvestre and Neto (2014) highlighted the potential flaw in overly focussing solely or primarily upon cleaner production-based technologies as a panacea for improving small-scale mining in Padua, Brazil. They emphasised the importance of complimentary participatory approaches, policy support and management dimensions in moving towards more sustainable and profitable mining systems. Their results add to other findings on the importance of institutional considerations, especially leadership, in achieving green remediation strategies (Hou et al. 2014) and institutional reform in the Chinese shale gas industry (Wan et al. 2014) as well as organization, design and management of work in avoiding hydrocarbon leaks (Bergh et al. 2014). In contrast to the other papers, Liu and Li (2013) found that management was not dominant in explaining safety performance. However, the combination of personnel and management effects had approximately double the statistical explanatory power of machinery and the environment. This indicates that while leadership *per se* is not dominant as the explanation, systems that target the machine and operating environment to control safety are likely to be less effective than a focus on the human dimension.

The topic of the nexus between water and energy has received increasing attention in recent years. A search conducted by the team on 14 July 2014 for the "water and energy nexus" on Thomson Reuters ISI Web of Science produced fifteen papers between 2001 and 2009 with thirteen, thirty-seven, forty-three, sixty-six and twenty-two in each subsequent year (2010, 2011, 2012, 2013 and 2014 respectively). However, none of these papers included the term mining.

This SV includes four papers on that nexus. Ihle et al. (2014a) provided a robust quantification of the trade-offs between energy and water in hydraulic transport systems. They concluded that the slurry and transport conditions are sufficiently important that such considerations should be included in the design of pipelines. Ihle (2014b) quantified the greenhouse gas emissions implications of water transport and concluded that a significant impact comes from long distance pipelines that should be considered in energy accounting.

Nguyen et al. (2014a) worked through a number of case studies that clearly separated various mine water management options on the basis of either their degree of synergy or lack of synergy with considerations of energy requirements. They documented that if mine water management priorities were considered alone without integrating the energy use reduction targets, that their energy use reduction targets would not be achieved. Sahoo (2014) also underscore the importance of this in mine dewatering.

Nguyen et al. (2014b) used exergy to quantify the total energy demand associated with a number of mine water management options. They found that exergy provided a useful measure upon which to base an assessment of reduction or avoidance of energy requirements associated with water management. This is consistent with the results of Bozena et al. (2014) and Swart et al. (2014) in that they found exergy-based indicators (see earlier summary) effective for choosing the most sustainable options for their assessment of metal refining and use options, respectively; their indicators, e.g., energy input to processes, were less effective or masked important process differences.

On the topic of energy provision in the Spanish national context, Zafrilla (2014) explored the social and environmental consequences that arose due to a policy shift in 2010 that promoted domestic coal production as part of the country's energy strategy. This detailed case study demonstrated the importance of governmental policy priorities in influencing energy developments. Their modelling revealed that Spain's CO_2 emissions have increased as a result of implementing the so-called *Coal Decree*.

3.6. Mining in the context of developing economies

Six papers in this SV were from developing countries or involved case studies from such economies. Some papers also focused on the nexus between mining and development. Kiefer et al. (2014) quantified the mercury content in amalgams and showed that all miners in their study used excess mercury. So, while research was undertaken to find alternatives to mercury for such miners, their work provided a practical case study to support improved communication that greatly reduced exposure to mercury and at the same time it does not negatively impact efficiency of gold recovery. Of course environmental and human impacts of mercury are reduced as a result of reduced exposure.

The primary importance of human safety in the policies and practices of operations of large multi-national mining companies is no longer questioned. Liu and Li (2014) undertook an empirical analysis of the relative importance of personnel, machinery, environment and management on safety performance on forty-one state-owned mines in China. They found a neural network was able to provide an acceptable fit to the data and that each of the factors provided approximately equal explanatory power. Such results are useful for informing managers and policy-makers about which single or combinations of interventions are most likely to be effective in improving safety performance.

Akiwumi (2014) examined an example of cultural and policy divergence in Sierra Leone. She documented how an entrenched system of western rights to land and minerals is fundamentally discordant with the local community's cultural perspective of strangers. Such studies provide valuable insights into why certain conflicts arise that might otherwise be simplistically interpreted and result in inappropriate responses.

Silvestre and Neto (2014) tested the proposition that cleaner production innovations would provide solutions to problems of productivity, environmental impacts and negative community implications in a poor mining region in Brazil. Their results showed that, while providing advantages, cleaner production *per se* was not a panacea to solving the challenges posed by operating in a poor economic context.

Yellishetti (2014) (see earlier for a summary of the main other findings of this paper) provided a case study of data for those with interests in the general picture of global supply and demand of mineral and energy commodities in terms of the degree of economic development of various economies. He did not document a difference in terms of the level of economic development of the countries, rather, he pointed towards Australia and Brazil having looming revenue flow challenges with iron ore depletion and China a heavy dependence on inflows to maintain steel production.

Authors of two papers explored the nexus between mining and development (Seccatore et al. 2014; Kuijpers et al. 2014). Seccatore et al. (2014) reviewed the roles of artisanal (ASM) and small-scale mining (SSM) in supporting livelihoods in remote locations, including southern Ecuador where their study was based. However, they expressed concerns about the long-term sustainability of this extractive process due to the associated environmental pollution and human health impacts. To overcome this dilemma, the authors proposed a methodology for converting ASM operations into sustainable and profitable industrial extractive units.

Another case at the intersection of mining and development was submitted by Kuijpers et al. (2014) who tracked the growth in hydroelectric dams in the Amazon, many of which support mining.

These expansions have been linked to several human rights impacts, which raise questions about where corporate responsibilities lie in relation to human rights impacts at the intersection of mining development and energy provision.

3.7. New frontiers in the oil and gas industries

In the CfPs, the team solicited submissions on issues associated with oil and gas production not only minerals and energy associated with mining. In the area of conventional oil production Bergh et al. (2014) examined the reasons behind the occurrence of hydrocarbon leaks. Somewhat surprisingly they did not find that technical factors were the dominant explanation for leaks based on empirical analyses of historical leaks in Norway. Rather, psychosocial factors (organisation, design and management of work) provided a stronger explanation for the leaks. Somewhat akin to Bergh et al.'s findings, the research of Hou et al. (2014) revealed that the 'obvious mechanical-technical' aspects were not the cause but the problems and potential solutions were found to be in the way the companies implemented their leadership and management.

In the less well-developed area of coal seam gas or CSG (coal bed methane or CBM) the community acceptance of the practice is increasingly being referred to under the title of "license to operate". Lacey and Lamont (2014) proposed that social license could be understood in terms of a social contract between the companies and communities. This provided them with an ethical interpretative framework within which they comment on the relative significance of justice-based and consent-based contracts. On the environmental/technical side of CBM Dahm et al. (2014) demonstrated that the spatial and temporal variation in the quality of water extracted from coal seams to release the methane needs to be taken into account when planning and designing water management schemes which are designed to provide beneficial uses of the water. It is also important because it provides information on the brine and other waste streams from water treatment that must ultimately be re-used or disposed. In terms of sustainability this raises the issue of minimizing impacts of resources extraction including not only the direct wastes but also the additional energy that is required to treat water. This type of water-energy nexus was the focus of two more papers in this SV (Ihle et al., 2014a; Nguyen et al., 2014a,b) that were discussed earlier in this paper.

An important geopolitical development of the early 21st century has been the global implications of the growth of shale gas in the USA (Rosenberg, 2014). Wan et al. (2014) describe the outcomes from an expert workshopping process that examined the opportunities and barriers to the development of China's shale gas reserves. They identified important institutional barriers to shale gas exploitation, e.g., monopoly control of tenures and the need to develop a domestic oil service market, as well as the more familiar environmental, water and reservoir characterisation issues. Other authors have reflected upon the possibilities of European gas development of a similar magnitude to China (Umbach, 2013). If these barriers are overcome, it seems that the world is poised for a new wave of fossil energy exploitation which is likely to further delay the radical shifts to renewable energy and improved energy efficiencies even if mineral supply constraints can be overcome (Habib and Wenzel, 2014). The implications of such large scale gas use, combined with possibilities of uranium supply constraint possibilities (Graetz, 2014) and the likelihood that ore grade decline will substantially reduce emissions benefits (Norgate et al., 2014), all point to the fact that massive challenges must be faced by the global population in coming to terms with climate change from anthropogenic emissions.

4. Discussion

Overall, articles in this SV covered an immense range and number of papers, concepts, issues, case studies and new methods and process innovations. In the following paragraphs, some reflections of the emergent topics/themes, which were derived from the papers, are provided.

A recurring topic across several papers was the key importance of institutional arrangements. This was highlighted in both government and corporate domains and from national to local scales. Lack of institutions, institutional failures and successes were all linked to likelihood of success in sustainability innovations, practices and policies. A related aspect that was frequently highlighted was the critical importance of institutional leadership.

A range of research methods was used including interviews, surveys, observations and secondary data analysis of reports and/or academic journals. The analyses of articles in academic journals were another research approach that was used. In the field of sustainability accounting, stakeholder and institutional theorising dominated the studies where theories were utilised but new approaches to theory such as Dryzek's 'discursive democracy' theoretical framework were also utilised.

The SV contains a group of papers in which a broad sustainability perspective or specific combination of dimensions, e.g., energy and emissions, was used as a rationale for the development of a processing chain innovation, e.g., infrastructure changes, process or chemical changes or other process efficiency improvements. This is an important theme because it formed not only the basic justification for the research but it builds a sound foundation for a business case for introduction of such innovations once they have been proven in concept.

A topic that was of increasingly broad societal significance was the importance of geo-politics in sustainability issues surrounding minerals and energy commodity supply and demand. The difficulty of finding high quality resources to exploit in mature mining economies is driving exploration and project development into more and more geopolitically and geographically challenging circumstances. Two illustrative examples of this were contained in this SV, namely, rare earths (Habib and Wenzel, 2014) and steel/iron ore (Yellishetti, 2014). The authors of these papers emphasised the need to ensure that we become increasingly more efficient and effective at managing metals once we have undertaken the necessary activities and their impacts to find, extract and refine metals into commodities. The case of geopolitical risks raises an important and challenging issue about whether it is better to expend energy and effort in the use and reuse of metals to avoid mining in these locations or whether it is also important to consider the opportunities for people in these locations to gain wealth and quality of life from the metal extraction. Clearly, over time a balance will need to be struck and ultimately *all* metal in use will have to be stewarded far more effectively than today.

A related theme with strong representation in this SV is the issue of improved waste management via the search for alternative beneficial uses for the waste(s). Several authors went beyond seeking use of single waste streams, to explore uses of mixed wastes from multiple sources to seek synergies. What might be termed "new mining", ie, the recovery of metals from previous activities of inefficient mining and from waste materials resulting from the use of metals emerged as an increasingly important dimension.

In drawing together the SV, several people were approached with an invitation to provide thought pieces on diverse topics to solicit discussion on issues of significance to the SV topic. Two of those invited responded (Hodge, 2014; Cummins, 2014). It is our hope that these contributions and the associated commentaries will trigger important transdisciplinary dialogue among academics,

industrialists, governmental officials, and members of the NGO sector and civil society on these and related topics.

Hodge (2014) posed the conundrum (he terms it an "apparent paradox") that even though the mining industry has improved in terms of policies and on the ground practices and via its interactions with local communities, the incidence of serious conflict continues to rise. He hypothesised an explanation in terms of system theory in which internal signals (company performance) and emergent broader system behaviour (community empowerment) interact. He suggested that overlapping consensus could provide a pathway or approach that could be adopted to resolve the apparent paradox. Constructive comments by Bebbington, (2014); Brereton, (2014); Hamann, (2014) question, to some degree, the extent to which company performance has sufficiently improved to support Hodge's contention. They express doubt about overlapping consensus as *the* solution and recognise the importance of seeking to pose these challenging questions and to enter into public dialogue in this manner.

The second think-piece (Cummings, 2014) is focused on the rehabilitation of mined land in Australia. Reflecting on over 20 years of diverse experiences working in this area, Cummings questioned whether the industry has maintained its momentum for progress, and suggests opportunities to rediscover a previously held leadership role. He suggested that companies and mining associations should take actions such as increasing investments in research, development, application, demonstration and communication of high quality land rehabilitation and re-use projects. Two responses to his comment were received (Carrick, 2014; Mulligan, 2014). Both commentators agree with the proposition that leadership has waned. Carrick presented the view that rehabilitation is notably better in places where the results are often viewed by more people, e.g., near urban areas. Mulligan appears pessimistic about using rehabilitation assurances to support research; he also expressed that short-term goals, particularly when they are focused primarily on production targets will be unlikely drive better rehabilitation outcomes. He was also not positive about the likelihood that compliance with improved regulations will lead to significant improvements. Interestingly Mulligan observed that the issue of expectations of performance is important, which links directly to the "apparent paradox" raised by Hodge in his piece.

5. Progressing the research agenda

The SV covered many issues, topics and scales of application. By scanning insights from this broad volume, the following research topics and questions, that require further attention, were formulated.

1 Exploration of the impact of integrated reporting developments on the mining industry.

Integrated reporting is an emerging practice that is designed to integrate financial information with sustainability information (IIRC, 2013) and there is a need for further literature in different contexts, especially in an environmentally sensitive industry such as the mining industry. Given that integrated reporting is at an embryonic stage, there were no papers on this for the SV but it is an area that requires increasing research attention.

2 Research on mining companies' responses to climate change issues and policies.

There is a need to extend the work of Pellegrino and Lodhia (2012) and to explore not only lobbying for and against climate change policies but also on how mining companies understand and respond to climate change and to the impacts of carbon pricing requirements on their operations; this is another issue which was not fully addressed by this SV. On account of the global operations of mining companies, such research should also consider how national governments could cooperate more effectively to develop a carbon pricing market that acts effectively for mining companies operating in a multinational context. National markets only have limited success in the absence of global-scale agreements, because it may result in companies moving operations to countries without a carbon market.

3 Investigation of the impacts of ethical investments on sustainability in the mining industry.

It is of interest to explore the effects ethical investments have on the sustainability practices of mining companies. Earlier research revealed that ethical investments encourage cleaner production and this does not have to be at the expense of long-term financial performance (see for example, O'Rourke, 2003). Ethical investments therefore, have the potential to be a vital driver of sustainability practices in the mining industry and research is needed to explore this matter.

4 Understanding of the impacts of human rights issues on the mining industry, especially in relation to operations in developed and developing countries.

As the demand for minerals increases and as ore grades decline in established mining regions, companies are expanding into new mining regions, many of which are situated in the developing world. This raises immense ethical dilemmas regarding the social license for mining companies to operate in these regions, and also with regards to ensuring that their activities are appropriately regulated. Such research necessitates multi-disciplinary approaches and insights that recognise human rights impacts from the community to the national level and the global level. Therefore, ethical behaviour with regard to workers and inhabitants in the vicinity of mining activities is an area, which urgently requires research attention.

5 Investigation of the NGOs perceptions of reality in mining and their involvement in partnerships with mining companies.

The role of NGOs in the mining industry is critical; their perceptions of sustainability of the mining industry and their involvement in working together with the mining industry through partnerships require further investigation and analysis.

6 Potential gains for various aspects of sustainability by formally including more of the metals and energy value chains.

A number of the papers used the context of value chain and some atrial value chain analyses, particularly broad scale material flow analysis. However, the models to support explicit, formal research for dramatic improvements in material and energy demands in production from ore bodies to commodity reuse and recycling remain elusive. This includes a lack of formal linking of new geological ore body properties to downstream improvements.

7 Investigating ways of linking of community benefits to the physical activities of minerals and energy commodity production and use.

Some papers justified the development of techniques, technologies or processes on the basis of asserted values to surrounding

communities. However, explicit demonstration of the links in practice, even via case studies, was scant.

8 Examples of implementation success of coupled sustainability innovations for radical systems improvements were not submitted.

There is strong evidence across a wide range of literature that piecemeal improvements in the efficiency of metal and energy supply chains is insufficient to deliver a reasonable quality of life to those in poverty while maintaining current levels for the more wealthy. A transition is needed in the way that society consumes minerals, from the design of products and energy systems through to the use, reuse and recovery phases. Addressing these immense societal challenges requires that research on minerals supply chains become more closely linked with supply and demand. It also necessitates that future research should incorporate approaches from the social sciences as a means for more effectively conceptualising the kinds of changes that are necessary and how they could be effectively implemented. Recently, Kunz et al. (2013b) argued about the importance of "coupling research" to achieve better integration between human and engineered systems to implement sustainability within the industrial sector, including mining. Research on sustainability transitions (Markard et al., 2012), cradle-to-cradle management (Braungart et al., 2007), and urban mining (Jones et al., 2014), may serve as foundations for revolutionising the future of minerals supply and demand networks.

9 The study of the impacts of mining at the regional scale was limited.

The locations of mineral deposits are dictated by geography. Mines therefore are often developed in close proximity to one another, giving rise to mining regions. However of the papers included in this SV, research at the regional scale was limited. It is timely to consider the multiple, cumulative effects of mining regions as socio-ecological systems.

10 A range of highly contentious issues surrounding unconventional oil and gas extraction require urgent scientific attention.

Articles in this SV touched upon the issues surrounding unconventional oil and gas extraction. However, the papers focused more on the needs for research than on presenting results that can enlighten best practices *per se*. For example, even though the team repeatedly solicited papers on the subject of hydraulic fracturing it proved to be very difficult to find authors with sufficient data and insight to produce full research papers. There is an increasing literature in this area but a great deal of new research is needed in the public domain to provide confidence in the ongoing safety of people and ecosystems.

11 Confusion abounds regarding the use (and utility) of the terms sustainable development and sustainability as they refer to mining, minerals and energy supply and demand. More clarity is needed and definitions and frameworks that can provide practical insights and assistance to implementation of systems that will lead to radical improvements in the supply and demand for minerals and energy.

An overview of some of the globally recognised and accepted sustainable development/sustainability frameworks are illustrated in Table 2. These frameworks cover management systems (ISO, AA1000), reporting (the Global Reporting Initiative, Integrated reporting), broad sustainability issues (Global Compact and ICMM principles) and sustainability within a specific context (Enduring Value).

Table 2 was not designed to be an exhaustive list of all possible sustainable development frameworks. That was beyond the scope and purpose of this introductory paper. However, the purpose of the table was to highlight the major documented sustainable development frameworks that have implications for the mining industry.

These frameworks cover a range of sustainability issues but one has to question whether merely managing and reporting these issues, or committing to sustainability principles, advances the sustainability of mining operations. Companies could self-select issues that are easily manageable and reported, while ignoring other issues that would be relevant to stakeholders. The broad, general underlying principles of these frameworks may not provide sufficiently specific guidance to mining companies in addressing critical sustainability issues for the industry. There is a need for a more comprehensive framework, one which is specific to the mining industry and which is cognisant of the diverse range of its sustainability challenges and stakeholders. Because of insights obtained from the articles of this SV, two authors took the first steps in proposing a comprehensive framework and in testing it by applying

Table 2
Major sustainable development/sustainability frameworks.

Framework	Overview	Mining Implications
1. Global Compact	Ten broad principles from the United Nations that companies sign up to. These encompass human rights, labour standards, the environment and anti-corruption.	Not specifically focused on Mining but all these issues apply equally to mining companies.
2. ISO standards	ISO 14001 provides guidance and accreditation of environmental management systems. ISO 26000 provides guidance for corporate social responsibility but no accreditation is provided.	Environmental management and corporate social responsibility systems can be used by Mining companies.
3. AA 1000	A voluntary guideline for management systems for sustainability, with emphasis on accountability and stakeholder engagement.	AA100 management systems can be used by mining companies.
4. Global Reporting Initiative	A comprehensive set of voluntary guidelines for reporting on the triple bottom line – economic, social and environmental information.	Has a mining sector supplement.
5. Integrated Reporting	A more recent development concerned with integrating economic information with social and environmental matter, and having integrated thinking embedded into organisational systems and processes. The International Integrated Reporting Council has released a draft framework in 2013.	Mining companies could focus on integrating their economic performance with their social and environmental performance.
6. ICMM principles for sustainable development	Ten principles for sustainable development for the mining industry.	Focuses exclusively on the mining industry.
7. Enduring Value	The Australian Minerals industry's sustainable development framework which operationalises the ICMM principles.	Focuses on the Australia Mining industry but could also apply to other mining contexts.

it to interpretation of the content of the papers in this SV (Moran and Kunz, 2014).

6. Conclusions

This SV is the one of the largest published within the JCLP, with papers covering a diverse range of topics and study contexts pertaining to mining and related dimensions. The strong author response revealed that there is a very active and growing global research community now working on issues associated with mining, minerals and energy supply and demand issues. There are opportunities for future research to build upon this foundational body of work to address the research gaps and to take advantage of synergies with existing research. Overall, it is concluded that as industry and governments develop and implement policies, regulations and actions, they can continue to be supported by a strong and active research community working across many dimensions. Much remains to be done but this SV in the context of the increasing literature pertaining to mining and minerals supply and demand provides an optimistic future for this evolving research field.

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