The Mineral Resources Landscape – An Expanded Conceptualisation of Minerals Sustainability

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ABSTRACT

As part of global systems of mineral production and consumption, the Australian minerals sector is facing sustainability challenges across technological, social, ecological, economic and governance domains, as well as between local, national and global scales. To ensure that the Australian minerals sector progresses towards sustainability, it is imperative to understand the possible ways in which Australia's mineral resources could support sustainable futures. A significant research gap exists between the complex nature of questions concerning minerals sustainability and the reductionist methods available to deal with them. This paper argues the need for broader, more integrated approaches to questions concerning minerals sustainability, which can address multiple human perspectives, complex and 'messy' patterns and processes across multiple organisational, temporal and geographical scales and whole systems of mineral production and consumption.

To inform the development of a new approach to minerals sustainability, this work reviews the contemporary understanding of the Australian minerals sustainability problematic, from the perspective of the Australian minerals sector (Minerals Council of Australia), the Australian research sector (Mudd 2007a, 2007b; Mudd and Ward 2008) and a multi-scale international project (MMSD 2002). This review shows the focus of current responses to the minerals sustainability problematic, identifies the need for an integrated approach to questions of minerals sustainability and addresses how different approaches are informed by underlying and unarticulated assumptions about the tolerability of tradeoffs between different societal goals, the treatment of uncertainty and the application of different conceptual geographical, organisational, temporal and life cycle scales to define the minerals sustainability problematic.

The Mineral Resources Landscape proposed, offers an expanded conceptualisation of minerals sustainability, to link minerals production and consumption in an integrated assessment across the entire minerals supply chain, connecting social, ecological, technological, economic and governance domains across local, national and global scales. The key leverage points governing change in the Mineral Resources Landscape are identified as:

- the material source,
- extraction and production technologies,
- level of service and value, and
- consumption patterns.

Mapping the key challenges facing the minerals sector, as identified in the review herein, indicates that the boundaries defining traditional conceptualisations of minerals sustainability focus on the material source and technology and ignore two very key drivers of the Mineral Resources Landscape – the 'services' minerals offer to society and the 'consumption trends' which assimilate these services into society. Understanding these overlooked aspects of the Mineral Resources Landscape, along with the conventional areas of focus, is essential for identifying the Australian minerals sector as a provider of sustainable mineral services. This insight prompts a reconsideration of the role of minerals services and consumption trends, together with the role of the material source and technology in shaping change and the emergence of sustainable systems of Australian minerals production and consumption, across multiple scales and domains.

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INTRODUCTION

> Sustainability lives in a world distinct from the present: one with a new vocabulary and cultural habits. As we reach toward that new world, we remain enmeshed in our modern milieu with the vocabulary and stories that have served us so well for centuries. Until the new story replaces the old, we will have to … hold on to two opposing models of reality and beliefs about ourselves while we use our intelligence to design the new tools and institutions that sustainability requires (Ehrenfeld, 2008, p 215).

In light of the global imperative to progress sustainability, the possible ways in which Australia's minerals resources may support sustainable futures and contribute to the transformation of global patterns of production and consumption, need to be understood. However a significant gap exists between the nature of questions concerning minerals sustainability, and the methods available to deal with them. This indicates the need for broad integrated approaches to questions concerning minerals sustainability, which can address multiple human perspectives, complex and 'messy' patterns and processes across multiple organisational, temporal and geographical scales and whole systems of mineral production and consumption. The contested, complex and messy nature of the mining and minerals sustainability problematic are described below, establishing the need for new, broader, integrated and adaptive approaches to understanding the possible ways in which Australia's minerals resources could serve sustainable futures.

Mining and minerals sustainability – the Australian context

As part of the global mineral supply chain, the Australian minerals sector faces challenges across local, regional and global scales relating to land management, economic development, local communities, the environment, information sharing, artisanal mining, governance, the viability of the minerals sector and the need for an integral approach to using minerals across systems of production and consumption (MMSD, 2002). Nationally, the Australian minerals sector is also facing a unique and complex sustainability problematic. As the rapid urbanisation of the global population drives further demand for Australian minerals resources, long term data indicates that ore grades for most base and precious metals are in gradual, but permanent decline, leading to increased greenhouse gas emissions, energy consumption, water consumption and waste rock and tailings volumes (Mudd, 2007b). These trends become critical in light of global efforts to combat climate change and improve water and energy efficiency, especially with regard to the constraints they could possibly impose to future production (Mudd and Ward, 2008).

A prominent response to these challenges has been to develop new technologies to access new resources, demonstrated by recent interest in the prospects of deep sea mining in Australia. Activity in Australia's seafloor exploration and mining sector is marked by the recent release of the Australian Offshore Minerals Location Map (CSIRO and Geoscience Australia, 2006), Australia's extended marine jurisdiction and CSIRO's recent report exploring the social viability of an expanded seafloor exploration and mining industry in Australia (Littleboy and Boughen, 2007).

Numerous authors claim that technological fixes will not work alone in addressing the complexity of today's sustainability problematic (Riedy, 2007; Slaughter, 2004; Wilber, 2000a). The integration of objective and subjective disciplinary perspectives is needed, to capture and the human dimensions and ethical debates associated with the implementation of new technologies. 'Modern technology renders ethical actions and responsibility problematic' (Ehrenfeld, 2008, p 31), and in its pervasive form, is regarded as a key dimension of unsustainability (Ehrenfeld, 2008; Slaughter, 2004). The need for technology to be assessed in a broader context is widely affirmed (Ehrenfeld, 2008; Rip and Kemp, 1998; Slaughter, 2004), however rarely practiced with regard to minerals extraction and production technologies. In order to delineate the role of Australia's mineral resources in servicing sustainable futures, the sustainable development of the Australian minerals sector needs to be assessed in an in integrated framework, by means of understanding the dynamics of the whole system pertaining to minerals production and use.

Multiple perspectives – the social construction of the mining and minerals sustainability problematic

The challenges facing the Australian minerals sector may be defined and prioritised in many ways, according to the multiple human perspectives, expectations, interests, value systems and ethical standpoints that exist. Consequently, questions surrounding mining and minerals sustainability are highly contested within society, as described by Bridge (2004) and Cowell et al (1999). This 'contested nature' emanates from the different ways in which people value the 'services' offered by minerals, as well as the 'services' offered by the ecosystems, landscapes and cultures which are transformed in the process of mineral extraction, processing and use. The 'services' offered by minerals are inherently subjective and socially constructed. One person may value gold for its role as jewellery, while another person may value gold for its role as a monetary metal or reserve backing. Additionally, another person may not be concerned with the 'services' offered by gold at all, but rather the significant environmental and social impacts associated with gold extraction and processing (Larmer 2009).

Metals may have a vital role to play in a sustainable future, however, what a sustainable economy looks like and how materials are used therein raises starkly contrasting human value systems and perceptions of equality, morality, need, wellbeing and growth. Due to the difficulty of integrating these highly subjective human dimensions into a systemic approach to minerals sustainability, these considerations receive too little attention.

Complex nature of questions concerning minerals sustainability

Systems of mineral extraction, production, and use involve interactions across social, technological, ecological, governance and economic domains, as well as between local, national and global scales. Coupled ecological and socioeconomic domains, interacting to form the dynamics of natural resource management, may be referred to as social-ecological systems (Kinzig et al, 2006). The minerals social-ecological system is complex, continuously evolving and adaptive, involving interactions between the social, institutional, environmental, economic and political forces with which the minerals sector has co-evolved. This forms a complex platform for conducting research in an integrated and holistic way. Additionally, understanding the full complexity of real world complex, adaptive social-ecological systems requires knowledge of linked systems at the scales above and below the scale of interest and the ways in which the systems at these three scales interact and influence one another (Walker and Salt, 2002). Therefore the complex, adaptive social-ecological system pertaining to the production and consumption of Australia's minerals resources needs to be assessed with consideration of the structure, function and influence of the relevant global and local complex, adaptive social-ecological systems describing minerals production and use.

'Messy' concepts – an approach for describing the contested and complex nature of questions concerning minerals sustainability

Due to the contested and complex nature of questions concerning minerals sustainability, any comprehensive attempt to define the problem of minerals sustainability conjugates a complex array of interrelated issues spanning the domains of science, sustainability, politics, technology, economics, governance, the environment, culture, ethics, psychology, philosophy and dynamics of power, among others. Following Ackoff (1974), this dynamic and evolving concoction of interacting issues may be seen as a 'system of problems', in which no problem ever exists in complete isolation and 'every problem interacts with other problems and is therefore part a set of interrelated problems' (Ackoff, 1974, p 21). Ackoff (1974) refers to such a 'system of problems' as a 'mess' and argues that 'messes' must be treated as whole, because solving the component parts independently of one another 'not only usually fails to solve the individual problems that are involved, but often intensifies the mess' (Ackoff, 1974, p 21).

A way forward

Faced with a contested, complex and messy problematic situation, current approaches to minerals sustainability persist in reducing the minerals social-ecological system to its measurable and quantifiable dimensions for objective analysis. As Rayner and Malone (1998, p xviii) suggest 'issues of human needs and wants, the social basis for cultural or institutional choices, uncertainty, imperfect knowledge, and irrationality are often elided because they are too difficult to represent in equations and computer models'. Such reductionist approaches only offer a piecemeal understanding of the situation, and lack the vital insights to be gained from understanding the key dynamics, interrelationships and emergent properties that form the whole complex, adaptive social-ecological system describing minerals production and use.

In order to address questions concerning the sustainability of minerals resources in a balanced way, it is necessary to strike a balance between:

- approaching the 'mess' as a whole, and
- reducing it to its critical independent parts.

This paper seeks to implement such a balance, in order to identify the critical drivers and leverage points that influence the minerals sustainability problematic as a whole. In order to assess questions concerning mining and minerals sustainability in an appropriately balanced and pragmatic way, it is necessary to consider whole, linked systems of minerals production and use, in order to identify the key variables governing change.

Paper objectives and outline

This paper seeks to develop a new approach for understanding and assessing the contested and innately complex questions concerning the future sustainability of minerals and mining, to enable informed decision making and actions for identifying the possible future roles of the Australian mineral sector in transforming global systems of production and consumption. This evidently involves expanding the boundaries of conventional approaches, to consider multiple perspectives, multiple scales and whole systems of minerals production and consumption. This is supported by a review of literature on futures methodology and sustainability, which reveals a solid consensus on the need to expand the geographical, temporal, organisational and disciplinary boundaries that define our conceptualisations of, and approaches to, sustainability predicaments (Ehrenfeld, 2008; Jackson, 2005; Liu et al, 2007; Ryan, 2005; Slaughter, 2004; Wilber, 2000a, 2000b). This paper presents:

- a synopsis of the Australian minerals sustainability problematic, to inform the development of a new and integrated approach for identifying the role of Australia's minerals resources in supporting sustainable futures;
- a critique of the assumptions underlying current perspectives and approaches to minerals sustainability, demonstrating the need for a new framework featuring a broader vision and more integrated approach; and
- a new and expanded framework, referred to as the Mineral Resources Landscape, for conceptualising the role of Australian minerals resources in providing the services needed for sustainable futures.

THE AUSTRALIAN MINERALS SUSTAINABILITY PROBLEMATIC

This section presents a review of the contemporary understanding of the Australian minerals sustainability problematic, undertaken to inform the development of an integrated framework for understanding the possible ways in which Australia's minerals resources may support sustainable futures. Given the contested and complex nature of the Australian minerals sustainability problematic, this review has been undertaken to demonstrate the extent to which various perceptions of the minerals sustainability problematic:

- differ according to various actors and various scales of focus;
- demonstrate an integrated awareness across whole systems of minerals production and consumption;
- engage with complexity and 'messy' concepts; and
- choose to reduce the whole complex, adaptive social-ecological system pertaining to minerals production and use to critical independent parts.

In doing so, this synopsis draws from multiple perspectives and multiple scales. Three key perspectives have been selected for review, including a perspective from the Australian minerals sector (Access Economics, 2008a, 2008b), a perspective from the Australian research sector (Mudd, 2007a, 2007b; Mudd and Ward, 2008) and a perspective from multiple scales and multiple sectors of interest (MMSD, 2002). The sector and context from which these perspectives are being presented are indicated in Table 1, along with the predominant scales at which these perspectives are focused and the extent to which they engage with complexity and 'messy' concepts.

Mining, Minerals and Sustainable Development (MMSD) – multi-scale, multi-sector perspective

Following a two-year independent process of research and consultation, the MMSD (2002) presents nine key challenges facing the minerals sector and suggests steps towards progressing sustainability. Many of the principles underpinning the MMSD (2002) are consistent with the key principles and objectives guiding this research. The key point of consistency lies in the need for expanded conceptualisations and approaches to engaging with the minerals sustainability problematic. One of the nine key challenges facing the minerals sector, identified by the MMSD (2002) through consultation with multiple stakeholders, is the need for an integrated approach to using minerals. The MMSD (2002) suggest a set of principles and objectives as a guide to implementing such an integrated approach. This paper seeks to progress the implementation of the MMSD (2002), by building upon these principles through the development of the Mineral Resources Landscape. Following a review of the MMSD (2002), it is evident that an integrated approach to the minerals sustainability problematic should encompass:

- Comprehensive assessments across the entire minerals supply chain, encompassing:
  - consideration of the 'use and downstream supply of mineral products' (MMSD, 2002, p xxi) along with the mining and processing of minerals, to include:
    - a focus on the equitable distribution of use between industrial and developing countries,
    - consideration of the social and economic dimensions of use, and
    - an assessment of the impacts associated with consumer preferences and demand.
  - Consideration of the efficiency with which minerals commodities are used. This necessitates an evaluation of recovery, extended product life, remanufacture, recycling and reuse, and avoidance of use.
  - Questions of sufficiency of access.
- A focus on mineral 'services' as opposed to minerals 'supply'.
- Careful acknowledgement and consideration of competing interests, conflicting perspectives and the existence of important interactions across and within local, national and global scales.
- The precautionary approach, to balance risks and uncertainties regarding the environmental and health impacts of different mineral products.
- Support for the responsible stewardship of minerals throughout the entire supply chain.
- Careful consideration of the needs of future societies.

In addition to the need for an integrated approach to using minerals, the MMSD (2002) identifies eight other key challenges facing the minerals sector. In order to maintain its social licence to operate, the minerals sector is expected to meet the expectations of a diverse set of stakeholders, including local communities, industry employees, local citizens, countries, environmental organisations, investors and consumers (MMSD, 2002). These multiple perspectives are reflected in the heterogeneous nature of the challenges identified and the extent to which they permeate through the economy, society, governance structures and the environment, at local, national and global scales. Therefore insights into the key challenges facing the industry, offered by the MMSD (2002), are extremely valuable for informing the development of the Mineral Resources Landscape. The eight challenges identified relate to:

1. viability of the minerals industry;
2. control, use and management of land;
3. economic development and minerals;
4. local communities and mines;
5. the environment, mining and minerals;
6. access to information;
7. artisanal and small-scale mining; and
8. governance at local, national and global scales.

TABLE 1

Background to perspectives sourced for evaluation of the sustainability of the Australian minerals sector.

Author/sponsor	Alignment with 'wicked' and 'messy' concepts	Sector	Scale of focus	Intention/context
The Mining, Minerals and Sustainable Development Project, a partnership between leading minerals companies, the International Institute for Environment and Development (IIED) and the World Business Council for Sustainable Development (WBCSD).	Yes – acknowledges contested aspects, complexity, multiple scales and need for an integrated approach.	Minerals Sector, WBCDS (Industrial Sector) and IIED (NGO).	Local, national and global.	An 'in-depth review of the mining and minerals sector from the perspective of sustainable development, undertaken with the support and engagement of mining companies, mining communities, labour, the research community, and a broad range of other stakeholders' (MMSD, 2002, p v).
Gavin Mudd (Mudd, 2007a, 2007b; Mudd and Ward, 2008).	Partly – seeks to highlight the contested aspects and illustrates the need for an integral approach.	Research	Local – Australia	An examination of the long-term trends in mining with a particular focus on environmental consequences.
Minerals Council of Australia (MCA) (Access Economics, 2008a, 2008b; Molloy and Yan Tan, 2008).	No – singular market economy perspective.	Minerals	Local – Australia	Potential industrial commodity demand scenarios, potential supply scenarios for Australian mineral production.

In response to the challenges identified, the MMSD (2002) presents four major categories of actions to support sustainable development in the minerals sector, in an attempt to organise the many suggestions offered throughout the report. The call for an increased understanding in sustainable development, through a commitment to education and research, is especially relevant to the intention of this paper. Understanding sustainable development in the minerals sector is central to addressing the situation as a complex, 'messy' problematic situation. To achieve an increased understanding of sustainable development, through a commitment to education and research, the MMSD (2002) calls for transdisciplinary research with the capacity to manage multiple perspectives through a broader approach, stating:

> Research will face increasing demands to ensure relevance to the concerns of stakeholders in the sector, and there is a need to find mechanisms to ensure this broadening of focus occurs … More funding could be committed to research that aims to integrate disparate sets of knowledge or expertise within a sustainable development framework (MMSD, 2002, p xxv).

To facilitate the integration of the value chain and the connection between minerals production and consumption, the MMSD (2002) also endorses futures inquiry, suggesting that 'one starting point could be for different groups to work together to produce scenarios of how needs for mineral commodities are likely to be met in the future' (MMSD, 2002, p 286).

In addressing these calls for an integrated, 'broader', transdisciplinary futures inquiry, this work will develop practical tools for navigating through the complex questions concerning the future sustainability of minerals and mining, to enable informed decision making and actions for identifying the Australian minerals sector's role in a sustainable future, as a contributor to the transformation of global systems of production and consumption.

Gavin Mudd – an Australian research and sustainability perspective

Just as the MMSD (2002) seeks to account for the contested nature of the minerals sustainability problematic through consideration of multiple interests and perspectives, in his assessment of the sustainability of mining in Australia, Mudd (2007b, p 8) also pays careful consideration to the highly variable 'concept and scope of sustainable mining'. The following seven themes are identified by Mudd (2007b, p 7) as the 'most commonly raised components' of the environmental and social impacts of mining. These themes strongly align with the key challenges facing the minerals sector, identified by the MMSD (2002), whilst not mentioning the need for an integrated approach to minerals. It is important to note that Mudd (2007b) has defined these themes bounded by a scope including only environmental and social impacts:

- Land use management.
- Environmental impact assessment and permitting.
- Environmental impacts during operations.
- Post-mining rehabilitation.
- Environmental costs of raw materials versus secondary sources.
- Economic parity, relating to the equitable distribution of the benefits from mining.
- Increasing scale – this relates to the extent to which the environmental impacts associated the increasing scale of mining may lead to potential constraints on modern mining. This is not addressed by the MMSD (2002) as a critical challenge facing the minerals sector.

'To address many of the above issues and provide a sound foundation to inform the various perspectives of sustainable mining' (Mudd, 2007b, p 8), Mudd (2007b) examines the long term trends in mining for almost all sectors of the Australian mining industry, through the compilation and assessment of master data sets on principle issues critical for quantifying the footprint or scale of mining.

Mudd's analysis, drawing from quantitative and qualitative historical data, illustrates a number of key trends, affecting the long-term sustainability of the Australian minerals sector, as summarised below (Mudd, 2007b, pp 126-127):

- Mineral production currently highest in history and growing rapidly.
- Ore grades are in general, but permanent decline.
- Scale of mines is increasing, for all minerals commodities studied.
- Solid waste rock/overburden and tailings are increasing per unit material produced.
- Economic resources are under pressure from continually expanding production. Future economic resources are

closely linked with developments in exploration, technology and economics.

- Ores are increasingly more complex, often with significant impurities. 'Over time the mining industry has needed to develop technologies to continue economic operations or expand production capacity' (Mudd, 2007b, p 127). The environmental impacts, including water and energy demands, associated with increasing ore complexity are relatively unknown.

Mudd and Ward (2008, p 9) show that if the above listed trends are allowed to continue, 'ultimately, the world may not physically 'run out' of copper, coal, gold or other minerals, but aggregate production must peak and decline as new mining operations become increasingly constrained by lower mineral deposits, greenhouse emissions, energy costs and water'. Unlike the MMSD (2002), Mudd and Ward's (2008) analysis does not consider recycling. They show that as ore grades decline, environmental costs, including energy inputs and greenhouse gas emissions increase, generally exponentially. For example, with respect to gold mining in Australia, ore grades are in continual and permanent decline, associated with an extreme decrease in resource efficiency, marked by increasing tailings volumes, greenhouse gas emissions, water consumption, cyanide consumption and waste rock/overburden (Mudd, 2007a). These trends become critical in light of necessary global efforts to improve energy and water efficiency and combat climate change, especially with regard to the constraints they could possibly impose on future production (Mudd and Ward, 2008).

Through the consideration of critical environmental indicators of sustainability, Mudd (2007a, 2007b) and Mudd and Ward (2008) illustrate the complexity of the minerals sustainability problematic. They show that future mineral production and the possible services minerals may provide to sustainable futures along the supply chain, rely heavily upon a complex interplay of governance, new discoveries, new technologies, economic factors, social dimensions, the environment, among others (Mudd and Ward, 2008). Mudd's work demonstrates the need for broad, integrated, balanced and adaptive approaches to addressing the management of Australia's minerals wealth, in order to truly understand the critical drivers governing the sustainability of minerals and mining, as called for by the MMSD (2002).

Minerals Council of Australia (MCA) 2020 Vision – an Australian industry perspective

Access Economics recently prepared two reports for the Minerals Council of Australia (MCA), presenting potential global industrial commodity demand scenarios (Access Economics, 2008a) and potential supply scenarios for Australian minerals production (Access Economics, 2008b) between now and 2020. Estimates for both reports are based solely on economic criteria, representing a singular 'market' perspective and omitting other aspects driving change in the minerals sector, as outlined by Mudd (2007b), Mudd and Ward (2008) and the MMSD (2002). The impacts of carbon prices are included, however in purely economic terms. The Labour Force Outlook in the Australian Minerals Sector 2008 to 2020, prepared by the National Institute of Labour Studies (NILS), for the MCA, addresses the need to build capacity in Australia's labour force to meet the global commodity demand boom predicted by Access Economics (2008a, 2008b). The provision of infrastructure and the creation of Australian labour force capacity are identified as two very important challenges facing the Australian minerals sector.

Access Economics (2008b, p v) insists that Australia must take full advantage of its comparative advantage in the global minerals sector, stressing that 'if we fail to maximise the growth potential in industries where our comparative advantages lie, then our living standards (defined as Australia's average level of productivity per worker) will be lower than its potential by the extent of our failure to maximise our future incomes'. This follows the need for very large increases in supply capacity to meet predictions of global demand. Driven mainly by the industrial revolution of the developing economies, by 2020, Access Economics (2008a, p iv) predict that global 'coal production needs to grow to be 45 per cent more than 2006 production levels, while iron ore has to grow 54 per cent above its 2006 scale, and aluminium to 58 per cent above its 2006 production scale'. Coal consumption is predicted to increase by 1908 million tonnes from 2007 to 2020, equating to 21 times the current output of Australia's largest coal supply chain, the Goonyella Coal Chain (Access Economics, 2008b).

The reports presented by Access Economics (2008a, 2008b) provide valuable insight into the momentum behind the industrial revolution in China and India. However, arguments concerning living standards, consumption and predictions of future minerals production based upon an economic perspective alone, precariously ignore key aspects of the global minerals social-ecological system which can also influence change. The vision of future minerals development, presented by Access Economics for the MCA, reduces the minerals sustainability problematic to its measurable and quantifiable parts, thereby reducing complexity and eliminating key variables that are likely to influence change, such as those relating to the environment, human behaviour, culture and technology.

ASSUMPTIONS AND APPROACHES TO THE MINERALS SUSTAINABILITY PROBLEMATIC

According to the MMSD (2002), the connection of minerals production with mineral-related materials consumption is critical to realising the services that minerals resources could possibly provide to sustainable futures. Traditional research efforts have approached minerals sustainability with a focus on pollution prevention, cleaner production and eco-efficiency (Hilson, 2000; Hilson, 2003; van Berkel, 2007). However, despite major improvements in these fields, unsustainable consumption trends continue to undermine these efforts, escalating environmental impacts and the inequality gap between the rich and the poor (Ryan, 2005; Tukker et al, 2006). In sustainability research, the need to move beyond eco-efficiency, to also understand sustainable consumption, is well established (Ehrenfeld, 2008; Jackson, 2005; Ryan, 2005; Tukker et al, 2006). However, moving beyond a focus on eco-efficiency to link minerals production and consumption in an integrated framework is a major challenge; as such systems are immensely complex, with attributes spanning conventional disciplinary approaches. The difficulty in integrating disciplinary perspectives has resulted in a significant gap between the nature of questions concerning minerals sustainability and the reductionist methodologies available to deal with them.

In order to evaluate and understand systems of mineral production and consumption, in a balanced and pragmatic way, we must first restructure the assumptions underlying conventional approaches to the minerals sustainability problematic. According to Cowell et al (1999, p 277), different approaches to sustainability can be traced back to 'underlying, often unarticulated assumptions' about the tolerability of tradeoffs between different societal goals, the treatment of uncertainty, and the perceived appropriateness of applying different conceptual geographical, organisational, temporal and life cycle scales to define sustainability. The MCA vision of future development to 2020 (Access Economics, 2008a, 2008b; Molloy and Tan, 2008) appears to align with Cowell et al's (1999, p 285) description of 'organisations seeing themselves primarily as producers of physical outputs and operators of mining sites … likely to define sustainable development in terms of meeting demand for their products and providing socially desirable employment'.

Research efforts aimed at linking minerals production and consumption must be underpinned by an assumption that the minerals sector can and should contribute to the transformation of global patterns of production and consumption, to create more sustainable patterns for meeting human needs. The Oslo Declaration on Sustainable Consumption (Tukker et al, 2006, p 11) calls for research to enhance our understanding of 'how to analyse, realise and govern the institutions that can facilitate sustainable consumption'. This research is guided by the assumption that as one of the top five producers of many of the world's key minerals commodities, the Australian minerals sector has the capability and responsibility to influence complex global patterns of production and consumption. To realise this potential, conventional conceptualisations of minerals sustainability need to be expanded to consider the multiple societal, ecological, geographical, organisational, temporal and life cycle scales at which systems of minerals production and consumption operate.

MINERAL RESOURCES LANDSCAPE – AN EXPANDED CONCEPTUALISATION OF MINERALS SUSTAINABILITY

The discussion thus far relates to the need for an integrated, balanced and broader transdisciplinary enquiry, for identifying the possible ways in which Australia's minerals commodities could serve sustainable futures and contribute to the transformation of global patterns of production and consumption. In responding to this research gap, the Mineral Resources Landscape has been developed to guide such an approach to questions of minerals sustainability (Figure 1).

Through an expanded conceptualisation of minerals sustainability, the Mineral Resources Landscape explicates the underlying and often unarticulated assumptions which are critical for guiding an integrated approach to the minerals sustainability problematic. We have argued the need to link minerals production with consumption in an integrated assessment, along with the notion that systems of minerals production and consumption are embedded in a complex adaptive social-ecological system. Such systems need to be assessed holistically. The Mineral Resources Landscape offers an expanded conceptualisation of minerals sustainability to link minerals production and consumption in an integrated assessment across the entire minerals supply chain. The significant aspects pertaining to this system have been identified as:

- the material source,
- extraction and production technologies,
- level of service and value, and
- consumption patterns.

These key leverage points represent the flow of minerals through the supply chain, from a primary or secondary source, through to processing and production, to offering some kind of 'service' or 'value' to society, for which it is taken up by society in global consumption trends.

The 'material source' refers to aspects concerning various primary or secondary mineral sources, including terrestrial landscapes, tailings which could be reprocessed, deep sea orebodies, scrap for recycling, and metals for direct reuse. 'Extraction and production technologies' encompass the influence of current and new technologies, including issues relating to the eco-efficiency of minerals production. Eco-efficiency relates to efforts to attain more 'value' for less impact (Ehrenfeld, 2008). The 'level of service and value' offered by minerals commodities relates to the 'services' and 'value' that minerals products offer to society. For example, gold is valued for the cultural, monetary and technical services it provides to society. Aspects of 'service' and 'value' are subjective, depending on individual and societal interests, 'wants' and 'needs'. As another key leverage point of the Mineral Resources Landscape, 'consumption patterns' encompass issues relating to the growing urban metabolism, demand, and human aspects of behaviour, use, culture, 'needs', 'wants', wellbeing, as well as the distribution of resources between industrial and developing countries. These four key aspects include technological, economic, social and environmental dimensions.

Governance, technology, economics, society and ecology interact and shape the dynamic behaviour of the Mineral Resources Landscape (Figure 2). The influence of these multiple and interacting domains on the Mineral Resources Landscape may be active, regulatory, voluntary or self-organising. A balanced transdisciplinary approach is needed to capture the full complexity of the Mineral Resources Landscape.

To evaluate and understand the Mineral Resources Landscape, the critical dynamics, interrelationships and leverage points in the system need to be identified. It is important to understand what parts of the Mineral Resources Landscape are critical to ensuring

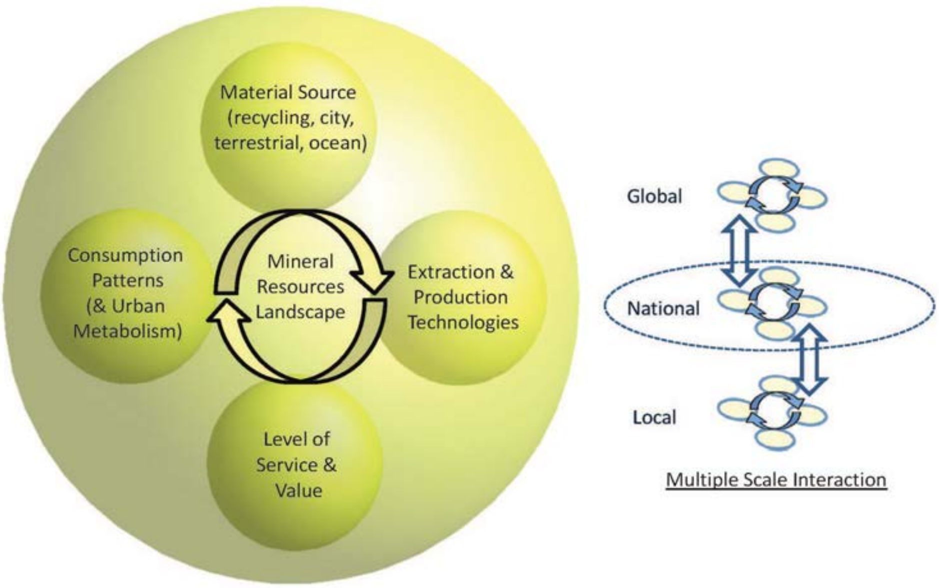

FIG 1 - The mineral resources landscape: demonstrating an expanded conceptualisation and multi-scale interactions.

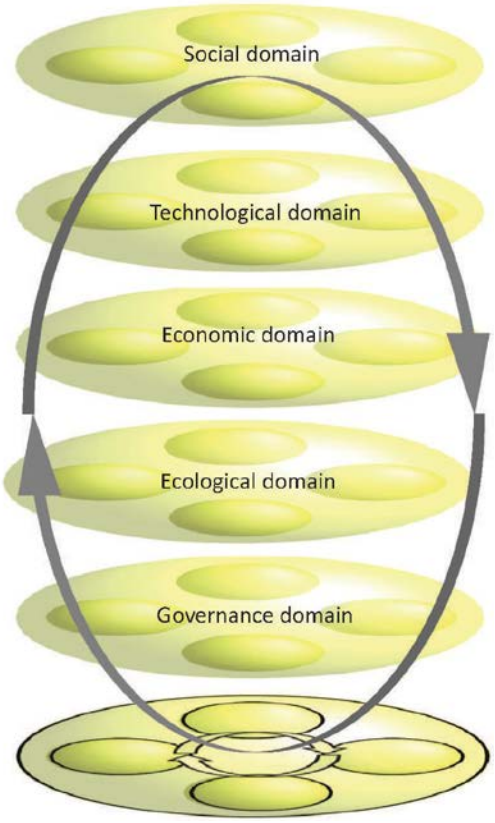

FIG 2 - Interacting domains of the mineral resources landscape.

that minerals resources will serve sustainable futures. Mapping the key challenges facing the minerals sector, as identified by the MMSD (2002), Mudd (2007b) and Access Economics for the MCA (2008a, 2008b) illustrates where current efforts and concerns lie on the Mineral Resources Landscape (Figure 3). The challenges raised by the MMSD (2002) Mudd (2007b) and the MCA 2020 outlook are highlighted black, white and light blue respectively. Additionally, the symbols (L), (N) and (G) indicate the challenges focused on a local, national and global scale respectively.

The MMSD (2002) clearly identifies the need for an integrated approach to using minerals as one of the nine key challenges facing the minerals sector, however the other eight key challenges ignore drivers of consumption and service. Similarly, the key challenges and trends identified by Mudd (2007b) relate to the environmental aspects of the material source and extraction and production technologies. The MCA 2020 outlook, prepared by Access Economics (2008a, 2008b) is largely concerned with the provision of infrastructure and the creation of a labour force with the capacity to meet market demand. Demand projections relate to economic drivers and do not consider the qualitative aspects involved in consumption. Therefore this outlook ignores the 'services' minerals provide to society and considers consumption trends in a reductionist way. In order to understand the role of mineral resources in supporting sustainable futures, it is necessary to also understand the subjective human dimensions of consumption.

Evidently, the boundaries defining traditional conceptualisations of minerals sustainability ignore two very key drivers of the Mineral Resources Landscape – the 'services' minerals offer to society, and the 'consumption trends' which assimilate these services into society. These ignored drivers of the Mineral Resources Landscape are highlighted white to differentiate them from the conventional areas of focus. Understanding these ignored

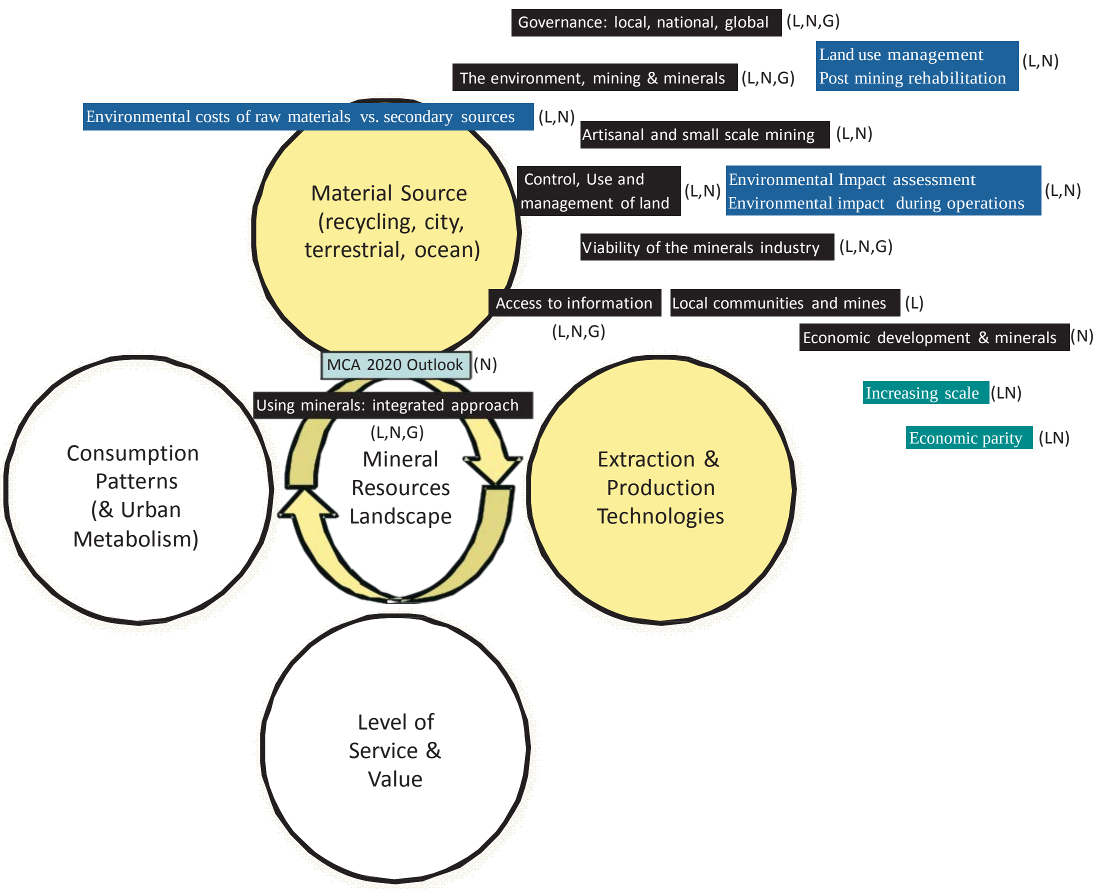

FIG 3 - Focus of key challenges identified by Mudd (2007b), the MMSD (2002) and the MCA 2020 outlook (Access Economics, 2008a, 2008b).

drivers for change, along with the conventional drivers, is essential for identifying the critical dynamics, interrelationships and leverage points in the system. Aspects of ‘service’ and ‘consumption’ are integral driving forces in the Mineral Resources Landscape. Many insights are to be gained from understanding their role in steering change towards sustainable mineral futures.

Understanding minerals consumption involves aspects of service, use, need and wellbeing. Such qualitative human dimensions need to be assessed in accordance with the appropriate theories, practices and paradigms established to deal with them. These subjective aspects also need to be understood in relation to the objective dimensions of minerals production and eco-efficiency. Therefore multiple disciplinary approaches are needed, to construct the many dimensions defining sustainable systems of minerals production and consumption.

CONCLUSIONS AND RECOMMENDATIONS

In light of the global imperative to progress towards sustainability, the possible ways in which minerals resources may serve sustainable futures and contribute to the transformation of global patterns of production and consumption, need to be understood. This requires new, broader and more integrated approaches to questions concerning minerals sustainability, which can address the highly contested, complex and ‘messy’ nature of the situation. In a response to this research gap, this paper develops the Mineral Resources Landscape, which offers an expanded conceptualisation of minerals sustainability, linking minerals production and consumption in an integrated assessment across the entire minerals supply chain.

The key challenges facing the minerals sector, from the perspective of the Australian minerals sector (Minerals Council of Australia), the Australian research sector (Mudd, 2007a, 2007b; Mudd and Ward, 2008) and a multi-scale international project (MMSD, 2002) have been mapped on the Mineral Resources Landscape, indicating that the boundaries defining current conceptualisations of minerals sustainability focus on the material source and technology, ignoring two important leverage points in the Mineral Resources Landscape – the ‘services’ minerals offer to society and the ‘consumption trends’ that assimilate these services into society. The Mineral Resources Landscape offers a valuable framework for prompting the reconsideration of these ignored and highly relevant drivers for change, along with the conventional drivers, across relevant domains and scales of influence. In so doing, the Mineral Resources Landscape guides an integrated inquiry into questions concerning the sustainable development of the Australian minerals sector, to ensure that all transitions contribute to the emergence of sustainable mineral services. Future work would look to identify the key variables governing the dynamics of the Mineral Resources Landscape and the critical linkages across social, ecological, technological, economic and governance domains, as well as between local, national and global scales.

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