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Viewpoint

The mineral foundation of the energy transition

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ABSTRACT

This *Viewpoint* briefly considers the implications of, and possible policy responses to, the critical role of minerals and metals in the current "energy transition". That transition is most often described in terms of the world's energy systems moving towards cleaner and low-carbon technologies and systems. No matter how the contours of this transition eventually manifest, it will likely have significant impacts on the supply and trade of certain minerals and metals. There are several recent scenarios analyses considering these implications with a focus on materials required for solar photovoltaics and electric vehicles. In addition to technical aspects, there are critical geopolitical, economic, environmental, social, and governance issues arising. The paper concludes with recommendations for possible policy and regulatory responses in areas ranging from resource mapping to political economy.

1. Context

The primary mineral and metal technical challenges of the energy transition are slowly emerging. So too are the geopolitical ramifications. Whilst the direction of travel in the energy transition is beginning to become clear, its pace and contours remain elusive (e.g., IEA, 2017a,b; BNEF, 2017; Araújo, 2014; Smil, 2010; Sovacool, 2016; Grubler, 2012).[1] Still, the tremendous growth in some specific technologies such as electric vehicles (EV), storage batteries, and solar photovoltaics (PV) appears ensured based on recent growth and cost trends.[2] Those technologies, along with possible system-wide changes in continued electrification and digitalization of the energy system,[3] have very different profiles in terms of their requirements for ("strategic" or "critical") mineral and metals than the existing portfolio. These potential impacts on markets and resources have begun to provide fodder for a nascent literature (as highlighted in later parts of the paper).[4]

Parts of the somewhat heterogeneous mining and extractive industries are adapting by refining their business practices and marketing towards that of an industry crucial to supporting a shift to a low-carbon and environmentally-friendly energy system.[5] Markets are responding with upticks and increased volatility in pricing in metals from nickel, to zinc, to cobalt.[6] At the same time that the implications of these changes begin to emerge, the United States Department of Interior (DoI) announced its withdraw from the Extractive Industries Transparency Initiative (EITI).[7] The DoI noted that despite this, it will remain, "a strong supporter of good governance and the principles of transparency represented by the EITI." Work on the security of supply chains has also emerged.

While some markets are responding favourably, this may have cost implications for the transition. The minerals of concern range from abundant ones with established markets such as copper, silver, silicon, cobalt, and nickel, to thinner and less geographically diverse markets for tellurium, indium, gallium, selenium, and molybdenum. Many (or most) of the countries with the largest potentials (and existing markets) for these minerals are emerging and developing economies. There are other concerns as well; governance and a changing geopolitical landscape both contribute to uncertainty.

As an example, much of the world's current cobalt (63% in 2016) is now produced in the Democratic Republic of the Congo. The demand is

[1] See also: http://cleanenergycanada.org/canadian-mines-clean-energy/; and http://www.shell.com/energy-and-innovation/the-energy-future/scenarios/new-lenses-on-the-future.html.

[2] For PV, see e.g., https://www.nrel.gov/news/press/2017/nrel-report-utility-scale-solar-pv-system-cost-fell-last-year.html. For EVs, see e.g., IEA, 2017b. For batteries, see e.g., https://data.bloomberglp.com/bnef/sites/14/2017/07/BNEF-Lithium-ion-battery-costs-and-market.pdf.

[3] For digitalization, see e.g., http://www.iea.org/digital/ For system electrification, see e.g., https://www.nrel.gov/analysis/electrification-futures.html.

[4] See e.g., https://earth.stanford.edu/news/critical-minerals-scarcity-could-threaten-renewable-energy-future.

[5] See several of the initiatives referenced in: https://www.bsr.org/our-insights/blog-view/worlds-leading-companies-clean-power-plan-necessary-part-us-climate-plan; or: https://commdev.org/userfiles/SUSTAIN_Extractives.pdf.

[6] https://www.ft.com/content/f269b268-b963-11e7-8c12-5661783e5589. For impacts on companies, see e.g., https://www.wsj.com/articles/electric-vehicle-boom-is-a-boon-for-coal-king-glencore-1513097249.

[7] https://www.doi.gov/eiti.

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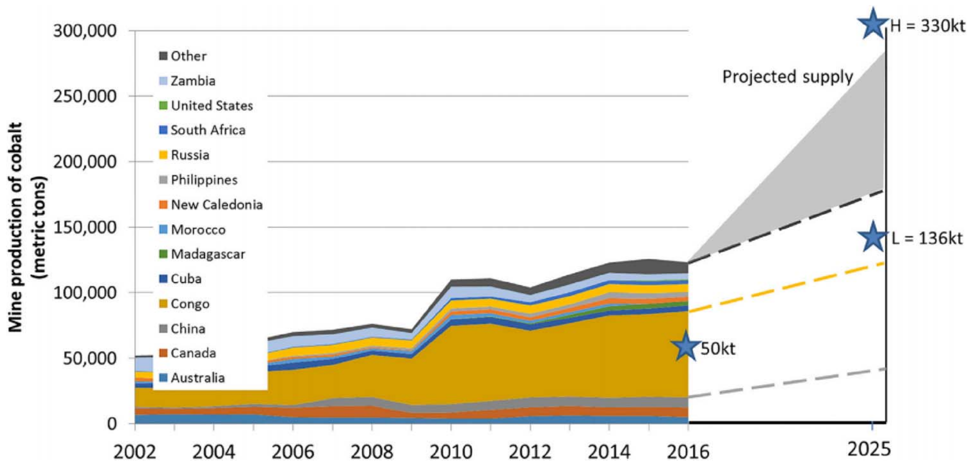

Fig. 1. Cobalt use for Lithium-ion batteries historically by country and projected supply under two scenarios (L and H to 2025) (Olivetti et al., 2017).

rising fast. Bloomberg's New Energy Finance predicts demand could be 47 times what it is now in 2030.[8] Bloomberg also wrote a similar piece on Lithium earlier this year (2017).[9] The country's potential for cobalt appears vast, still, it is one of the world's lowest ranking countries on the Worldwide Governance Indicators on areas such as government effectiveness, control of corruption, rule of law, and political stability.[10] Other examples, abound, including from conflict states like Afghanistan.[11] Ali et al. (2017) considers many of the governance implications of the wider sustainable development framework in detail.

The journal "The Extractive Industries and Society" has covered several topics related to the issues discussed here. This includes treatment of the effectiveness and progress of the EITI (Van Alstine, 2017). The engagement of local communities is well-covered (e.g., Rodrigues, 2017). The role of foreign investment and development is another topic often highlighted (Weng et al., 2017). The relationship between mining industries and economic development are prevalent as well (Gamu, 2015). Finally, the issues of resource governance and conflict are central to several papers (Cuvelier, 2014). This *Viewpoint* builds on that research, and draws heavily from the gray literature (given the topic's recent manifestation), in presenting a high-level account of the analysis, trends, challenges and opportunities facing the minerals and metals sector in a rapidly changing relationship to the energy and transport sectors.

The remainder of the paper is structured as follows: Section 2 considers the growing literature on the topic. Section 3 highlights some recent scenario analysis, as well as the bottlenecks identified. Section 4 has a focus on governance issues, and Section 5 concludes with multiple areas requiring policy and regulatory attention.

2. Recent literature

The mineral and metal impacts of the energy transition have emerged in the literature over the last few years in the time since the pace and the scale of the transition towards the widespread use of PV, batteries, and EVs seems more clear. Previously, these issues were typically regulated to the life-cycle and energy return on investment literature (See e.g., Sherwani et al., 2010; and Peng et al., 2013). In 2013, the implications for rare earths for renewable energy (RE) described a rapidly changing pattern of trade and market pressures (Ridder, 2013). In the same year, another report focused on rare earths for RE.[12] This focus was, in part, a response to very high price rises for some rare earths in 2011.[13]

By 2015, headlines had changed to: "The energy transition consumes large amounts of metals.[14] The Critical materials Institute (CMI), a cooperative research program across several institutions, was established to focus on the materials needed to ensure American competitiveness in clean energy.[15] CMI focuses on, "five critical rare earths and two near-critical materials: dysprosium, terbium, europium, neodymium and yttrium, as well as lithium and tellurium." Some of CMI's goals are directly related to addressing geographical and geopolitical risks, such as: "Produce a neodymium-iron-boron magnet using materials and technologies located entirely within the U.S."

More specific technology assessments for PVs, EVs, and batteries have now emerged. The most comprehensively treated market in the academic literature appears to be for lithium (e.g., Kushnir and Sandén, 2012; and Narins, 2017). Pehlken et al. (2017) suggest a move towards, "… a shift from managing primary resources, resource uses, and waste separately, towards managing materials, i.e., resource flows and their implications over the entire life cycle." A consideration of: Li, CO, Ni, and Mn for use in Lithium-ion batteries is presented in Olivetti et al. (2017). They include some focus on cobalt (Fig. 1).

While, as noted, the PV life-cycle analysis literature has a long history, more recent analysis focuses on the realities of the much larger market size than previously considered, and some emerging technologies. The minerals implications for PV are very different depending on the cell type—especially between thin film classes and crystalline types (e.g., Kavlak, 2015).

3. Scenarios and bottlenecks

To consider the possible resource constraints, in terms of scale, trade implications, resource governance, etc. scenarios have been developed. WWF (2014) used their previously developed 100% RE by 2050 scenarios to look at the implications for PVs, wind turbines, batteries,

[8] https://www.bloomberg.com/news/articles/2017-10-26/battery-boom-relies-on-one-african-nation-avoiding-chaos-of-past.

[9] https://about.bnef.com/blog/mad-scramble-for-lithium-mines-stretches-from-congo-to-cornwall/.

[10] http://info.worldbank.org/governance/wgi/#home.

[11] http://nationalinterest.org/feature/afghanistan-has-only-one-hope-lithium-18372?page=show.

[12] https://e360.yale.edu/features/a_scarcity_of_rare_metals_is_hindering_green_technologies.

[13] That same year (2011) the U.S. DOE published its "Critical Materials Strategy", and in 2010 the USGS published "The Principal Rare Earth Elements Deposits of the United States—A Summary of Domestic Deposits and a Global Perspective (https://pubs.usgs.gov/sir/2010/5220/).

[14] https://www.greeneuropeanjournal.eu/the-energy-transition-consumes-large-amounts-of-metals/.

[15] https://cmi.ameslab.gov/sites/default/files/cmi-annual-report-2017.pdf.

Table 1
Critical materials and low-carbon technologies (Moss et al., 2013).

Element	Rating	Associated Technology
Rare Earths: Dy, Pr, Nd	High	vehicles, wind
Rare Earths: Eu, Tb, Y	High	lighting
Gallium	High	lighting, solar
Tellurium	High	solar
Graphite	Medium-High	vehicles, wind
Rhenium	Medium-High	fossil fuels
Hafnium	Medium-High	nuclear
Germanium	Medium-High	lighting
Platinum	Medium-High	fuel cells
Indium	Medium-High	solar, lighting, nuclear

lighting, smart electronics, motors, lighting, and power transmission. They identified lithium ad cobalt as the most critical "bottlenecks", and offered suggestions to address these challenges by, "…by recycling lithium, substituting lithium in other sectors, and by using less cobalt-intensive cathodes."

In 2013, the European Union's Joint Research Centre undertook analysis on metals required in low-carbon scenarios to 2030 for 60 metals in 11 technologies (Moss et al., 2013). They found that eight metals have a high criticality rating for possible supply bottlenecks, namely: dysprosium, europium, terbium, yttrium, praseodymium, neodymium, gallium and tellurium (Table 1). Six metals were rated as "medium-high". The work also considered ways to mitigate these possible constraints, such as for substitution and recycling.

In 2017, the World Bank Group published a report looking at similar markets for minerals and metals, but used the International Energy Agency's (IEA) Energy Technology Perspectives (ETP) (Drexhage et al., 2017). Those scenarios related to global warming at levels of 2 °C (2DS), 4 °C (4DS) and 6 °C (6DS) temperature increase limitation goals (Fig. 2 for thin film PV). Renewable energy generation (including hydropower and biomass) increases in the three climate scenarios from 14% of the current energy mix to 18% in the 6DS scenario, and a high of 44% in the 2DS scenario.

While there may be some bottlenecks to supply, along with price implications for markets, the absolute amounts of materials needed do not seem to be a principal constraint (Olivetti et al., 2017). Additionally, Bloomberg estimated that doubling current prices on lithium or cobalt would raise the price of a battery by 8% or 10.8%, respectively.[16]

4. Governance issues

The location of the critical minerals and metals shows the clear need to focus on issues around environmental, social, trade, and other governance-related issues. Governments are actively considering their roles in these markets.[17] The reality of many of these resources is that the largest potential reserves exist in developing countries. As an example, 75% of the production of cobalt is from developing countries, and 68% of the reserves. The Bank study finds that the regional potential for minerals such as copper, nickel and lithium look positive for Latin America. And that Africa should seek to find benefits from deposits of platinum, manganese, bauxite, and chromium. Places in Asia like Malaysia and Indonesia have good deposits of nickel and others, while China's current dominance in base and rare earths remains the case into the future (Table 2).

The scenarios from the World Bank were considered through a governance lens by the Natural Resource Governance Institute (NRG).[18] By analyzing the scenarios against the NRGI Resource Governance Index, and found that: "on average 42 percent of reserves are in countries with 'good' or "satisfactory" resource governance, 37 percent are in countries with "weak" scores (China accounts for 14 percent of this total) and a further 7 percent are in countries that score "poor." Governance issues range from social and environmental, to financial; they can thus have a major impact on the reliability of the supply of these materials, and on the communities and countries in which they are mined. Others echo the important point that developing countries are especially dependent on the revenues from mining, this typically serves to exacerbate governance challenges.[19]

Sharland et al. (2017) considered the relationship between the mining sector and violent extremism (Fig. 3). They provide a wide range of recommendations to both governments and mining companies in terms of how best to establish proactive dialogues to help prevent and counter violence. These include establishing good practice frameworks, and incorporating risk assessments into mining company's impact assessments and due diligence. There work focuses on threats from al-Shabaab in East Africa and the Horn, and from AQIM and affiliates in West Africa.

5. Policy and regulatory levers

The categories of required interventions are apparent across economies and range from: resource mapping and minerals-specific scenario analytics; to technological constraints and advances in technology design and engineering; to market development and other economic approaches; to governance improvements along the value chain; to new ways of approaching diplomacy; to international trade policy; and social protection and environmental management. These areas also have direct relevance to the energy transition (e.g., O'Sullivan et al., 2017; Meadowcroft, 2009; Geels, 2014; Späth and Rohracher, 2014). There are examples of both ongoing work and gaps in each of these areas:

- Undertaking further analytical work on scenarios of the role and scale of metals and minerals in a low-carbon future will be required to hone these insights and the approaches required to mitigate risk. As an example, the World Bank report (Drexhage et al., 2017) notes significant gaps in resource mapping in developing countries. This creates a serious information gap for both international dialogue and domestic policy decision-making. A WRI initiative called "Rights to Resources" includes mapping of a wide swath of natural resources (including mining) to citizen and community rights in Africa.[20] Several related databases are collated by NRGI.[21]
- Technology research, like that of the CMI, will also be essential in addressing bottlenecks, whether through the identification and design of substitute materials, improved recycling, or completely new technologies. Several of the CMI "Grand Challenges" are directly related to the issues discussed in this paper, including "Anticipating which materials may go critical.[22]
- Developing new financial instruments in the relevant commodity markets will help provide both some level of risk mitigation, but also mandate increased levels of transparency. Benchmark Minerals

[16] https://about.bnef.com/blog/lithium-price-spike-has-moderate-effect-on-batteries/.
[17] https://www.nrc-cnrc.gc.ca/eng/publications/nrc_pubs/energy_storage/2016/fall_main_article2016.html.
[18] https://resourcegovernance.org/blog/low-carbon-future-better-mineral-governance-could-power-development.
[19] https://www.wider.unu.edu/publication/it-or-not-poor-countries-are-increasingly-dependent-mining-and-oil-gas.
[20] http://www.wri.org/resources/maps/rights-to-resources.
[21] https://resourcegovernance.org/analysis-tools/tools/extractive-industries-data-ecosystem-database-available-data-tools-natural.
[22] https://cmi.ameslab.gov/grand-challenges. As evidence of technology evolution as it relates to the scale of materials required, Bloomberg notes that a 2008 Tesla car battery contained about 38 kg of cobalt, while the same-sized battery on a 2017 model would weigh only 4.8 kg. https://www.bloomberg.com/gadfly/articles/2017-09-28/cobalt-s-chemistry-experiment.

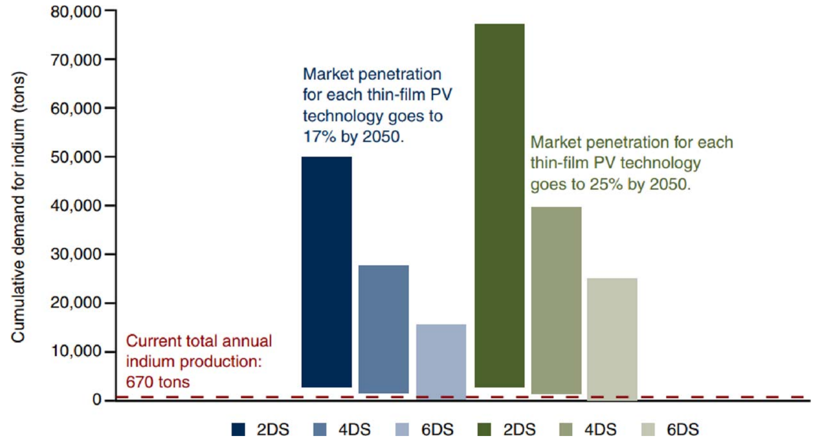

Fig. 2. Example of demand results for Indium in CIGS PV to 2050 (Drexhage et al., 2017).

Table 2
Cobalt production and reserves (metric tons) (Drexhage et al., 2017 based on USGS, 2016).

Country	Mine production	Reserves
Congo (Kinshasa)	63,000	3,400,000
Australia	6000	1,100,000
Cuba	4200	500,000
Zambia	2800	270,000
Philippines	4600	250,000
Russia	6300	250,000
Canada	6300	240,000
New Caledonia	3300	200,000
Madagascar	3600	130,000
China	7200	80,000
Brazil	2600	78,000
South Africa	2800	31,000
Other countries	7700	633,000
Total	120,400	7,162,000

(2016) puts the issue of markets for the lithium ion battery supply chain this way: “They are typically not exchange traded, largely inflexible and unresponsive in the short term. End-market developments can take months to be felt upstream, while supply side volatility can send shockwaves through the supply chain.”

- Continued monitoring of governance metrics through both the Worldwide Governance Indicators and the NRGI Index will be helpful in highlighting countries or regions of key concern. The significant governance programs in place for decades from other natural resource commodities, such as oil, can be applied to some of these smaller or less global markets and resource bases. Interesting applications of technologies like blockchain may also support more transparency in transactions in the future.[23]
- Mapping the new geopolitical landscape, or at least the changes to its contours will be essential to informing foreign policy and diplomacy. New or re-purposed UN bodies or Conventions may need to be put in place. A related effort has begun. It published a report entitled: “Mapping Mining to the Sustainable Development Goals (SDGs)”, which considers how mining sector can move towards sustainability writ large.[24]
- Establish dialogues between mining companies and government agencies in charge of plans for countering and preventing violent extremism. In most countries, these dialogues are not well-established, and must be linked to wider efforts of conflict prevention.
- While trade policies, including tariff-setting mechanisms and dispute mechanisms are in place through the WTO, they will need to be augmented and refined to tackle the new patterns and scale in trade for certain of the minerals. In 2016, the EU reached a deal on legislation related to the sustainable provision of minerals and metals into the bloc.[25] On similar topics, UNCTAD hosts the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF).
- Existing social and environmental protection and legislation in some of the countries with large reserves will need to be prioritized by both funding bodies like the World Bank and by environmental organizations like UNEP and local NGOs. A Massive Open Online Course (MOOC) is now available, with support from the World Bank and others, on the topic of oil, gas, and mining governance.[26] Numerous “extractive industries forums” have been convened on these topics at the national level.[27]

Finally, it must be acknowledged that these issues go well-beyond the energy and extractives sectors. As an example, they will have implications for water security, industrial growth, responsible consumption and production, decent work, gender equality, and several other of the Sustainable Development Goals.

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[23] https://mobile-reuters-com.cdn.ampproject.org/c/s/mobile.reuters.com/article/amp/idUSKBN1FM0Y2.

[24] http://unsdsn.org/resources/publications/mapping-mining-to-the-sustainable-development-goals-an-atlas/. At a national level, President Trump, on December 20, 2017, signed an executive order to devise, “a strategy to reduce the Nation’s reliance on critical minerals.” https://www.washingtonpost.com/news/energy-environment/wp/2017/12/19/zinke-wants-to-expand-critical-minerals-production-saying-we-are-vulnerable-as-a-nation/?tid=sm_tw&utm_term=.9165260a1adb.

[25] https://www.ictsd.org/bridges-news/bridges/news/eu-reaches-deal-aimed-at-sustainable-mineral-metal-supply-chains.

[26] https://blogs.worldbank.org/voices/join-our-online-course-natural-resources-sustainable-development.

[27] http://www.worldbank.org/en/news/press-release/2014/10/07/ethiopia-extractive-industries-forum-convenes-experts-to-maximize-the-contribution-of-extractive-industries-to-ethiopias-sustainable-development.

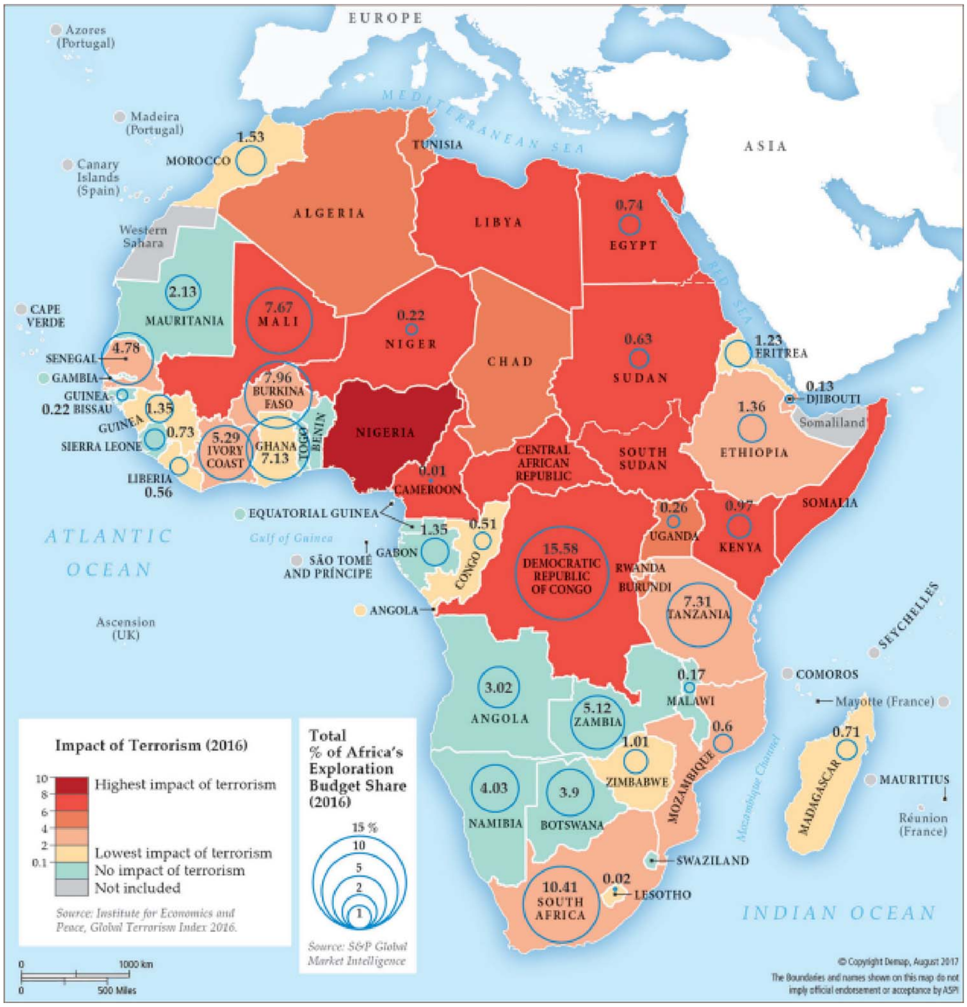

Fig. 3. Mining exploration budget and terrorism impact (Sharland et al., 2017).

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