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Climate change and the extractives sector

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Abstract: The extractives industries must adjust their operations to shifting patterns of demand for oil, natural gas, and coal together with metals and minerals – as policies and new technologies encourage progress along low-carbon pathways in energy, transportation and construction to combat climate change. Adoption of renewable energy is accelerating across the world, but fossil fuels will be in use for many years (with natural gas replacing coal in electricity generation, especially in Asia). Large amounts of fossil-fuels will eventually be unusable ('stranded') if international goals to contain greenhouse gas emissions are to be met. Low-carbon technologies and pathways are likely to be more intensive in metals and materials than existing fossil-fuel technologies. This offers great opportunities for countries with mining sectors, but there are major concerns over the distribution of the economic benefits, and mining itself must reduce its environmental footprint together with its own greenhouse gas emissions.

Keywords: extractives, oil, natural gas, coal, metals, energy, climate change

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1 Introduction

Climate change is one of the world's most complex and urgent global problems: indeed, many would argue that it is *the* greatest challenge.[1] Climate change adaption and mitigation are fundamental to the evolution of our economies and societies over the rest of the 21st century and beyond. The extractives industries are in many ways at the heart of the climate change challenge. The extractives sector must support national and international efforts to respond to climate change, by adjusting exploration and production to shifting patterns of demand for energy and minerals – as policies and new technologies encourage progress along low-carbon pathways.[2] None of this is easy, and success is not assured.

This is a large topic, and the task of this study is to set out some of its main issues as they relate to the extractives sector. The first section summarises some of the technologies and policies that shape our energy future. Adoption of renewable energy technologies is accelerating, but without major technological breakthroughs, fossil fuels will continue to dominate the immediate energy future. The paper then discusses three vital issues for the transition: natural gas as an energy bridge; carbon sequestration; and energy efficiency. After that, the paper considers the policy dilemmas inherent in the 'stranding' of fossil-fuel resources, and the responses to climate change by extractives companies. The paper's second half considers the implications for minerals and metals of the transition to low-carbon pathways. The evidence points to a conclusion that achieving a 'net zero carbon' future will be considerably *more* materially intensive than existing fossil fuel technologies. While low-carbon pathways offer considerable opportunities for developing countries with the right mineral resources, there are major concerns as well, including the distribution of the benefits within what are often highly fragile nations. The paper concludes that with greenhouse gas (GHG) emissions reaching their highest ever levels, recent progress in sustainable development and poverty reduction is in imminent danger, posing a great challenge for the extractive industries and their host countries.

2 Looking to the energy future

Peering into the energy future is fraught with difficulties (see Stevens, 2016). Forecasts by fossil fuel and mining companies have been repeatedly wrong (especially on prices) despite their strong incentives to get forecasting right. The authoritative forecasts of the International Energy Agency (IEA) are regularly revised to incorporate the impact of new developments in technologies and markets. The governments of resource-abundant countries frequently stick to erroneous assumptions (especially in their revenue projections) long after the markets have turned, and despite the vital importance of the extractives sector to their economies and public finances.

[1] The Intergovernmental Panel on Climate Change (IPCC) provides the most exhaustive review of the state of research on climate change through its three Working Groups on the Physical Science Basis (WG 1); Impact, Vulnerability and Adaptation (WG 2); and, Options for Mitigating Climate Change (WG 3). See https://www.ipcc.ch/report/ar5/

[2] While the paper uses the shorthand terms 'low-carbon pathways' and 'net zero-carbon' future, emissions of other greenhouse gases such as methane must be cut as well.

This is an especially difficult time to look ahead. While technology continually shapes the energy future, the world is now in an era of 'renewables acceleration' driven by falling costs.[3] For solar photovoltaic (PV) the IEA's 2017 estimate for capacity growth to 2022 is *one-third* higher than its 2016 estimate (IEA, 2017a). Renewables now account for almost two-thirds of the world's additional (net) power capacity (IEA, 2017a). By 2022, renewables could be providing 30 per cent of global electricity generation, ahead of natural gas, and equivalent to the total power consumption of China, India and Germany (IEA, 2017a).

But such a fast growth in renewables still leaves fossil fuels (coal as well as oil and gas) with a dominant, if reduced, share of global energy production. Innovation in battery storage is the game-changer to watch. The power from renewables such as solar, wind and tide fluctuates. Cheaply capturing and storing their energy in large-capacity batteries would eliminate this drawback. The technology of 'flow batteries' holds promise for large-scale storage. But they remain expensive (pricey vanadium is used). Grid energy storage together with the shift to electric vehicles now underway will require lots of cobalt, lithium and other materials to the benefit of the producing countries (see later discussion). Research will eventually replace the expensive materials with cheaper alternatives, heralding a new era of large-scale (and cheap) grid storage. But we are not there yet.

Public policy also shapes the energy future; regulations, taxes and subsidies have profound effects on incentives. Fossil fuels subsidies amount to billions of dollars annually. Estimates of their annual size range from US$200-500 billion and upwards, depending on whether subsidies to production are included, or just those to consumption. [4] When environmental externalities are accounted for, fossil fuel subsidies amount to trillions of dollars. One IMF study calculates that if all the externalities of fossil fuels are included (such as harm to human health) then fossil fuel subsidies amounted to US$5.3 trillion in 2015: equivalent to 6.5 per cent of global GDP (Coady et al., 2017). In sum, fossil fuel subsidies far exceed subsidies to renewables in power generation, which amounted to US$140 billion in 2016 (Shirai and Adam, 2017).

Coal is abundant and relatively cheap, and historically the price has not reflected its many negative environmental externalities. Coal accounts for well over half of all electricity generated in China and India (IEA, 2017b). Globally, about US$750 billion was invested in new coal power plants in 2000–2010 alone. Hundreds of coal-fired facilities could still be operational in the coming decades, and more than 2,400 new coal-fired power stations are already planned for construction by 2030 (van Breevoort et al., 2015). Coal has been called the 'zombie fuel' – dying, but far from dead. Proponents of 'clean coal' even argue that carbon sequestration, discussed later, will breathe new life into the use of this fossil fuel.

That coal will be around for a long time, even in a much-reduced role, is a worrying scenario for human health let alone planetary health. More than half the world's deaths from ambient air

[3] On uncertainty and carbon-pathways see: Hughes et al. (2013) and Usher and Strachan (2012). Rhodes et al. (2014) discuss the drivers of energy innovation, and the respective roles of the private and public sectors.

[4] On the methodologies for measuring fossil fuel subsidies see McCulloch (2017). Estimates vary depending on whether consumption and/or production subsidies are counted. Some 11 European countries and the EU itself provided at least €112 billion in annual subsidies over 2014-16 towards the production *and* consumption of fossil fuels (Gençsü, et al, 2017). Production subsidies at the US federal and state-levels were US$20.5 billion in 2015, with 80 per cent going to oil and gas, and 20 per cent to coal (OCI, 2017: 5). Broadening the definitions of subsidies to include the harm that fossil fuels do to the environment and human health (respiratory illnesses etc.) yields much larger estimates (Coady et al., 2017).

pollution occur in China and India, and coal is a big culprit.[5] Irrespective of climate change mitigation, the leaderships of China and India want to cut air pollution, and are now willing to trade some growth for cleaner air. Emissions of nitrogen dioxide and sulphur dioxide (the major air pollutants) from gas-fired plants are a fraction of those of coal-fired plants (de Gouw et al., 2014). Stronger environmental regulations are squeezing the use of coal to the benefit of gas. China, which consumes half the world's coal, has cut its own production (by an amount equal to the total production of South Africa, the world's fifth largest coal exporter) and is curbing imports as well (IEA, 2017b). China is today responsible for around half the global take up of solar PV, as it increasingly switches to renewables (IEA, 2017b).

Carbon pricing shifts incentives in electricity generation away from coal and towards natural gas (which emits much less CO_2 than coal in power generation) and, best of all, towards renewables. The UK's 'carbon price support', a tax paid by its coal and gas generators, helped reduce coal's share to a record low of 2 per cent by mid-2017, when the UK had its first day without coal-fired power generation since the industrial revolution (Aurora Energy Research, 2017). Some 40 national and 25 subnational jurisdictions now put a price on carbon, a doubling over the last decade (World Bank/ECOFYS, 2017: 2). Official carbon pricing covers some 15 per cent of the world's GHG emissions (World Bank/ECOFYS, 2017: 2). This will rise to around 25 per cent when China introduces a national carbon market by the end of 2017, making it the world's largest scheme. In Canada, the federal government plans to introduce a carbon-pricing regime to support existing provincial carbon-pricing initiatives.

Both regulation and market-based instruments like carbon pricing alter business behaviour. In its principles for climate change policy design, the International Council on Mining and Metals (ICMM) states that: "without a clear price signal, members' ability to plan and make sound decisions is at risk" (ICMM (2011: 4).[6] As more key mining jurisdictions move to carbon pricing systems (Chile and South Africa, for example) companies will need to adjust their operations accordingly.

The 2015 UN Paris climate agreement opens a new chapter in the global energy future, one in which the shift from fossil fuels to renewables should accelerate.[7] However, progress is not assured. In 2017 President Trump announced US withdrawal from the Paris agreement, a decision that is, however, "open to review" and one that faces strong domestic opposition at state and city government levels (meanwhile other signatories remain committed, notably the EU, China, and India). Although the EU's emissions trading scheme (ETS) was the world's first and most comprehensive scheme, the price for its carbon credits is now too low to deter Europe's heavy emitters: gas has not replaced coal on the scale initially expected in Europe (Stern, 2017). Australia has scrapped its carbon tax, replacing it with a weaker ETS-style scheme. The UK's carbon price must now rise otherwise coal-fired power generation will return. Some fossil-fuel companies continue to lobby against increased regulation, carbon pricing and, indeed, the Paris Agreement itself.

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[5] Lancet Commission on Pollution and Health (http://www.thelancet.com/commissions/pollution-and-health).

[6] The ICMM (2011) principles for climate change policy design were re-affirmed by ICMM members in 2015 prior to the Paris Climate Conference. For the oil and gas industry, IPIECA (2015) also affirms the importance in climate policy of long-term price signals and market certainty. In expectation of increased regulation on emissions (and carbon pricing), more companies are using an internal carbon price in their business planning (CDP, 2017: 5).

[7] The Paris Agreement was reached at the 21st session of the Conference of Parties to the UN Framework Convention on Climate Change (UNFCCC) in December 2015.

2.1 Natural gas, carbon sequestration and energy efficiency

Even under very optimistic scenarios for emissions reductions, fossil fuels will still be in use for many decades while renewables grow their market share as the costs of the technologies fall. This tension between climate goals and the pace of technology could be eased by three sets of measures: the first is heavily promoted (natural gas), the second is untested at scale (Carbon Capture and Storage (CCS) or 'carbon sequestration') and the third has very wide support (energy efficiency).

Champions of natural gas, including (not surprisingly) the producing companies and the countries with the resource, argue that it is a vital 'energy bridge' from the era of hydrocarbons to the low-carbon future. High efficiency gas-powered plants using combined cycle technology (CCGT), emit less than half as much CO_2 as the typical coal-fired plant, per unit of energy produced (de Gouw et al., 2014). Gas is now the fastest-growing fossil fuel (IEA, 2017c). Liquified Natural Gas (LNG) is showing especially strong growth: 40 countries now import LNG, up from 17 a decade ago (BP 2016). New gas producers, like those in East Africa, have high hopes of selling LNG to Asia, especially to China as it moves on from coal.

However, the notion of gas as an energy bridge is contested. The main constituent of natural gas is methane (CH_4). This is emitted into the atmosphere via deliberate venting as well as from leaky gas wells and pipelines (with corroded iron pipes and other old infrastructure leaking more). Methane is a more potent GHG than CO_2, and contributes about 17 per cent of radiative forcing (the warming impact on climate) (NOAA, 2016). Whether gas has a better climate footprint than coal depends on how much methane emissions can be reduced. A methane leakage rate of 1.3 per cent of gas production (the EPA's leakage estimate for the US) is associated with a 46 per cent emissions reduction (when efficient gas plants substitute for coal power) whereas a 5 per cent leakage rate (found in other US estimates) implies only a 24 per cent reduction (Lazarus et al., 2015: 4). After reviewing the US evidence, Brandt et al. (2014) conclude that methane leakage is substantially underestimated. Shale gas is of special concern; Howarth (2015) concludes that when methane emissions are properly measured, the greenhouse footprint of shale gas exceeds that of conventional gas, coal and oil.

The necessary technology exists to cut methane emissions (Balcombe et al. 2017). US regulation is now tighter, and the US industry has successfully reduced its methane emissions (Schwietzke et al., 2016). Is this feasible elsewhere, especially in Eurasia and the Middle-East which account for around half the world's methane emissions? Gould and McGlade (2017) calculate that it is cost-effective to avoid three-quarters of current global methane emissions (in part because captured methane can be sold). If gas is to act as an energy bridge, then a great deal hinges on putting methane abatement measures in place globally, especially for shale gas.

There are additional concerns around natural gas that call into question the optimism of its champions. These include the environmental costs of its extraction (local pollution from shale gas 'fracking' is a worry) and a concern that switching to cheap gas, with all its attendant investment in production and distribution infrastructure, will delay the adoption of near-zero carbon technologies. Some modelling exercises find only a small reduction in CO_2 emissions and indeed, in some scenarios, an increase in climate forcing (McJeon et al., 2014). Several studies argue that gas can only act as a bridge fuel (to displace coal) until around 2030 (a shorter time than many policymakers expect); renewables must then take the lead if the world is to achieve the target of keeping the increase in global temperature within 2°C above its preindustrial level (the 2DS goal) (Banks and Taraska, 2013).[8]

We are left with a conundrum: how to maintain energy supplies while keeping to global emissions goals? Carbon sequestration and improved energy efficiency might both help.[9]

Advocates of carbon sequestration see it as a transitional mitigation technology allowing the continued use of fossil energy (particularly gas) as the share of renewables grows. More controversially, proponents of coal see it as means to keep, and indeed grow, coal's share in energy generation. This is a major concern for critics of CCS: by keeping coal alive, CCS could divert resources from clean energy technologies – CCS will absorb a lot of resources as it has large initial investment costs – and reduce the incentive to adopt renewables and improve energy efficiency.

Many climate models find that CCS will be essential to achieving international targets (IPCC, 2014: 82). Industrial sectors such as iron, steel and cement have few if any alternatives for achieving deep emission reductions (Florin and Fennell, 2010). Their technologies have already seen large gains in energy efficiency (DECC, 2015). Moreover, the production of cement, chemicals and steel, as well as petroleum refining, generate significant additional CO_2 emissions as a by-product of the chemical reactions inherent in the industrial process; these cannot be eliminated (ZEP, 2013).

How much could CCS achieve in emissions reduction? Much is unknown. On some estimates, CCS could deliver 13 per cent of the cumulative reduction in emissions require by 2050 to meet the 2DS goal (IEA, 2015a). But for the present, CCS projects are mostly small-scale, there are strong concerns regarding operational safety and risks in transporting large volumes of liquefied CO_2. Fundamentally, there is little experience with long-term CO_2 storage and certainly no proof that storage can be managed nor safely guaranteed for centuries.

In sum, CCS will have a role in the industrial sectors. In the power sector, CCS may have a role in coal decarbonisation in the short term – provided it does not delay the energy transition – and perhaps a vital role in decarbonizing natural gas use in the medium- and long- terms, as gas replaces coal in electricity generation. But at what scale this occurs is uncertain for technical, economic, and legal reasons.

Continuing to improve energy efficiency will therefore be imperative if 2DS is to be met: it must have one of the biggest roles in reducing emissions, especially in construction, industry and transport (IEA, 2015b; UNEP, 2011). Some US$14 trillion in energy efficiency investments are needed up to 2035 (IEA, 2014). This implies more demand for the minerals and metals that go into the technologies that achieve greater energy efficiency; in lighting and temperature control in buildings, and in public transport, for example. This demand will be additional to that for energy storage and electric vehicles. We return to the implications for the mining sector later in this paper.

[8] The 2DS goal was adopted at the 16th session of the Conference of the Parties to the UN Framework Convention on Climate Change (in 2010). To keep the rise in the global temperature within 2°C above preindustrial levels, the concentration of atmospheric GHGs must be stabilized within 450 parts per million (ppm) CO_2 equivalent by 2050.

[9] Space limitations preclude a full discussion of carbon sequestration and energy efficiency. The reader is instead referred to Sovacool et al. (2016) and Sovacool (2017).

2.2 Stranded assets

Cutting methane emissions from gas infrastructure, together with carbon sequestration and improved energy efficiency, will reduce some of the pressure to leave fossil fuels unused and 'in the ground'. Nevertheless, a radical readjustment in the world's GHG emissions to meet the Paris commitments will render a substantial portion of the known stock of fossil fuel reserves unusable, and they will become, in effect, 'stranded assets' (Cust et al., 2017; van der Ploeg, 2016). One much-cited study concludes: "Our results suggest that, globally, a third of oil reserves, half of gas reserves and over 80 per cent of current coal reserves should remain unused from 2010 to 2050 in order to meet the target of 2°C" (McGlade and Elkins, 2015: 187).

Fossil fuels are of growing concern to the investment community. Norway's sovereign wealth fund (which invests the country's oil wealth); the heirs to the Rockefeller oil fortune; French bank BNP Paribas; the World Council of Churches; and universities such as Stanford are among the investors and public and private organizations that are selling all or part of their fossil fuel investments (coal mining, oil and gas extracted from shale and tar sands, and Arctic oil and gas exploration and production feature in the disinvestments). This does not for the present deprive fossil fuel companies of capital as environmentally-insensitive investors will buy the assets. But disinvestment does reinforce the political message that action on climate change is urgent.

Eventually fossil fuel companies will face a rising cost of capital as the value of their assets declines, the consequence of ever-cheaper renewable energy. As we discussed earlier, firm implementation of the Paris Agreement will make obsolete billions of dollars of existing and planned investments in oil, gas and coal as these resources are stranded. For the largest publicly traded oil and gas producers, Carbon Tracker Initiative (2017) reckons that one-third of potential capital investment up to 2025 could become obsolescent. This has become a concern for financial regulators as well.[10]

Large adjustments must be made by fossil fuel companies, but even more so by countries with the oil, gas, and coal resources. Companies can gradually shrink the size of their businesses, and diversify into renewables: "companies could, if they wanted to, run down their existing reserves in less than 15 years … most countries must wait 45 years on average to liquidate their fossil fuel wealth (Cust et al., 2017: 47-48). Countries can only convert their resource wealth into revenue once it is developed and produced. This becomes tougher for countries with high-production costs as prices weaken and they become less attractive to companies (relative to lower-cost producers). Their dreams of large revenues to finance ambitious economic and social development plans may never be fulfilled.

Consider natural gas for instance. At present, the global market is glutted.[11] As a result, companies are keenest on longstanding low-cost supplies like Qatar with its large reserves as well as new and large low-cost producers like the US (whose exports, supplied by the shale gas boom, could match Qatar's). Existing producing countries, and the companies operating in their jurisdictions, are keen to grow their exports while it remains remunerative to do so. New producers such as Tanzania, which hopes to develop LNG for export to Asia, are entering a buyers-market for gas. One consequence is that a more attractive tax package is now necessary to encourage companies to

[10] The Bank of England has a task force on climate-related financial disclosures. (www.fsb-tcfd.org). See also Zenghelis and Stern (2016).

[11] After the Fukushima nuclear disaster, Japan's import price for LNG tripled between the Millennium and 2012, but by 2017 it was back around its 2000 level.

invest than in the years of high prices when countries expected a revenue and foreign-exchange bonanza.[12]

Prices could recover, but international climate action and the shift to renewables are strong headwinds for producers of fossil fuels. Governments would be well-advised to reduce their dependence on revenues from oil and gas (and especially coal) by broadening their tax bases and systems of tax collection to raise more non-resource revenues (Addison et al., 2018). They also need to build fiscal buffers by saving more revenue in readiness for unexpected earnings-shocks, including future breakthroughs in renewable energy technologies that eat into the market shares of oil, gas and coal. Some fossil-fuel-rich countries also have reserves of those metals and minerals that are in high-demand as the world transitions onto low-carbon pathways (see our discussion below). Developing these would help reduce their existing over-dependence on one or two fossil fuels for revenues (and foreign-exchange). Above all, investing resource revenues into high value-added activities in agriculture, manufacturing and services will diversify the economies of countries with abundant fossil fuels. This in turn requires an active 'industrial policy' (Dietsche, 2017). None of this will be politically or technically easy but countries need to be well-prepared to take the necessary action.

Phasing out generous subsidies to consumers of gasoline and other fuels as well as subsidies to exploration and production will further reduce the exposure to carbon-market risk of fossil-fuel-abundant countries (Cust et al., 2017). This is also politically difficult, as consumers, the transport sector, and businesses are used to cheap fuels, while state-owned oil and gas companies are vigorous champions of more investment in their sector. Low-income countries (LICs) and middle-income countries (MICs) will need financial and technical assistance to adjust (including accelerated investment in renewable energy). So far, aid donors have done little to encourage development partners to cut fossil-fuel subsidies (McCulloch, 2017). The UK's DFID, for instance, gives twice as much support to projects relating to fossil fuels as it does to renewables (Wykes and Scott, 2017: 4).

Given the internationally agreed temperature target (2DS etc.), there will come a time when humanity has used up its cumulative GHG budget (IPCC, 2015). That could be within a few decades. Caney (2016) poses three vital questions: (i) for a given GHG budget, how is it decided which producing countries have the best case to continue production? (ii) do the countries with unused fossil fuels merit compensation? (iii) If so, who should pay? From the perspective of distributive justice, LICs and MICs have a stronger case for continuing to produce than do high-income countries (HICs), which owe a good portion of their present prosperity to the use of their own fossil-fuel resources.

Politically, it is hard for LICs and MICs to agree to strand their fossil fuels. Their resource revenues are generally much larger than any aid flows, and 'aid fatigue' prevails among donors – so full compensation (including that from new streams of climate finance) may not appear credible to them. Many of today's largest producers of fossil-fuels are HICs. The US is now the world's third largest oil producer, and is closing fast on the leading oil and gas exporters, Saudi Arabia and Russia. President Trump is also trying to revive the US coal industry. Would any US administration agree to curtail US fossil fuel development for the benefit of poorer countries like Mozambique (which has natural gas and abundant coal)? Whether wealthy or poor, every fossil-fuel-abundant country wants to avoid catastrophic climate damage. Yet political short-termism works against HICs taking on the burden of responsibility and stranding their own fossil-fuel reserves. In sum,

[12] Scurfield and Manley (2017) assess Tanzania's options in the current global gas market.

distributive justice would favour an international agreement. But in its absence, resolution of the question of which countries get the revenues, and which are left with the stranded fossil-fuel assets, will be left to hard global politics – in which the LICs have the least power.

2.3 Implications for extractives companies

In a warming world, extractives companies must adapt their operations to higher temperatures and rising sea levels, and more frequent droughts, floods, heatwaves and storms (ICMM, 2013a). Every stage of the extractives cycle is at risk from physical damage as well as breakdowns in supply chains and vital public services: the exploration and discovery of resources; the construction of the infrastructure to exploit the deposit; the operation of the asset over its life (often spanning decades); and the reclamation of the site at closure and after. Other climate risks include disrupted supplies of power, water, materials and equipment to the site, and delays in transporting products to refiners, manufacturers and end-markets. Companies operating in politically-fragile nations, where the state has only limited capacity to respond to disaster, are most vulnerable to extreme weather events. Disasters constitute commercial risks for companies and economic risks for host countries (especially to the public finances when revenues are lost from production stoppages).

Mines, oil/gas rigs, and associated infrastructure require engineering excellence and high-level risk management, not least in extreme and isolated environments. The extractives industries now have the tools to assess their risks.[13] Effective risk management requires an ecosystem perspective that is unique to each location. Mining as well as oil operations inevitably disrupt the landscape, and potentially stress the ecosystem in ways that accentuate its vulnerability to climate change (and thereby endanger the livelihoods of local communities). Land degradation can also compromise the structural integrity of mine sites as well as oil and gas wells together with their supporting water, energy & transport infrastructure (ICMMa, 2013a). For these reasons, some companies have stepped up the protection of the ecosystem around their operations, as well as to meet their sustainability objectives.

Inevitably, there are business and financial consequences: higher operating costs (to raise safety margins); unplanned capital expenditures (to climate-proof older infrastructure); as well as reputational and financial costs arising from litigation, regulatory non-compliance and adverse publicity (ICMM, 2013a and 2013b). These will affect the value of both private and publicly-listed companies. Consequently, there is more pressure on extractives companies to incorporate climate risk into their strategic plans, environmental and social impact assessments, safety management systems, and engineering practices. That pressure comes from within the industry itself (and industry associations), host governments (including sector regulators who must protect the public interest), campaigning NGOs (both national and international), and increasingly from investors such as pension funds, as well as regulators of financial markets.

Minimizing mining's footprint is important since forest clearance for mining and associated infrastructure contributes to GHG emissions (and biodiversity loss). Some mining companies are investing to 'green' their operations by use of renewables to power their operations and measures to reduce their carbon footprint. The use of renewable energy, particularly solar PV and wind power, is scaling up in mining projects, notably in Canada and Australia. However, there are many GHG emissions from mining, particularly in transport, that are not under the industry's direct

[13] On corporate risk management and climate change in the oil and gas industry see IPIECA (2013) and in mining see (ICMM, 2013a). Though not climate related, the Exxon Valdez and Deepwater Horizon oil spills, as well as the Samarco (Beno Rodriques) tailings-dam collapse, illustrate the damage that major accidents can cause.

control (ICMM, 2013b). This is a major challenge to the industry given the expected scale of mining's expansion over coming decades.

3 Impact of a 'net zero carbon' future for minerals and metals

Achieving the necessary reduction in emissions alongside the UN Sustainable Development Goals (SDGs) represents a massive and unprecedented challenge. The five areas where emission reductions will be most critical are in: power; transportation; buildings; industry; and land-use management. Constructing the necessary new technologies and infrastructures requires minerals and metals for non-carbon power providers (hydro and nuclear), renewable power technologies (wind turbines, solar PV and tidal power), zero emission buildings, hybrid/electric transportation vehicles and alternative transportation modes (especially rail). To reach a 'net zero carbon future' the IEA estimates that annual investments in low-carbon technologies and energy efficiency need to more than double by 2020 to US$790 billion and to increase by about 6 times to reach US$2.3 trillion by 2035 (IEA, 2014).

It is difficult to exaggerate the potential implications for the growth in demand for key minerals and metals if the world does move successfully towards clean energy and onto low-carbon pathways (IRP, 2017). The most comprehensive and recent assessment is provided in a study undertaken by the World Bank with support from ICMM (World Bank, 2017). This predicts future demand for metals in the transition to a low-carbon future, based on the IEA's Energy Technology Perspective (ETP) scenarios (IEA 2015b). The IEA study examines the implications for renewable technologies of meeting the 2°C (2DS), 4°C (4DS), and 6°C (6DS) goals for global temperature warming (IPCC, 2014). Renewables (solar, wind hydropower, biomass etc.) rise in the ETP scenarios from 14 per cent of the present energy mix to 18 per cent in the 6DS scenario, and 44 per cent in the 2DS scenario (IEA 2015b).

The World Bank study concentrates on wind, solar, and energy storage batteries as they are critical to future energy supplies in a carbon-constrained world, while recognizing that there are many other important technologies and transmission systems (including power, transportation, buildings, industry, and land use management) (World Bank, 2017). It identifies what materials will be required, and by how much, as these technologies are scaled-up under the various climate goal scenarios (especially 2DS). Of course, forecasting metals demand is highly contingent, not least on intra-technology choices (which types of wind technology are adopted, for example) and whether the Paris Agreement holds.

For mineral-abundant countries and mining companies, the World Bank's main conclusion has great significance: "The report clearly shows that the technologies assumed to populate the clean energy shift—wind, solar, hydrogen, and electricity systems—are in fact significantly MORE material intensive in their composition than current traditional fossil-fuel-based energy supply systems" (World Bank, 2017: xii). This is a striking result. Inevitably the demand for metals for use in low-carbon technologies is much greater under the ambitious 2DS scenario than the 4DS scenario; this is especially so for aluminium, cobalt, iron, lead, lithium, manganese, and nickel.

Similar conclusions emerge from other studies. Vidal et. al. (2013) examine the material requirements necessary for the world to achieve 100 per cent renewable energy by 2050, a target of the World Wildlife Fund for Nature (WWF, 2011). Vidal et. al. (2013) conclude that the material requirements of solar and wind installations greatly exceed those of conventional energy infrastructure. Relative to an equivalent installation from traditional (fossil-fuel) energy technologies, renewable technologies require 15 times more concrete, 90 times more aluminium, and 50 times more iron, copper and glass. To reach the WWF goal, this would mean 3,200 million tonnes of steel, 310 million tonnes of aluminium and 40 million tonnes of copper; this amounts to an increase of 5-18 per cent in annual production over the next 40 years (Vidal et. al., 2013).

Clean-energy is very demanding of materials, a message underscored by Kleijn et. al. (2010) who explore potential resource constraints in a hydrogen centred economy with a scenario whereby renewables generate all energy. This study estimates an increase in iron/steel production of 6 times to service wind turbines and 40 times should specially constructed pipelines be required. If electricity is the main carrier/transmitting agent for clean power, it would mean an increase of copper production by 70 times from its current levels.

Wind technologies require copper, iron ore (steel) and neodymium (Kleijn et. al., 2010: 2790). For Solar PV and concentrated solar power systems (CSPs) it is expected that demand for the 'rare earths' could substantially exceed production capacity, thereby encouraging the development and adoption of synthetic substitutes (Kleijn, et. al: 2010: 2789). Smart grid systems integrated with solar and wind installations will raise the demand for base metals even further.

In the case of zero-carbon vehicles, strong growth in fuel cells implies dramatic growth in platinum demand and production (possibly exhausting current reserves) and neodymium production levels would need to increase by 200 per cent (Kleijn et. al., 2010). Lithium, copper, nickel and platinum will see considerable demand growth under a net zero-carbon scenario for transport (García-Olivares et al., 2012: 567). CCS at scale will require significant amounts of nickel and molybdenum (Kleijn et. al., 2011: 5647).

3.1 Supply concerns

The metals required for a low-carbon future are experiencing increasing demand and higher prices. The evolution of the future pattern of demand will depend upon the mix of technologies adopted and how these evolve over time as new scientific breakthroughs are made. Finding cheaper substitutes for the most expensive metals in batteries is a pressing concern (Dawkins et al., 2012).

Increasing recycling can reduce some of the pressure on supplies. Creating a closed-loop or 'circular' material economy can save energy (compared with producing new material from ore, biomass or oil) and contribute to reducing GHG emissions. Increasing rates of steel recycling would reduce the demand for primary steel production and save about 75 per cent of emissions for every ton of scrap recycled (Climate Strategies, 2014: 5). There are, however, many technical challenges in recycling (Reck and Graedel, 2012). Moreover, the potential for recycling is constrained by the volume of material available (Allwood et al., 2013; Pauliuk et al., 2013). The availability of material from end-of-life products is limited by the time delay between initial production and the discard of products. If the global demand for materials and metals continues growing, then recycling will no longer be able to create a closed-loop or 'circular' material economy. Older developed economies (like the UK) could possibly operate a closed-cycle for steel, whereas emerging economies such as China and India cannot do this until their stocks have grown further (Müller et al., 2011).

Consequently, there is an extremely promising development opportunity for mineral abundant countries and an excellent commercial opportunity for many miners. Investors in metals have taken note and speculation drove the price of lithium up by 80 per cent in 2016, and cobalt's price rose by 80 per cent over 2017 (making it the year's best performing financial asset) as investment funds accumulated large stockpiles in anticipation of growing demand. Cobalt and lithium were already in demand for smartphone and laptop batteries; and demand is now growing even faster – stimulated by electric vehicle manufacture and associated battery technologies, which are expected to result in a 39 per cent growth in cobalt demand through to 2022.[14] China is central to this dynamic: 80 per cent of its cobalt imports are used to manufacture rechargeable batteries (USGS, 2017: 53). Car makers are trying to lock-in cobalt supplies, but in 2017 Volkswagen failed to secure five years of supply at a fixed price.[15] As grid-storage technologies become commercially viable they will add greatly to the demand for cobalt, lithium and other metals.

3.2 Development impacts and concerns

Our knowledge of the scale and distribution of the world's mineral and metal resources remains patchy. This is especially so for the rare earths; there are no data on production and reserves for Africa and, in the developing country group, only Brazil, China, India, Malaysia and Thailand have data (World Bank, 2017: 50, citing the US Geological Survey). From what we do know, Latin America is especially well-placed for the low-carbon energy transition. It has many of the mineral resources central to the transition, notably lithium for batteries; Chile and Argentina (the world's second and third largest producers, respectively) together with Bolivia constitute Latin America's so-called 'lithium triangle'. India has iron and steel and titanium, Indonesia, Malaysia and the Philippines have bauxite and nickel, while Oceania's small islands also have resources (New Caledonia's has 10 per cent of the world's nickel reserves, for instance). For the rare earths, China has the largest production and reserves with Australia coming a distant second in production (World Bank, 2017: 50).

Africa is mineral rich, and its metals will see growing demand from the energy revolution. The Democratic Republic of the Congo (DRC) has between 47-60 per cent of the world's cobalt reserves, and supplies more than half the world's total production (USGS, 2017: 53).[16] There are at present no other sources of cobalt that match those of the DRC. Despite considerable mining investment over the last decade, Africa's potential remains largely untapped. Africa's shares of world production are often far below its shares of world reserves; Guinea, for example, has 26 per cent of known bauxite reserves but accounts for only 6.5 per cent of global production (World Bank, 2017: 26).

In sum, the developing world is potentially well-placed to benefit from the material needs of the various low-carbon pathways. However, there are at least four concerns (in addition to uncertainty around the Paris Agreement, as well as the difficulty that countries face in managing resource booms in general).

First, those countries and companies expected to meet increasing demands for base and rarer metals and minerals face an uphill task in reducing their own GHG emissions and the material footprint of their operations (discussed earlier in this paper). Increasing extraction and production levels, as well as decreasing ore grades, imply that the relative GHG, energy and water intensity of operations will also increase. Increasing the share of renewables in the power supplied to mines, and in the transport system which serves them, will be vital. Achieving this greatly depends on shifting the host country's power system towards renewable energy.

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[14] 'Five Charts That Matter for Investors', Financial Times, *12 October*, 2017.

[15] 'VW fails to secure long-term cobalt supply for electric vehicles'. *Financial Times* (15 October, 2017).

[16] The DRC's cobalt reserves are reported as 60 per cent of total world reserves in many sources, but the USGS figure is 47 per cent (Yager, 2014).

Second, countries with mineral wealth cannot enjoy the associated earnings and revenues unless they mine. Here there is a marked gap between the success of emerging economies like Brazil, Chile, and China with their high levels of production relative to reserves, and those of the LICs (and some MICs) where the gap between their reserves and production is often very wide (Guinea's bauxite is an example). This requires large investments, supporting infrastructure (especially reliable power systems and good railways and ports) and a supportive and stable policy framework. This is sadly lacking in many countries.

Third, who will benefit in the producing countries from any resource boom resulting from the low-carbon transition? Some 42 per cent of the reserves of metals and minerals required for a clean energy future are in countries with 'good' or satisfactory resource governance, while 37 per cent are in countries with weak scores according to analysis by Tilley and Manley (2017) which runs the World Bank (2017) data against the NRGI's Resource Governance Index. The countries with weak scores are often fragile states, with high poverty rates. Global poverty is falling, yet many resource-rich countries are exceptions, including mineral-rich countries like the DRC, Zambia, and Zimbabwe. In these countries both the number of poor people, and their share of the total population, are rising (Ferreira et al., 2017). The DRC's resources include copper, cobalt and nickel – all essential to clean energy technologies – but the country's politics are highly unstable and exclusionary, and over 60 per cent of the population is poor (Nanivazo and Mahrt, 2016). Zimbabwe is the world's fifth largest producer of lithium, with deposits which may be among the world's largest (USGS, 2017: 101). Yet, Zimbabwe's mineral wealth has enriched its ruling elite and funded an oppressive security apparatus (Global Witness, 2017). Will any lithium boom play out differently? It seems unlikely until Zimbabwe's politics improves.

Fourth, it would be unacceptable if scaling-up mining to facilitate the low-carbon transition results in large environmental and social costs around mine sites and for local people. The supply-chain for cobalt is especially worrying, as it relies on the DRC which provides over half the world's supply. A handful of industrial miners dominate the DRC's cobalt mining sector, which is attracting more foreign investment.[17] Environmental damage together with human rights abuses in unregulated artisanal mining (including child labour, lack of workplace safety, and forced relocation of villages) are widespread (Amnesty International, 2016; Frankel, 2016; SOMO 2016). To curb the funding of Congolese militias, US law requires companies registered with the US Securities and Exchange Commission (SEC), and which sell products containing gold, tantalum, tin or tungsten, to disclose whether these are sourced from the DRC or adjoining countries (subject to independent audit).[18] While cobalt is not implicated in militia-funding, many campaigners (and some companies) argue that cobalt's inclusion in the list would help to curb human rights abuses in the DRC's mining (Frankel, 2016).

Batteries for electric vehicles, together with the much larger batteries of grid-storage, require far more cobalt than IT devices. The renewable energy, electric vehicle (and IT industries) all face a serious dilemma, as their technologies greatly depend on the DRC's cobalt. A leading battery maker, LG Chem, stopped buying DRC-sourced minerals, including cobalt, in 2015.[19] Car manufacturer Tesla is trying to replace DRC cobalt with North American supplies for its electric cars. This will be difficult as combined Canadian and US production is less than one-sixth of the DRC's, and the DRC's reserves are more than three times those of Australia, which has the second-

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[17] China Molybdenum bought the Tenke copper and cobalt mine in the DRC in 2016.

[18] This is a provision in the Dodd-Frank Wall Street Reform and Consumer Protection Act, passed into law by congress in July 2010.

[19] Apple is also working to reform its cobalt supply chain (Frankel, 2016).

largest reserves (USGS, 2017: 53). Battery makers are searching for substitutes (nickel is favoured, but iron, manganese and silicate may be feasible). Research results are promising, but moving from the laboratory to commercial manufacture is some years ahead. Meanwhile, the technologies underlying the renewables (and information) revolutions depend on a mineral supplied by one of the world's most fragile nations.

Cobalt is only one example of the many important minerals that are sourced from fragile states. Embedding these supply-chains in a proper framework of governance and transparency (that also avoids environmental damage and human rights abuses) is essential if this resource wealth is to serve inclusive development and help countries end their fragility (Ali et al. 2017).[20] Strengthening state effectiveness and accountability is essential as well (Addison and Brück, 2009). Weak resource governance deters the investment necessary to develop the sector and provide the revenues (e.g. Zimbabwe's output of lithium is far below other producing countries, despite having much larger reserves). Fragile states like the DRC risk missing the many development benefits of a future in which low-carbon pathways generate a rising demand for their metals and minerals.

4 Conclusions

In 2016, atmospheric concentrations of CO_2 reached their highest level in 800,000 years, and atmospheric methane also reached new highs (WMO, 2017). Since 1990 there has been a 40 per cent increase in radiative forcing by all GHGs (NOAA, 2016). To avoid more than a 2°C temperature rise will require GHG concentrations to not exceed more than 430–450 ppmv; this means that GHG emissions must peak within the next few decades and the world must then achieve zero net-emissions (IPCC, 2015).

The shape of the energy future and of the societies that it underpins, as well as the prospects for producers of fossil fuels and manufacturers of low-carbon technologies (and the metals and minerals that go into them), depend on a myriad of decisions by private and public actors, whose decisions interact. Billions of dollars of private investment in extractives (together with investments in renewable energy, electric vehicles, energy efficient buildings etc.) hinge on the Parties to the Paris Agreement fulfilling their commitments and supporting the transition with publicly-funded research – thereby encouraging the private-sector to shift decisively towards delivering low-carbon pathways for economies and societies. This includes companies in the extractives sector who need to reduce their carbon footprint while, in the case of miners, increasing the production of the metals and minerals essential to the technologies of the low-carbon future.

The cost of renewables is falling at an unexpectedly fast pace yet fossil fuels will dominate power generation for many more years, even as societies improve their energy efficiency. Eventually, much of the world's remaining reserves of fossil fuels must remain unused (unless there is a massive scaling up of carbon sequestration, which is itself problematic). Many of the LICs and MICs still hoping for rapid prosperity based on their oil, gas and coal reserves face the stranding of these assets in a carbon-constrained future. Although there may be scope for prioritizing their supplies while maintaining a fixed global carbon budget, this requires an international agreement that will be tough to achieve.

[20] The OECD has a set of guidelines on responsible supply-chain management in conflict-affected countries (OECD, 2013). Other actions are outlined in RESOLVE (2010).

At the same time, those LICs and MICs which have reserves of the materials and metals essential to the construction of wind, solar, electricity transmission, and public transportation face a brighter future than that of fossil-fuel producers. If international climate action, including implementation of the Paris Agreement, is robust then minerals and materials that should see sustained demand-growth include: copper, nickel, high grade steel, aluminium, zinc, molybdenum, platinum, chromium, cobalt, lithium, silver and a range of rare earths. Renewables have a much greater need for metals and materials than fossil-fuel power generation. This represents a promising market opportunity for producing countries. However, they will face great challenges in simultaneously meeting their Paris goals (to reduce their own GHG emissions) and their SDG goals (to reduce the material footprint of their economic activities). International assistance is vital, especially for the poorer countries.

The story of extractives and climate makes for a complex and intriguing narrative. Success is vital to humanity's continued progress and to reducing the dangers posed by climate change to sustainable development, poverty reduction – and to humanity's very existence.

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