STRANDED ASSETS AND SOVEREIGN STATES

Amy Myers Jaffe*

There is evidence that the risk of stranded assets in the oil and gas sector is underpriced in financial markets. Publicly traded Western oil and gas companies are starting to write down assets, opening up the possibility that more rationalisation of value is likely to come. To the extent that large oil companies diversify portfolios to include cleaner energy and carbon sequestration technologies, it could reduce the risk of a sudden cascading change in the stock valuation of these firms and related bond and credit markets. Instead, the vast majority of oil and gas assets that will be stranded are in the control of sovereign states whose national budgets are highly dependent on oil and gas revenues. Thus, the problem of stranded asset risk for the oil and gas sector may be most relevant in markets for sovereign credit as well as risks that go beyond financial losses.

Keywords: oil, climate, stranded assets, transition, innovation, strategy.

JEL codes: Q35; Q55; L1.

1. Introduction

In 2009, an important group of scientists published a paper that calculated how much of the world's remaining proven oil, gas, and coal reserves would have to remain unburnable to ensure that global warming would not exceed 2 degrees Celsius above pre-industrial levels (Meinshausen *et al*., 2009). Subsequently, a global climate agreement was reached in 2015 within the United Nations Framework Convention on Climate Change to keep the increase in global average temperatures well below 2 degrees above pre-industrial levels and to pursue efforts to limit the increase to 1.5 degrees in an effort to reduce the adverse impacts of climate change. The 2009 article, published in *Nature,* suggested that close to half of these reserves would become stranded or obsolete, under climate change scenarios that would ameliorate global warming via government policies and technological advancements. The paper went on to be ranked as one of the most cited environmental papers in recent years. A later analysis by McGlade and Ekins looked at economic, technical and geographic factors and concluded that a third of all oil reserves needs to be left unburned and posited that certain reserves would be more susceptible to stranding than others (McGlade and Elkins, 2015). The researchers suggested the most vulnerable oil resources to become obsolete were Canadian oil sands, Arctic oil resources and over 260 billion barrels in Middle East reserves.

Since these science articles have been published, discussion of the potential problem of stranded oil and gas assets as a matter of financial market stability has become more prevalent. Former US Vice President Al Gore published a notable opinion piece on the coming crisis of the carbon financial bubble in the *Wall Street Journal* (Gore and Blood, 2013). The *Economist Magazine* published a Special Report on the topic of stranded oil and gas assets in November 2016 (*The Economist*, 2016). Citi released a report in 2015 that suggested the value of fossil fuel reserves that could go unproduced could total over $100 trillion (Parkinson, 2015). HSBC's note to investors on the topic discussed investor options which it categorised as fully divesting from fossil fuels companies, shedding highest risk operators, or engaging with fossil fuel corporate leaders to respond to climate risk (Paun *et al*., 2015). More recently, central bankers have warned of potential systemic financial risks from climate change (Tooze, 2019).

In 2017, at a gathering in the Lofoten Islands of Norway, a group of academics, analysts, and activists offered a view on how the decline of global fossil fuel production should be handled to promote a just energy transition (Lenferna, 2017). The *Lofoten Declaration for a Managed Decline of Fossil Fuel Production* stated that wealthy nations like Norway should lead in abandoning

* Council on Foreign Relations, New York. E-mail: ajaffe@cfr.org

fossil fuel production because their economies have already benefited most from burning fossil fuels and have superior capability to diversify away from fossil fuel production and use. But with more than 50 per cent of Norway's reserves still untapped, Norwegian politicians are resisting such calls from local civic groups that the nation go first to strand its own reserves (Milne, 2019).

It is now clear that the stranding of carbon-intensive assets is inevitable. But, to date, it remains unclear how markets will allocate which oil and gas reserves will become stranded and over what time period. Also in question is the speed at which financial markets and investors will absorb this realisation, the forces that will dominate the process of transition away from fossil fuels, and the geopolitical tensions that may arise as a result. This paper reviews the available evidence on these issues, including how financial markets have responded so far to the growing body of scientific evidence that demonstrates that the vast majority of remaining fossil fuel reserves will remain untapped. This discussion is followed by an overview of the key forces driving the transition away from fossil fuels, emphasising the role of innovation and technology. The following section reviews transition strategies and evidence of behavioural change by firms and national actors to date. The final section concludes and warns of some risks beyond financial losses that may emerge during the transition away from carbon-intensive fuels.

2. Stranded assets and market valuations

Despite increased attention to the science underpinning the calculation that the vast majority of remaining fossil fuel reserves *need* to remain unburned if catastrophic climate change is to be avoided, translating the science of unburnable carbon reserves into concrete investment information has proved elusive. In 2009, in the immediate aftermath of publication of the first scientific survey explaining the potentially high level of unburnable carbon reserves, the average stock price of the 63 largest publicly traded American oil and gas companies fell by almost 2 per cent (Griffin, Jaffe *et al.*, 2015). However, in the months and years that followed, further penalties to the stocks attributed to new articles about unburnable carbon were minimal. This is likely the case because many uncertainties exist, not the least of which is whether governments themselves will be effective in restricting fossil fuel use in the first place. Global carbon emissions rose in 2018, even as countries began to implement their intended nationally determined contributions under the Paris climate agreement. Another uncertainty is the pace and scale to which carbon sequestration and storage technologies will become available to allow continued use of high carbon content fuels by mid-century. A group of 13 major oil and gas producers, known as the Oil and Gas Climate Initiative (OGCI), has said it plans to double carbon sequestration linked to oil and gas usage by 2030 but this is still very far from the levels needed.

Academic studies have noted that there are structural reasons why inertia has so far dominated investor response to the risk of stranded oil and gas assets. Silver (2016) argues that institutional investors are 'blind' to oil and gas stranded asset risk because current best practice for asset allocation incentivises the use of historical metrics of risk that back cast and therefore structurally underprice a long-dated future risk such as climate change (Silver, 2016). Bebbington *et al.* found that financial experts interviewed on the subject of stranded assets hold a common belief that as carbon regulation becomes more prevalent and the need to reduce emissions more pressing, a greater impact on fossil fuel firm valuations will emerge (Bebbington *et al.*, 2019).

But markets often assess risks that are uncertain, and the fact that investors might currently be underestimating future valuation risk for carbon-intensive energy firms does not mean that stranded asset risk will remain undervalued indefinitely. Policy makers and scholars have raised the question: will such risk get priced slowly over time as markets shift gradually to lower carbon energy or might an unblocking event or series of events create a sudden market cascade that could reverberate in equity and credit markets? Many investors are likely of the opinion that chances are demand for fossil fuels will be relatively stable for at least two more decades, given the host of technical, social, political, and commercial obstacles to a rapid transition in global energy infrastructure. This apparent consensus view implies that carbon risk may have been overstated, and that public traded companies will manage to produce most of their legacy oil and gas assets before a serious peaking in demand arrives (Meyer *et al.*, 2015).

Still, the dramatic shrinkage of market capitalisation of the eleven largest US coal companies – declining from $62 billion in 2007 to under $10 billion in 2018 – should give pause to the notion that just because there is current supporting demand for carbon-intensive commodities, markets would not reassign risk-adjusted value to producers out of anxiety about long-run prospects. The growing list of banks and other kinds of financial institutions that will no longer finance investment in

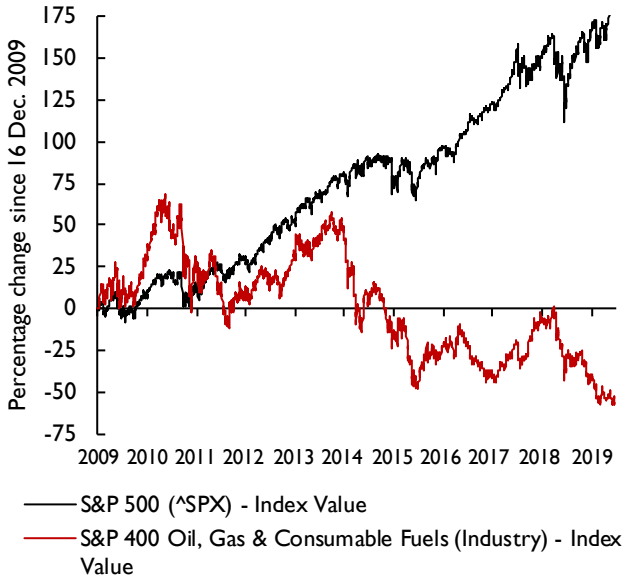
coal mining and new coal-fired thermal generation demonstrates that at least where US coal is concerned, a future timeline has moved forward out of anticipation of future risk.

That US coal firm valuations have been marked down sharply belie the reality that many countries, especially in the developing world but also including the United States and Europe, are still using considerable amounts of coal to generate baseload electricity supply. The politics of coal phase-out plans has been volatile, with recent elections in the United States and Australia reversing previous policy commitments to regulate coal more heavily. China has also backpedalled on coal substitution in light of economic pressures and energy security concerns related to Middle East oil disruptions.

A wide number of substitutes exist for coal in power generation, and this is allowing many countries around the world to actively fashion policies to limit its use. By contrast, the case of oil and gas is more complex because while substitutes are appearing on the horizon, they have not been introduced at the pace and scale required, especially in the transportation sector. In oil's case, what is needed is a range of fuels to readily replace a substantial portion of the 100 million b/d of oil demand that currently exists across many sectors worldwide. As the introduction of electrification and, to a smaller extent, hydrogen, becomes more prevalent in transport, oil's dominant reign will certainly weaken. But the transition time is likely to be lengthy, and that has made the question of stranded assets seem more esoteric than the fate of coal. Moreover, the pathways to remove oil from use in heavy industry and plastics manufacturing remain challenging.

Even so, equities of the largest exchange-listed oil and gas firms have underperformed the index of all equities for the past several years despite the fact that demand for those commodities is still growing steadily (figure 1). Generally speaking, valuation of the largest privately traded oil companies has historically been linked to oil price levels, oil company production rates, and to companies' performance replacing or adding to oil reserves (Osmundsen *et al.*, 2006). For senior management in the sector, in the 1990s especially, reserve replacement was seen as a 'lead indicator' to distinguish success (Stevens, 2016). But in the 2010s, in light of the global commitment to tackle climate change, new models were needed that required restructuring to shrink areas of operations to those with the highest potential to earn returns and to "provide cash for their shareholders" (Stevens, 2016). Increasingly, Wall Street

Figure 1. Oil and gas stocks underperformance



Source: Bloomberg.

analysts have begun to suggest that investors in oil firms will increasingly shift away from this historical focus on oil reserve growth and look instead at the business' ability to generate revenues as the lens for stock performance (Elliott, 2019).

The confused situation for energy investing is one manifestation of the fact that policy makers have failed to provide sustained guidance and planning for a smooth energy transition. The longer governments delay in committing to a definite pathway, the more susceptible investors will be to transition risk. If markets cannot predictably assess when and where fossil fuel assets will become obsolete, risk of an informational cascade will remain a feature of energy investing. The problem for investors is rendered more complex by the fact that many of them have lost money in early bets on clean energy. This is not surprising since incumbents often take action to defend their market share for as long as possible (Nelson, 1993). Regulatory capture is one manner in which incumbents have traditionally blocked disruptors from early successes. Business leaders and workers of incumbent technologies fight hard in national political arenas to ensure their products and jobs will not be replaced by new emerging technologies. Thus, part of the task of properly managing the energy transition is to remedy situations that can lead to market failures. So far, insufficient progress is being made.

3. Forces driving energy transition

Energy transition risk posits that the valuation of high carbon fuels like coal, oil and gas could experience declines in value as demand for such commodities is superseded by cleaner, low or zero carbon fuel sources. Since the pace and scale of transition is uncertain, the timeline for such losses in value are also unclear.

3.1 Regulation

There are several elements that could determine the speed and size of the loss of demand, and thereby with it a decline in value for coal, oil and gas assets including, notably, the prospects that governments will implement rules and regulations to restrict burning of fossil fuels and dictate a transition to a low or net-zero economy by a specified target date. A pivotal example was the 2015 Paris climate accords under which 196 governments and the European Union agreed to limit their greenhouse gas emissions in an effort to combat climate change. National and sub-national policies are also relevant, such as the increased number of countries, regions, states and cities imposing a price on carbon dioxide emissions and/or setting targets for clean energy.

3.2 Physical risks of climate change

But government intervention as a defining feature taken alone may, in fact, be too narrow. Changes in the natural environment as a result of climate change might also influence the competition of fuels and the pace and nature of the energy transition (Odgen, 2019). Water is an essential resource for energy production and some energy sources are more vulnerable to water scarcity than others. For example, thermal and nuclear power generation is highly water intensive. In addition, some kinds of energy production infrastructure are more susceptible to disruption by severe weather than others and harder and more time consuming to repair than others. The high concentration of oil refining in coastal regions makes it more susceptible to cutoff by severe storms. By contrast, generally speaking, renewable energy tends to be more geographically diversified, meaning that the chances of a major cutoff from a single weather event are lessened (Ogden, 2019). Solar energy is also faster and easier to install, making it more resilient to repairs or quick installation than large centralised thermal or nuclear energy plants. But renewable energy is not without problems. Grids can come under additional pressure if an unexpected outage happens to coincide with solar or wind intermittency, as Hawaii experienced on a cloudy day in the summer of 2019 (Star-Advertiser, 2019).

3.3 Technology and innovation

It is equally possible that new innovative and disruptive technologies will reduce demand for oil and gas as a fuel regardless of the regulatory context (Jaffe, 2019a). Already, the drop in levelised costs for solar and wind energy, for example, have made it a more formidable competitor to coal and natural gas in many locations. New vehicle technologies may similarly impact gasoline sales over time. In this way, energy transition risk comprises two direct pathways, which may or may not be linked over time: regulatory risk and technology risk.

3.4 Technology and peak oil demand

Ultimately, for now, world oil demand is still growing. Global oil demand stood at 98.7 million b/d in January of 2018. It was 100.5 million b/d in January 2019. Global oil use over the course of 2019 was forecast to grow by an average of between 800,000 b/d to 1 million b/d with a similar outlook for 2020.

Still, the rapid pace of digital innovation in the energy sphere raises the prospect of a different kind of risk – one where technological disruption might render oil a less vital input to economic activity and quicken the timeline for a peaking in oil demand. The process through which this could happen is difficult to model, however, given the disruptive nature of many of the technologies, and thus is generally unpredictable and even erratic.

The speed at which key digital technologies such as ride hailing or logistics optimisation for freight has been adopted has been relatively swift. Other technologies such as autonomous vehicle self-driving and three-dimensional (3D) printing are likely to take longer to take hold. As I point out in my report *The Tech Enabled Energy Future*, "Investment decision making in new technologies remains decentralised among many independent players in the private sector. With no centralised government roadmap, the outcomes of widespread deployment of digital products so far have varied widely in time and scale, and analysts are divided in predictions on what effect they will have on the oil industry and over what period of time" (Jaffe, 2019a).

Early modelling on revolutionary digital technology trends in the transportation sector posits that partial automation could have substantial energy savings (Wadud *et al*., 2016). Crash avoidance sensors and self-driving can facilitate energy saving light weighting of vehicles, while computer-assisted efficient routing and other features offer the potential to reduce the level of fuel use per vehicle significantly (Wadud *et al*., 2016).

The availability of digitally-assisted ride hailing is lessening the impetus for car ownership, especially in

urban settings and among younger generations. The algorithms that programme ride hailing theoretically allow for correct vehicle size and horsepower to be optimised per trip purpose. Vans and buses hailed by smart phone are increasingly being considered to service custom routes, replacing inefficient, large city buses. Electrified rapid bus systems are being enabled by wireless fast chargers. Online shopping is replacing individual trips to the mall, with deliveries optimised using big data and artificial intelligence so that oil use and vehicle miles travelled can be reduced (Mathers, 2013). Dedicated lanes for autonomous trucks could reduce congestion, thereby lowering fuel consumption and emissions (Kim *et al*., 2018).

Proponents of autonomous vehicles argue that self-driving cars will allow ride hailing companies to coordinate with public transit, enable cleaner fuels, and reduce congestion. Fewer cars could handle the same mobility needs (Fagnant and Kockelman, 2014). The concept is that autonomous vehicles would be able to communicate digitally with each other and connect to smart traffic management systems that would regulate traffic flow, eliminating stop and go traffic that eats up fuel from the constant braking and accelerating. The reduced potential for accidents would allow light weighting of vehicles, again lowering the amount of fuel needed to make the same trips. Greenblatt and Saxena (2015) found that electrified autonomous fleets where vehicle choice was right-sized to what was most appropriate to the kind of trip could reduce greenhouse gas emissions significantly if the cars were charged with electricity derived from renewable energy. The ride hailing algorithm in this case would select a large vehicle only when it was needed. Today large vehicles are used for every trip in cases where an individual family has only one vehicle and its size is typically chosen for the longest journeys that will have the most passengers even though most trips are likely to be a single passenger going short distances.

However, the potential of ride hailing to reduce oil use can go unrealised if the service is used to replace public transit. One survey in Boston found that over 40 per cent of ride sharing customers would have opted to use public transit had ride hailing services not been available (Gerhke *et al*., 2018). New York City has regulated ride hailing firms following data analysis that suggested it was adding significantly to vehicle miles travelled inside city limits (Shaheen, 2018). These experiences demonstrate the need for policy intervention to ensure that digital mobility applications complement public transit, rather than replace and weaken it.

Even more than transport technology, additive manufacturing such as 3D printing could be particularly disruptive to fossil fuel use, if it helps eliminate oil intensive globalised supply chains. Traditional manufacturing has come to rely on specialisation where component parts are manufactured in multiple, global locations and shipped to industrial plants where labour costs are low for assembly of goods and machinery. This mode of organisation requires oil intensive shipping services to transport components around the globe. Additive manufacturing could change this in three ways. Firstly, products, especially heavy machinery, made through the additive process, will tend to have less parts. In addition, advanced manufactured goods and machinery will also likely be produced closer to end-users, shrinking the distance over which component parts need to be transported. In many cases, parts will be created at the manufacturing site itself. Finally, engines and other machinery produced by additive manufacturing will be lighter weight than their predecessors, requiring less energy to operate. The implications of this manufacturing operational change is that oil use in global freight could be dramatically reduced. Verhoef *et al*. (2018) suggest widespread use of additive manufacturing could reduce global energy demand in the aerospace and construction sectors by 5 to 27 per cent by 2050. The study found that transport costs in the construction industry could be reduced by up to 40 per cent by the advent of additive manufacturing by reducing the weight of materials. It also found that removing an intermediate step in the production process of the Airbus A320 by utilising additive manufacturing processes could reduce energy used to transport materials by over 50 per cent (Verhoef *et al*., 2018).

4. Transition strategies and evidence of changing behaviour

Confirmation of the trend line for energy transition is slowly emerging in a few key markets. There is evidence that oil demand is already slowing in regions where climate change regulation is strongest. OECD Europe's oil demand has been flat to declining in recent years and now stands roughly at 14 million b/d, down from 16 million b/d in the winter of 2006. It is expected to continue to decline. Germany, the continent's largest economy, has seen total oil demand fall from 2.7 million b/d in 2006 to 2.36 in September 2019. Total average OECD oil demand has generally been flat for over a decade. Even in its business as usual baseline scenario that casts forward energy use based on today's set of technologies and policies, the IEA expects oil demand in the industrialised economies to fall by 10 million b/d by 2040.

China has announced aspirations to shift to greener energy sources and advanced vehicles, but so far, oil demand is still rising, driven largely by a fast-growing economy. China's oil use topped 13.4 million b/d in November 2019, up from 12.9 million b/d a year earlier. China's president Xi Jinping has stated that China hopes its push into new energy vehicles will improve China's industrial strength, and building innovation capacity for China's auto sector is a priority. Chinese officials have expressed the view that the country's oil use could peak in the 2020s. But its efforts at promoting electric vehicles and renewable energy, while robust compared to other countries, saw setbacks in early 2019 when the federal government reduced subsidies for individual purchase by 50 per cent, leading to a slowdown in electric vehicles sales in China. Still, a plausible thesis holds that increased use of ride sharing and mounting congestion has dented local enthusiasm for individual car ownership. It is not uncommon, for example, for drivers to get stuck in traffic jams in Beijing for eight hours at a time. In 2019, Chinese car sales began to slow noticeably, declining 12 per cent in the first half of this year. The decline in sales of automobiles in 2019 was even more pronounced in India, another market that is predicted to see rising oil use.

Significantly, China has announced plans to ban the sales of internal combustion engine (ICE) automobiles by 2050, motivated by environmental concerns such as urban air pollution, energy security, and industrial competitiveness. A recent report by a well-placed think tank, known for its advisory role to government policy makers in China, suggested that China will implement its ban in stages, starting with major cities such as Beijing, Shanghai, and Shenzhen (iCET, 2019). A second and third phase would cover provincial cities such as Xi'an, Nanjing, and Hebei. Later phases would cover less developed areas in the country's northeast and western regions. Chinese passenger vehicles and municipal service vehicles will be the first to be required to shift away from ICEs. Later, medium and heavy freight vehicles will be targeted for alternative fuels. The policy is significant since China is the largest car market in the world, with total sales of over 30 million vehicles in 2018. Automobiles accounted for over 40 per cent of China's total oil consumption in 2018.

China is not alone in announcing plans to ban sales of ICE automotive technology after 2040 as a key policy to reduce air pollution and greenhouse gas emissions. France and the UK have also announced aspirations to restrict new sales of ICE cars by 2040. Ireland, the Netherlands, Norway, Slovenia, and India have set more ambitious timelines for banning ICE cars (IEA, 2018). There is also a trend to ban ICE passenger cars in city centres in Europe and Canada (Garfield, 2018), with some major cities pledging to restrict diesel and gasoline ICE vehicles between 2024 and 2040 (IEA, 2018). But it would take a phase-in of a global ban on ICE passenger cars to promote a dramatic peak in global oil demand via this one policy mechanism (Fulton *et al*., 2019). A more limited ICE ban in Europe and China by 2040 is projected to eliminate roughly 5 million b/d of oil use in its first ten years since passenger vehicles often remain in active circulation for fifteen years or more, often across multiple geographies. Patrick Plotz *et al*. (2019) write that ICE vehicles would need to be banned completely by 2035 or 2040 to "align with deep GHG-reduction goals."

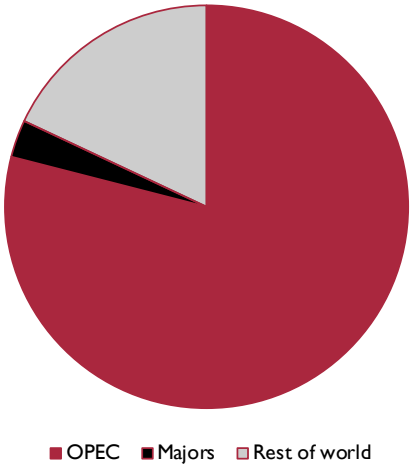
Still, the concept that oil demand could peak, whether due to technology disruption or stricter carbon policies by governments or both, is already influencing investment strategies of oil producers from both the private sector and sovereign nations. What is important is not the certitude of such a peak (which is still questioned in energy circles); even its possibility is proving sufficient to stimulate a major shift in paradigm.

Historically, oil sector investment strategies have been influenced by the finite nature of the commodity. The belief in future scarcity of resources drove private sector companies and national oil companies of large oil consuming nations, like China, India and Japan, to seek massive investments in new reserves. Petro-states were willing to hold back production and delay investment for exploiting undeveloped reserves because they believed that the value of those assets would rise over time, as oil output from older oil fields in North America, Europe, and Australia began to decline from natural physical geological limitations. What has changed now is that oil seems to be in greater abundance, just at the time when uncertainty about future demand is emerging. As a result, companies are having to reimagine their strategies because oil businesses premised on adding to reserves onto balance sheets are no longer being rewarded by investors for expansion in resource holdings. For investors, there is also the question of whether and what proportion of the assets that do get stranded will be in the hands of national sovereigns for whom the only shareholder is the state. Much of the ownership of oil and gas reserves rests with national governments whose state-owned oil companies do not offer equity for trading in financial markets. Thus, in most cases, it will be sovereigns, not private investors, who will bear the brunt of stranded oil and gas assets.

To put the exposure of sovereigns in perspective, the largest traded private oil companies, which include ExxonMobil, Royal Dutch Shell, Chevron, Total, BP, Equinor, ENI, and ConocoPhillips, hold total oil reserves of 49 billion barrels (Energy Intelligence, 2018). This represents only about 3 per cent of total proven world oil reserves of 1.7 trillion barrels. In comparison, the share of world oil reserves by nations that are members of the Organization of Petroleum Exporting Countries (OPEC) is 79 per cent, with Venezuela controlling 25 per cent, Saudi Arabia 22 per cent, Iran 13 per cent, Iraq 12 per cent, and Kuwait and United Arab Emirates roughly 8 per cent each (OPEC, 2018). This reality of reserve ownership means that the burden of stranded assets risk will fall more squarely on the oil industries of sovereign nations, which are largely controlled by national oil companies (NOCs).

There are some exceptions because certain national oil companies have partially privatised and offer shares for trading on international stock exchanges that do privatise some of their stranded assets risk. For example, the Chinese national oil companies PetroChina, China National Offshore Oil Corporation (CNOOC), and Sinopec held initial public offerings for a limited number of shares from 2000 to 2007 on the Hong Kong and Shanghai stock exchanges. India's ONGC held an initial public offering for 10 per cent of the company in 2004. Rosneft sold shares valued at $10 billion on the London and Moscow stock exchanges in 2006 or about 14 per cent of the company, in an effort to retire debt to Western banks. In 2000, Brazil's Petrobras offered $4.3 billion in shares on the Brazilian stock exchange and American Depository Receipts on the New York Stock Exchange. Most recently, state oil giant Saudi Aramco sold shares representing 1.5 per cent of the firm on the Saudi stock market to much fanfare.

Figure 2. Share of world oil reserves



Source: Energy Intelligence Group.

Shojaeddini *et al.* (2019) note that international oil companies (IOCs) and national oil companies (NOCs) have begun to diversify investments to include renewable energy while at the same time trying to lower emissions from their oil and gas operations. Several oil majors have invested in a variety of kinds of clean tech ventures including solar, wind, geothermal, biofuels, hydro-power, and marine energy. In Europe, IOCs are investing in hydrogen and electric fuelling infrastructure, battery storage, and carbon capture as well as increasing the share of natural gas businesses in their overall mix of fossil fuel assets.

A recent Barclays equity research team report on 'Rewarding Low Carbon' notes that the "willingness of investors to factor in longer-term value for energy stocks seems to have diminished" (Rainforth *et al.*, 2019). The bank says it is shifting the level of oil and gas reserves it uses in valuation of companies to the proved and probable reserves classifications that typically represent about 20 years reserve life span, and increasing the discount rate used in calculating associated cash flows. As a result, Barclays' valuations of energy companies are roughly 15 per cent lower. The bank also assesses companies on a sustainability basis that includes considering their commitment to low-carbon businesses, higher share of natural gas to oil, efficiency of operations, and potential to lower emissions from their operations (Rainforth *et al.*, 2019). These sustainability measures demonstrate that the IOCs have multiple ways they can pivot to address the energy transition and, while not every company is making equal efforts, it remains possible for IOCs to protect cash flows by shifting over time to an increase in spending in low carbon technologies and products to align with market and regulatory changes as they transpire.

In recent months, several major oil companies have increased dividends to try to sustain investor enthusiasm for their shares. ConocoPhillips raised its dividend in October 2019 and announced a $3 billion stock buyback programme in response to investor pressure on US shale companies to return cash to shareholders rather than reinvest it in the business. Analysts say it is too early to say whether the pressure on companies to

pay out is structural, related to long-term concerns about stranded asset risk, or whether it is more in response to poor recent performance. ConocoPhillips, for example, has underperformed the S&P 500 by 13 per cent so far this year. The company's experience is not unique. US exploration and production (E&P) indexes have consistently traded below the broader public equities market for the past several years. In fact, oil and gas firms' share of the market capitalisation of the S&P 500 has fallen to less than 4.5 per cent, down from 15 per cent just a decade ago (Dempsey, 2019).

But the adjustment by international oil companies only tells part of the story. The national oil companies of the Persian Gulf, notably Saudi Arabia, the United Arab Emirates, and Kuwait are among the NOCs taking the most ambitious measures to reduce energy consumption and emissions in oil production processes and facilities and to pivot to investment in renewable energy. A comprehensive study of oil and gas upstream emissions published in *Science* found that upstream production accounts for 5 per cent of all greenhouse gas emissions and that Saudi Aramco, which funded the study, did in fact have the lowest carbon emissions per barrel among major producers (Masnadi *et al.*, 2018). Saudi Aramco plans a 2 per cent annual reduction in energy intensity of its industrial facilities via energy efficiency and carbon management technologies. It has invested in a master gas system to reduce natural gas flaring to less than 1 per cent of gas production and is adding renewable energy to power remote sites such as the Turaif oil storage facility. Saudi Aramco has also begun to invest heavily in carbon capture and storage (CCS) to position itself to be the lowest cost, lowest carbon source of oil in the coming decades in an effort to be the most competitive source for oil as market demand shrinks. Saudi Aramco launched the first large-scale CCS facility in the Middle East which is a C02-EOR demonstration project that captures roughly 0.8 million tons of carbon a year from the Hawiyah natural gas liquids recovery plant. Saudi Aramco is also investing $5 billion to produce 10 GW of power from renewable energy by 2023. The state firm also has a research facility in Detroit which is studying direct capture technologies for $C0_2$ including from vehicle tailpipes.

Kuwait has set the goal to produce at least 15 per cent of its energy from renewables by 2030 with its national oil company Kuwait Petroleum Corporation (KPC) participating in the effort. The country has launched a 10 MW solar electricity complex and is installing smaller-scale solar in other facilities, such as office complexes, road lighting, and fuel stations.

Abu Dhabi NOC ADNOC is also actively pursuing an alternative energy project, though Abu Dhabi Future Energy Company takes the lead on renewable energy in the emirate. ADNOC has been installing CNG conversion centres and fuelling and has plans to provide EV fast chargers at ten sites in the coming years. It is also supporting pilots for hydrogen fuelling. Like Saudi Aramco, ADNOC is embarking on CCS, building the first carbon capture and usage facility in the region. The new company, a joint venture between ADNOC and Masdar called Reyadah, stores carbon from Emirates Steel Industries for use in enhanced oil recovery and plans to expand to capture additional $C0_2$ from ADNOC's gas processing plants.

Still, not all national oil companies have developed strategies to address the question of stranded assets. In fact, some countries are worse positioned than others to address this challenge. For example, Venezuela is highly exposed to stranded asset risk not only because it holds the largest oil reserves in the world but also because of the current dire situation of its national industry. The country's internal problems have led to gross mismanagement of the sector, in addition to looting and other damage to most major facilities, that has all but crippled state firm PDVSA's ability to operate. Oil production has fallen to less than 750,000 b/d, down from over 3.5 million b/d before Hugo Chavez took office. Surface equipment in many major production regions of Venezuela's oil sector have been badly damaged or destroyed and some oil fields have suffered reservoir damage that would require drilling of new wells in fields to restore production, where possible. Before bureaucratic mismanagement, massive state economic decline, and then US sanctions hit the firm, PDVSA used to spend upwards of $3 billion to $4 billion a year just to arrest wellhead declines in its mature oil basins (Jaffe, 2019b). Capacity expansions at the country's extra heavy oil Orinoco Belt region would take tens of billions of dollars.

Availability of this capital to finance a restoration of Venezuela's oil sector remains unclear. The country is deep in debt, including over $20 billion owed to China alone, and it will take any government, including a new government, years to stabilise finances. Moreover, since many international oil companies will be less interested in amassing large reserves in the coming years, and the poor state of Venezuela's fields and the country's political instability weigh against foreign investment, Caracas will have more difficulty finding parties who will be willing to invest large sums into its oil sector. The longer Venezuela's current internal political crisis continues, the harder it will be for the country to tap its oil reserves as a means to pay for its future.

Countries currently facing sanctions that restrict access to external finance, such as Iran and Russia, could face similar problems coping with stranded asset risk due to lack of access to external finance. China National Petroleum Corporation (CNPC) recently withdrew from the $5 billion deal to develop Iran's offshore gas and condensate field at South Pars, in a major blow to Iran's oil and gas sector development. Total pulled out of the South Pars project earlier in response to US sanctions on Iran. Delays in investment in mega-projects like South Pars increase the risks that some portion of developed reserves could become obsolete as other oil producing countries develop their reserves more quickly, capturing market share in a world that will eventually need less oil.

For Russia, the risks posed by climate change to its oil sector are enormous. Western sanctions against Russia have slowed, but not completely shut off, its access to foreign capital for its oil sector but the country faces other climate related risks that will hinder its oil industry in the coming decades. The Intergovernmental Panel on Climate Change (IPCC), in its latest report on Ocean and Cryosphere in a Changing Climate, suggests about 45 per cent of the oil and natural gas production field in the Russian Arctic is located in the 'highest hazard zone' for instability in structural performance and functional capabilities, due to permafrost melting that is creating a loss of load bearing capacity (Lee, 2019). Arctic melting is shortening Russia's winter drilling season when ice roads and frozen ground facilitate transportation and use of heavy equipment. Melting permafrost also means increased landslides and building collapses that will threaten much of Russia's aging infrastructure in Siberia, increasing costs and potentially causing major damage to pipelines and processing plants.

Still, Russian firms have begun preparation to address carbon transition risk, including instituting programmes to reduce emissions levels to position its oil and gas for markets, such as Europe, that might tax imports based on carbon performance. State oil and gas giant Gazprom has set a goal to reduce its greenhouse gas emissions substantially through energy savings, energy efficiency, and methane leakage monitoring in its operations. The company's energy savings and efficiency programme is slated to save 28.8 million tons of fuel equivalent from 2011 to 2020, reduce its own natural gas consumption in operations and limit greenhouse gas emissions by 48.6 million tons of $C0_2$ equivalent. Gazprom has also moved to increase the share of renewable energy in its power generation mix to include more renewables, such as geothermal, wind, solar and thermoelectric generators. Gazprom is also expanding Russia's natural gas vehicle market by investing in more compressed natural gas filling stations.

5. Prospects and associated risks of asset stranding

Generally speaking, energy transition is considered decadal in nature. Brandt *et al.* (2013) suggest that energy efficiency improvements and alternative fuels in transport such as electricity won't be able to lower the requirements for conventional oil production and unconventional oil production until 2070. The International Energy Agency (IEA), which analyses possible scenarios for energy demand, suggests via its sustainable development scenario (SDS) that oil demand could peak earlier, around 2020, and then start to decline as oil use in the transportation sector begins to decline, should governments get very serious about climate policy (IEA, 2018). IEA's SDS scenario includes projections that electric vehicles will soar to close to one billion on the road by 2040 while about 20 per cent of trucks will feature low carbon fuels. Under the scenario, demand for oil for petrochemicals will continue to grow but at a slower pace than a business-as-usual reference case. In the SDS scenario, global oil use falls to 67 million b/d by 2040, down from 100 million b/d currently. Notably, oil use is not fully eliminated under the SDS scenario which is designed to align with a 1.5–2 degrees Celsius temperature increase compared to pre-industrial levels. The IEA SDS scenario assumes both strong government intervention and technological advance. Norwegian energy firm Equinor's 2 degrees C scenario posits that global oil demand could fall to 52 million b/d by 2050, compared to a business-as-usual outlook of 118 million b/d (Equinor, 2019).

Political scientists have noted that the combined forces of technological change, climate change policy, and proliferation of shale oil represent "an existential threat to the future of the fossil fuel system" with wide ranging implications (Van De Graaf and Bradshaw, 2018). Indeed, the possibility that a large portion of existing proven oil and gas reserves might become stranded raises important questions about the future economic and political stability of petro-dependent states. Risks could go beyond financial losses, creating new challenges like those emerging in capitals around the globe where citizens are dissatisfied with the capacity of current leaders and institutions to provide adequate basic public services and a sustainable future.

Western central banks and policy makers have focused on the risks stranded oil and gas assets might bring

to global financial markets. There is evidence that this risk is undervalued in financial markets. In the United States, looming financial risks from energy transition have already hit certain energy firms, including large coal mining companies, several of which have filed for bankruptcy in the last few years. But the longer lead time to the phase-out of oil-based fuels compared to coal, and the different structure of the oil industry, means that the eventual stranding of oil and gas reserves may hit sovereign national budgets harder than any interruption in exchange-traded equities and corporate credit markets. Oil and gas companies' share of the S&P 500 has shrunk considerably as oil exploration and production firms have underperformed financially compared to tech stocks and the overall stock market. Western oil and gas companies are starting to write down more assets, opening up the possibility that more rationalisation of value is likely to come. Large oil companies are also starting to diversify portfolios to include cleaner energy and carbon sequestration technology. To the extent that these kinds of activities gain pace, it could reduce the risk of a sudden cascading change in energy company valuations to overall market stability.

But the vast majority of assets that will be stranded are not in the hands of publicly traded major oil companies. Rather, it is sovereigns that control the vast spectrum of reserves that may never be produced. Thus, the problem of stranded asset risk may be most relevant in markets for sovereign credit and for overall geopolitical risk.

One key problem related to stranded asset risk is that elevated oil revenues that have historically supported government budgets will dry up over time, destabilising national institutions which in many petro-nations are already weakened. The World Bank, in a study that extended from 1980 to 2005, found Malaysia to be the only major petro-state that had adequately invested oil receipts to sustainably diversify its economy (World Bank, 2011). How countries manage any transition away from plentiful resource rents will be material to global stability. A number of oil producing countries are already experiencing economic distress and internal unrest even though global oil demand is currently robust. Thus, the potential vulnerability of these states to a more negative, long-run outlook for oil revenues still looms as a risk to global financial markets via sovereign debt, bond issuances and shrinking foreign reserves. The case of Venezuela's financial collapse, though *sui generis*, is a warning sign of what mismanagement of the challenges could spell.

In the International Monetary Fund's October 2019 *Global Financial Stability Report* entitled "Lower for Longer" it notes that state-owned enterprise debt represents a "significant portion" of total emerging market debt securities. The IMF report notes that emerging market oil and gas state enterprise (SOE) leverage has nearly doubled over the past fifteen years at the same time these same firms are experiencing a decline in profitability. The IMF report also states: "IMF staff analysis indicates a widening in spreads in major SOEs can spill over to sovereign spreads and these spillovers have been rising in recent years, in contrast to the spillovers from sovereigns to SOEs" (IMF, 2019). For countries that already suffer from high debt levels, a worsening credit position in light of stranded asset risk for oil and gas national flagships could result in a worsening fiscal position for sovereigns. IMF statistics for the Middle East, North Africa, Afghanistan and Pakistan region (MENAP), for example, indicate that oil exporters have already seen total government net debt rise from 3.3 per cent of GDP in 2016 to 12.7 per cent by 2018. Projections are for net government debt to reach 21.9 per cent in 2020. Gross external debt for MENAP oil producers is roughly 40 per cent of GDP.

Some individual state firms are already taking steps to reduce risks going forward. Some countries such as the United Arab Emirates and Saudi Arabia have begun preparing for the energy transition by creating forward-looking investment vehicles to diversify their economies away from high dependence on oil export revenues. One tool to achieve this diversification has been to privatise a portion of state oil businesses to gain more revenue for sovereign wealth funds. The fuel distribution unit of ADNOC launched an initial public offering (IPO) in December 2018 priced at $831 million. The much-hailed IPO of shares in Saudi Aramco is aimed to provide additional funding to the Public Investment Fund (PIF) of Saudi Arabia which has invested in firms such as Uber, Tesla, Lucid Motors, and augmented reality start-up Magic Leap. Notably, Saudi Arabia's PIF has launched a $1 billion initiative, called the Jada Initiative, that will create a new investment vehicle that will invest in venture capital and private equity funds to support start-up businesses and small to medium enterprises.

But for countries that fail to prepare, populations may find a harsher reality. In some cases, governments may resort to increased internal repression as existing patronage systems become less sustainable in coopting disparate political interests. As they come under increased pressure, the intensity of regional conflicts could subside as parties to disputes are constrained by loss of oil revenues (Gause, 2015). But there is also the possibility that petro-states will seek a substitute for the

waning influence previously established by their vast oil and gas reserves. It is unlikely that threats of oil cutoffs can serve as a diplomatic coercive lever over time as consuming states become less worried about energy supplies and more reliant on domestically produced renewables and energy saving digital technologies. One option petro-states will be tempted to take is to assert their geopolitical interests more directly with brute military power rather than suffer a decline in influence. Viewed through this lens, recent military buildups in the Middle East by Russia, and Iran's recent attacks on shipping and oil installations in the Persian Gulf, may take on deeper implications.

The hard truth is that many resource-dependent economies could come under stress in the coming decades, just as climate change increases the burden on governments to respond. Moreover, as the oil intensity of the global economy lessens, the opportunity for petro-states to amass fiscal surpluses will shrink over time, requiring economic reforms and restructuring that will be politically unpopular at home. External debt for several oil producing states is already on the rise. As Venezuela's crisis has deepened, its external debt has risen to over $156 billion, with faltering chances of servicing its obligations, according to the Institute of International Finance. Nigeria's national debt which stands at 20 per cent of GDP could take up a very high proportion of retained government revenue if oil prices recede. These cases are at the extreme end of the spectrum but highlight the need for other countries like Brazil, Colombia, Mexico, Algeria, and Iraq to take the hard steps of economic reforms now, while oil revenues are relatively stable, to prepare for a future that might look different from the past two decades of commodity growth. For international institutions, it is not too early to work with countries to prepare for adjusted expectations for the future, while mindful that populations are increasingly restive to the failure of governments to provide adequate services and job growth in the face of declining commodity outlooks, combined with a history of corruption and waste.

REFERENCES:

Bebbington, J., Schneider, T., Stevenson, L. and Fox, A. (2019), 'Fossil fuel reserves and resources reporting and unburnable carbon: investigating conflicting accounts', *Critical Perspectives on Accounting* (*forthcoming*).

Brandt, A.R., Millard-Ball, A., Ganser, M. and Gorelick, S.M. (2013), 'Peak oil demand: the role of fuel efficiency and alternative fuels in a global oil production decline', *Environmental Science and Technology*, 47(14), pp. 8031–41: DOI:101021/es401419t.

Dempsey, H. (2019), 'Why U.S. energy investors are experiencing a crisis of faith', *Financial Times*: https://www.ft.com/content/71655bca-c8c2-11e9-a1f4-3669401ba76f.

Elliott, R. (2019), 'Are oil-and-gas companies a good investment?', *Wall Street Journal*: https://www.wsj.com/articles/are-oil-and-gas-companies-a-good-investment-11574208302.

Energy Intelligence Group (2018), *Energy Intelligence Top 50: How the Firms Stack Up*.

Equinor Energy Perspectives 2019 (2019): https://www.equinor.com/en/how-and-why/energy-perspectives.html.

Fagnant, D. and Kockelman, K. (2014), 'The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios', T*ransportation Research Part C: Emerging Technologies*, 40, 1–13: https://doi.org/10.1016/j.trc2013.12.001.

Fulton, L. *et al.* (2019), 'Internal combustion engine bans and global oil use', Institute of Transportation Studies, working paper series: https://escholarship.org/uc/item/52j400b1.

Garfield, L. (2018), '13 cities that are starting to ban cars', *Business Insider*: http://www.businessinsider.com/cities-going-car-free-ban-2017-8.

Gause, III, F.G. (2015), 'Sultans of swing? The geopolitics of falling oil prices', *Policy Brief*, Brookings: https://www.brookings.edu/wp-content/uploads/2016/06/Falling-Oil-Prices-English.pdf.

Gehrke, S.R., Felix, A. and Reardon, T. (2018), *Fare Choices: A survey of ride-hailing Passengers in Metro Boston*, Metropolitan Area Planning Council, Report 1: https://www.mapc.org/farechoices/.

Gore, A. and Blood, D. (2013), 'The coming carbon asset bubble', *Wall Street Journal*: https://www.wsj.com/articles/the-coming-carbon-asset-bubblethe-coming-carbon-asset-bubble-1383076555.

Greenblatt, J.B. and Saxena, S. (2015), 'Autonomous taxis could greatly reduce greenhouse-gas emissions of U.S. light-duty vehicles', *Nature Climate Change*, 5, pp. 860–3: DOI:10.1038/nclimate2685.

Griffin, P.A., Jaffe, A.M., Lont, D.H. and Dominguez-Faus, R. (2015), 'Science and the stock market: investors' recognition of unburnable carbon', *Energy Economics*, 52, pp. 1–12.

IEA (2018), *World Energy Outlook 2019*, Paris, France: International Energy Agency: https://www.iea.org/weo2018/fuels/.

Innovation Center for Energy and Technology (iCET) (2019), *A Study On China's Timetable For Phasing-Out Traditional Ice-Vehicles*: http://nrdc.cn/Public/uploads/2019-05-24/5ce7931eb51b3.pdf.

International Monetary Fund (2019), *Lower for Longer, Global Financial Stability Report*, October, International Monetary Fund, https://www.elibrary.imf.org/view/IMF082/26206-9781498324021/26206-9781498324021/26206-9781498324021.xml?redirect=true.

Jaffe, A.M. (2019a), *The Tech Enabled Future*, Council on Foreign Relations: https://www.cfr.org/report/tech-enabled-energy-future.

—(2019b), 'Amid political uncertainties, Venezuela's oil industry situation worsens', *Energy Realpolitik*, Council on Foreign Relations: https://www.cfr.org/blog/amid-political-uncertainties-venezuelas-oil-industry-situation-worsens.

Kim, D. *et al.* (2018), *Energy and Air Quality Impacts of Truck-Only Lanes: A Case Study of Interstate 75 Between Macon and McDonough, Georgia*, National Center for Sustainable Transportation and Georgia Institute of Technology: https://escholarship.org/content/qt56m5b78f/qt56m5b78f.pdf.

Lee, J. (2019), 'Why Vladimir Putin suddenly believes in global warming', *Bloomberg Opinion*: https://www.bloomberg.com/opinion/articles/2019-09-29/climate-change-russia-s-oil-and-gas-heartlands-are-under-threat.

Lenferna, G.A. (2017), 'Can we equitably manage the end of the

fossil fuel era?', *Energy Research and Social Science*, 35, pp. 217–23: https://doi.org/10.1016/j.erss.2017.11.007.
Masnadi, M.S. *et al.* (2018), 'Global carbon intensity of crude oil production', *Science*, 361, 6405, pp. 851–3.
Mathers, J. (2013), 'Is online shopping better for the environment?', *Environmental Defense Fund*: http://business.edf.org/blog/2013/12/21/is-online-shopping-better-for-the-environment.
McGlade, C. and Ekins, P. (2015), 'The geographical distribution of fossil fuels unused when limiting global warming to 2 degrees C', *Nature*, 517, (7533), pp. 187–90: doi: 10.1038/nature14016.
Meinshausen, M., Meinshausen, N., Hare, W., Raper, S.C.B., Frieler, K., Knutti, R., Frame, D.J. and Allen, M.R. (2009), 'Greenhouse-gas emission targets for limiting global warming to 2 degrees C', *Nature*, 458 (7242), pp. 1158–63: doi: 10.1038/nature08017.
Meyer, N., Brinker, L. *et al.* (2015), *Deflating the 'Carbon Bubble*', IHS Markit: https://ihsmarkit.com/research-analysis/q22-deflating-the-carbon-bubble.html.
Milne, R. (2019), 'Norway resists growing environmental pressure over oil', *Financial Times*: https://www.ft.com/content/0666ec58-218c-11ea-b8a1-584213ee7b2b.
Nelson, R. (1993), *National Innovation Systems*, Oxford University Press.
Ogden, J. (2019), 'Climate change impacts on critical U.S. energy infrastructure', *Climate Risk to the Energy System*, Council on Foreign Relations (September), pp. 32–43.
OPEC, (2018), *Annual Statistical Bulletin*: https://www.opec.org/opec_web/en/data_graphs/330.htm.
Osmundsen, P. *et al.* (2006), 'Valuation of international oil companies', *The Energy Journal*, 27 (3), pp. 49–64.
Paun, A. *et al.* (2015), 'Stranded assets: what next?', London, UK: HSBC Bank Global Research, https://www.research.hsbc.com/midas/Res/RDV?p=pdf&key=myvAGZ6YRG&n=456399.PDF.
Parkinson, G. (2015), 'Citigroup predicts $100 trillion in standard assets if Paris summit succeeds', *CleanTechnica*: https://cleantechnica.com/2015/08/26/citigroup-predicts-100-trillion-in-stranded-assets-if-paris-summit-succeeds/.
Plotz, P., Axsen, J., Funke, S.A. and Gnann, T. (2019), 'Designing car bans for sustainable transportation', *Nature Sustainability*, 2, pp. 534–6: doi:10.1038/s41893-019-0328-9 https://www.nature.com/articles/s41893-019-0328-9.
Rainforth, L. *et al.*, (2019), *Rewarding Low Carbon*, Barclays Equity Research.
Shaheen, S. (2018), *Shared Mobility: The Potential of Ride Hailing and Pooling*, Berkeley, CA: University of California, Transportation Sustainability Research Center: https://escholarship.org/uc/item/46p6n2sk.
Shojaeddini, E., Naimoli, S., Ladislaw, S. and Bazilian, M. (2019), 'Oil and gas company strategies regarding the energy transition', *Progress in Energy*, 1 012001.
Silver, N. (2016), 'Blindness to risk: why institutional investors ignore the risk of stranded assets', *Journal of Sustainable Finance and Investment*, 7, 1, pp. 1–13: doi: 10.1080/20430795.2016.1207996.
Star-Advertiser (2019), 'Kauai electricity customers face rolling blackouts; utility urges energy conservation', *Star Advertiser*: https://www.staradvertiser.com/2019/07/21/hawaii-news/fault-at-kauai-power-station-causes-island-wide-blackout/.
Stevens, P. (2016), *The International Oil Companies: The Death of the Old Business Model*, Chatham House: https://www.chathamhouse.org/sites/default/files/publications/research/2016-05-05-international-oil-companies-stevens.pdf.
The Economist (2016), 'How to deal with worries about stranded assets', *The Economist*: https://www.economist.com/special-report/2016/11/24/how-to-deal-with-worries-about-stranded-assets.
Tooze, A. (2019), 'Why central banks need to step up on global warming', *Foreign Policy*: https://foreignpolicy.com/2019/07/20/why-central-banks-need-to-step-up-on-global-warming/.
Van De Graaf, T. and Bradshaw, M. (2018), 'Stranded wealth: rethinking the politics of oil in an age of abundance', *International Affairs*, 94, 6, pp.1309–28: doi: 10.1093/ia/iiy197.
Verhoef, L.A. *et al.* (2018), 'The effect of additive manufacturing on global energy demand: an assessment using a bottom-up approach', *Energy Policy*, 112, pp. 349–60: doi: 10.1016/j.enpol.2017.10.034.
Wadud, Z. *et al.* (2016), 'Help or hindrance? The travel energy and carbon impacts of highly automated vehicles', *Transport Research Part A: Policy and Practice*, 86, pp. 1–18: https://doi.org/10.1016/j.tra.2015.12.001.
World Bank (2011), *The Changing Wealth of Nations: Measuring Sustainable Development in the New Millennium*.