Introduction

Producing and consuming energy resources often come with consequences for other resources. Oil and natural gas are no different. For example, once an oil well has been drilled, water is generally injected into the reservoir (water flooding), to build up pressure in the reservoir and to stimulate the production of oil. To transport natural gas by pipeline, land has to be cleared, with consequences for local flora and fauna. Finally, as widely documented and acknowledged by close to 200 national governments in the Paris Agreement that was signed in December 2015, the consumption (burning) of fossil fuels, including oil and natural gas, results in greenhouse gas emissions, including carbon, which is widely acknowledged as a key contributor to climate change.

One of the most, and possibly the most, impactful developments in global energy markets in the last two decades has been the advance of so-called unconventional technologies to extract oil and natural gas from different types of rock with low permeability. Commencing in the early 2000s for natural gas, and just before 2010 for oil, analysts are still grappling with the long-term economic, geopolitical, and environmental consequences of this phenomenon. In addition, it seems only a matter of time before unconventional production will further spread globally. Next to the US, which has largely served as the global unconventional oil and gas laboratory, commercial production of natural gas from shale now takes place in China, Canada, and Argentina, with more countries to follow.

Unconventional oil and gas production has not come without controversy. Next to more general but increasingly vocal opposition to fossil-fuel production and consumption, several environmental concerns continue to be linked explicitly to so-called hydraulic fracturing, or ‘fracking’, of shale and other tight reservoirs. These include increased seismic activity, methane leakage, water contamination and land degradation. While initial reports were alarming, by now, a broad body of literature has emerged, which allows us to present a more nuanced and fact-based view of these concerns. Oil sands, previously known as ‘tar sands’, involve techniques such as surface mining and steam-assisted drainage which involve substantial water consumption, risk of water pollution, significant greenhouse gas emissions and, in the case of mining, land disturbance.

This chapter focuses on the linkages between oil and natural gas production on the one hand, and water, land and air quality on the other. It also contains a brief discussion of other debates surrounding unconventional oil and gas production, but in line with this book, the emphasis is on the nexus between various resources. Our analysis is based on primary and secondary data. We
both spent a substantial amount of time researching unconventional oil and gas in various parts of the world, predominantly in North America, Europe, and Asia. This chapter does not include new data, but provides an overview of existing research, following our own publications, and available literature. We focus on places where unconventional oil and gas extraction actually take place, or where at least attempts have been made, but draw mainly on shale gas as this has recently become the most widely practiced, and contentious form. We provide several broad conclusions about unconventional oil and gas and the resource nexus, and initial suggestions for future synergies.

Unconventional oil and gas production and the resource nexus

The term “unconventional” as applied to oil and gas production is rather misleading because what has been classified as unconventional has now become or is becoming conventional. In broad terms, the oil or gas in a conventional field has been created by heat and pressure in an organic-rich source rock, and then migrated to a porous and permeable reservoir rock where it has become trapped in a geological structure. Conventional oil and gas production involves drilling a well into the reservoir and allowing the oil or gas to flow to the surface under natural geological pressure. The oil industry has developed several techniques over the last few decades that can enhance flow rates or improve recovery of the hydrocarbons. These include pumping water, chemicals or gas into the reservoir, hydraulic fracturing of the reservoir to improve permeability and horizontal drilling. By themselves, these techniques are today regarded as conventional, though sometimes referred to as ‘enhanced oil recovery (EOR)’. The key characteristic that is common for all unconventional oil and gas accumulations is that the rock which hosts the hydrocarbon has very low permeability. Therefore, what today are called ‘unconventional’ oil and gas accumulations cannot be easily or economically produced by the techniques described above, at least not when such techniques are deployed in isolation. Instead, commercial production requires either a combination of these techniques or the deployment of new techniques.

Several different types of unconventional oil and gas accumulations can be recognized (Table 25.1), yet fall into two distinct categories. In one category lie those accumulations in which the hydrocarbon has remained in its original source rock (indicated by “S” in Table 25.1). The production of shale gas and tight oil shale generally requires a sophisticated combination of horizontal drilling and hydraulic fracturing with the use of chemical or gas stimulants, as well as other techniques such as measurement-while-drilling and down-hole seismic. It is this approach that has led to the unconventional oil and gas revolutions in North America. Coal-bed methane is another case where natural gas remains in its original source rock, but the use of horizontal drilling and hydraulic fracturing are optional techniques. The distinctive feature of coal-bed methane production is the need to drain massive amounts of water from the coal in order to release the methane. In the case of oil shale, the organic material remains in the form of kerogen and requires heating to convert the kerogen into oil. The normal procedure is to mine the shale and then process it, though in situ processes are being tested.

Tight gas and extra heavy oil are examples of unconventional hydrocarbons that have migrated from their source rock to a reservoir rock. However, production through conventional techniques is not viable because flow rates are too low. In the case of tight gas this is due to the low permeability of the reservoir rock, a problem that is overcome through a combination of horizontal drilling and hydraulic fracturing, as with shale gas and tight shale oil. In contrast, the low flow rates from oil sands arise from the heavy and viscous nature of the oil that may even occur as solid bitumen. Production has normally involved surface mining of the oil sands followed by heating to extract the oil and upgrading by adding lighter oils. More recently, companies have been deploying in situ heating by steam-assisted drainage.
Table 25.1 Key technical attributes of main types of unconventional gas and oil

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horizontal drilling</td>
</tr>
<tr>
<td>Gas</td>
<td></td>
</tr>
<tr>
<td>Coal-bed methane</td>
<td>Coal (†)</td>
</tr>
<tr>
<td>Shale gas</td>
<td>Shale (†)</td>
</tr>
<tr>
<td>Tight gas</td>
<td>Sandstone, limestone</td>
</tr>
<tr>
<td>Gas hydrates</td>
<td>Deep ocean sediment, permafrost</td>
</tr>
<tr>
<td>Oil</td>
<td></td>
</tr>
<tr>
<td>Tight shale oil</td>
<td>Shale (†)</td>
</tr>
<tr>
<td>Extra heavy oil</td>
<td>Sandstone</td>
</tr>
<tr>
<td>Oil shale</td>
<td>Shale (†)</td>
</tr>
</tbody>
</table>

†: Source rock
‡: Technique normally deployed
*: Technique optional
–: Technique not normally deployed

Table 25.2 Key alleged potential negative nexus impacts arising from the extraction of the main types of unconventional gas and oil

<table>
<thead>
<tr>
<th>Water</th>
<th>Land</th>
<th>Atmosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Consumption</td>
<td>Contamination</td>
</tr>
<tr>
<td>Gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal-bed methane</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>Shale gas</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Tight gas</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Gas hydrates</td>
<td>-</td>
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</tr>
<tr>
<td>Oil</td>
<td></td>
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<tr>
<td>Tight shale oil</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Extra heavy oil</td>
<td>X</td>
<td>XX</td>
</tr>
<tr>
<td>Oil shale</td>
<td>X</td>
<td>XX</td>
</tr>
</tbody>
</table>

X: Moderate probability of measurable impact if best practice is not followed
XX: Significant probability of measurable impact if best practice is not followed

A final form of unconventional hydrocarbon takes the form of methane hydrate that occurs in vast quantities on the deep ocean floor as well as in permafrost. The methane originates from deep geological sources as well as from shallow biogenic processes. Production is still at the experimental phase. Potential techniques to release methane from the hydrate include depressurizing the reservoir, and injecting chemicals, inert gases, hot water or steam. The main nexus risks are associated with the catastrophic release of large volumes of methane into the atmosphere.

The deployment of these unconventional techniques raises the possibility of measurable or significant negative impacts on other resources in the nexus in comparison with conventional techniques, especially if best practices are not followed and the most advanced techniques are not deployed. Table 25.2 summarizes, in a simplified form, the potential negative impacts arising...
Unconventional oil and gas production

from the production of each form of unconventional hydrocarbon, and shows the connections to water, land, and the atmosphere, as well as seismicity.

Prevailing debates anno 2017

Taking a birds-eye perspective, academic discussions related to unconventional oil and gas extraction have greatly evolved, but are still similar compared to those made a number of years ago. New literature continues to emerge on several environmental concerns that have been linked to (aspects of) hydraulic fracturing. We discuss contemporary debates on these issues in this chapter. It is important to note that unconventional oil and gas extraction is still a relatively new phenomenon, and therefore many questions have not yet been answered in full. We emphasize this because all too often analysts and policymakers are tempted to take firm stances on what the future will bring, albeit regarding future commercial production, or the spread of this technology beyond North America. The truth is that all too often we do not really know and time, and practice, must tell. However, we do observe that in the US the tone of the debate about the benefits and costs of hydraulic fracturing is changing. This has most markedly been demonstrated by the decision of the NY state legislature to ban hydraulic fracturing by law (which is significant as it prohibits industrial activity in a part of the most productive shale gas play in the country, the Marcellus Shale). In addition, in the period prior to the November 8, 2016, elections, several presidential candidates took a tough stance against unconventional oil and gas extraction, the most outspoken one being Senator Sanders, who proposed to ban fracking altogether. We did not expect that to happen, nor do we think it will happen going forward, given that an estimated 60% of all natural gas produced in the country now comes from shale. The Senator did force his opponent, Secretary Clinton, to shift gears as well. Furthermore, several events over the course of recent years, such as the Aliso Canyon methane leak in California and the final confirmation that fracking indeed caused water pollution in Pavillion, Wyoming, and continued resistance against expansion of natural gas infrastructure in New England, have not improved natural gas’s image. After November 8, President Trump has, in line with the occasional broad statement made during his campaign, reiterated his ambition to further expand domestic fossil-fuel production, including natural gas and oil. The president is widely believed to incentivize incremental production by lowering regulatory burdens where possible. There is reason to be skeptical whether regulation has under the previous administration in fact curtailed domestic oil and gas production. Instead, it is more likely that prices, albeit domestic or international, incentivize US oil and gas production. In addition, major uncertainties remain whether possible trade restrictions could harm domestic energy producers, rather than support them. At the time of writing, it is too early to proclaim anything about future energy and climate policy in the US with an amount of certainty.

In contrast, efforts to exploit shale gas continue unabated in China, despite the more challenging geological conditions. Companies are also pressing ahead in Argentina. In the UK, initial enthusiasm for shale gas exploration was constrained by public opposition and consequent inability of the companies to obtain permission from local governments. This situation was relieved in May 2016 when the county council of north Yorkshire gave permission for the hydraulic fracturing of a well drilled in 2013, yet public opposition continues to be fierce, making it difficult to predict with certainty whether commercial shale gas production will occur in the UK.

Next to the scholarly literature, and a significant increase of available data, we also observe clear learning curves regarding (at least some) regulatory approaches and/or industry practices to address environmental concerns. To give an example, the amount of wastewater that is recycled has increased substantially, and in most states, discharging wastewater to surface water is not
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allowed. Jackson et al. (2014) report that prior to 2011 only 13% of wastewater in the Marcellus Shale was recycled, but that by 2011 this was the case for 56% of the wastewater. In 2013 this number had grown to 67% of all the water used in oil and gas extraction (Harkness et al., 2014).

The other form of unconventional hydrocarbon that has attracted a lot of criticism is the extra heavy oil that is exploited in Alberta, western Canada. In the past this has involved open cast mining, and extensive use of water and heat. Although production of these oil sands dates back to the 1960s, a combination of high oil prices and technological advances led to a surge in both production and development plans from the early 2000s. These heavy oils now dominate Canada’s crude oil production, and output continued to rise through 2015 despite declining oil prices. Alleged and actual negative consequences include physical land disturbance, pollution of land, water and air, greenhouse gas emissions, as well as consequences for human health and biodiversity (Gosselin et al., 2010; Gordon, 2012; Paskey et al., 2013).

Other prevailing debates regarding unconventional oil and gas extraction focus on economic impacts, albeit local impacts or broader energy market impacts, and geopolitical ripple effects. Although longer term consequences remain the topic of substantial debate, the US has become the world’s largest producer of natural gas, and consequently is set to become one of the world’s major exporters of natural gas (as a result of expanded pipeline capacity to Mexico, and increasingly significant liquefaction capacity that will impact the market in coming years). Increased natural gas production in 2008/2009 contributed to a broader pattern of global oversupply, which had substantial impacts on pricing structures in the more liquid parts of the European gas market (e.g. Boersma, 2015). In the coming years because of a wave of new liquefaction capacity, particularly in Australia and the US, there will be knock-on effects on global markets, and contribute to what can be labelled the coming of age of global LNG markets (Boersma and Losz, 2017). In the US, very competitive natural gas has made major market inroads. As we discuss in more detail later, in electricity generation natural gas has trumped coal in the merit order, leading to significant carbon and other GHG emissions reductions. We have also witnessed some increased demand for major industrial processes that use natural gas as a feedstock. As investments in gas-fired electricity generation capacity continue, and natural gas is increasingly becoming an interesting feedstock for parts of the transportation sector, US policymakers are facing questions how to square large-scale investments in natural gas with long-term scenarios of deep decarbonization (Boersma, 2016).

In the following sections, we return to the resource nexus, and discuss the most profound environmental concerns, the state of the academic literature, industry practices and regulatory lessons, before we draw conclusions.

Water

Risks to water resources in the literature broadly fall into four categories: (1) contamination of shallow aquifers with fugitive hydrocarbon gases; (2) contamination of surface water and shallow groundwater from spills, leaks, and/or the disposal of inadequately treated wastewater; (3) accumulation of toxic elements in soil or stream sediments near disposal or spill sites; and (4) the over usage of water in areas where water is scarce (Vengosh et al., 2014).

Stray gas contamination mostly happens due to improperly constructed or failing gas wells, but the extent to which this is problematic continues to be debated. Jackson et al. (2014) give detailed descriptions of the importance of wellbore integrity and cite several studies where degraded wellbore integrity contributed to groundwater contamination through fugitive methane. Other studies however found no statistically significant relationship between dissolved methane concentrations in groundwater from domestic water wells and proximity to
pre-existing oil and gas wells (Siegel et al., 2015). Earlier analyses have found that casing failures in Pennsylvania between 2010 and 2013 comprised 3% to 6% of total production in the first three years of well life (Ingraffea et al., 2014). Other studies report that the failure rate may be substantially higher, and up to 12% within the first year of operation (Hildenbrand et al., 2015). Although their analysis of 550 groundwater samples from the Barnett Shale in Texas detected numerous volatile organic compounds in aquifers above the Barnett Shale, this did not necessarily implicate unconventional oil and gas extraction as the source of contamination. Notably, Rahm et al. (2015) found that shale gas development entails more risk related to spills and solid waste management, while conventional gas development entails more risk associated with cementing and casing issues, and site restoration. They observe that conventional and typically older gas wells in their case study in Pennsylvania, were perhaps less environmentally protected, thus drawing less regulatory scrutiny.

Wastewater produced during hydraulic fracturing operations includes flowback water, which returns to the surface immediately after fracturing the well, and produced water, which is brought to the surface during oil and gas production. The balance of flowback and produced water across the Marcellus in Pennsylvania in 2011 was 43% flowback and 45% produced water (Jackson et al., 2014). Rough estimates show that each unconventional shale gas well produces between 3500 and 7200 m$^3$ of wastewater during its lifetime (Harkness et al., 2014). The total annual volume of oil and gas wastewater for Pennsylvania in 2011 and 2012 was estimated between 3000 and 5000 million liters of water (Ibid.). In most states, wastewater is injected in deep saline aquifers after treatment. In states where injection in aquifers is not possible, like Pennsylvania, wastewater is increasingly recycled and then reused, or in some instances treated in municipal treatment plants, and then discharged. Even though in most states wastewater management is regulated, risks remain, particularly from spills, and inadequate treatment. Harkness et al. (2014) in their study of three treatment plants in Pennsylvania found that wastewater release to the environment is associated with significant levels of iodide and ammonium. They recommend that the issue of adequate treatment of wastewater, and tight controls on discharging and leak prevention, is particularly important in countries where deep-well injection is not allowed, such as China and the EU. Jackson et al. (2014) report a number of studies which mention surface leaks and spills from well pads and wastewater holding ponds, as well as inadequate treatment before wastewater discharge.

In parts of the US, and many other parts of the world, water availability can be a (growing) concern. As Jackson et al. (2014) illustrate, context is helpful in interpreting water usage by the oil and gas industry. In Texas, for example, a state with rather intensive drilling, the total amount of water used for hydraulic fracturing on an annual basis is less than 1% of total usage. However, on the local level these numbers may change dramatically, with several counties in the Barnett Shale region in Texas for instance reporting that up to 30% of their annual water use goes to the oil and gas industry. In some cases, this has resulted in competition between the energy industry and the agricultural sector (which in the case of Texas historically holds most of the water rights). The flipside is that as the costs of water rights in some instances increased, so did the incentive for the industry to develop alternative fluids for use in hydraulic fracturing, for instance liquids, or brackish groundwater (which is too saline to use for agricultural activity, or human consumption). As these technologies are increasingly refined and applied, their costs decrease, making them potentially more attractive for application in other countries in the world like China, South Africa, and Algeria (see for instance Vengosh et al., 2014; Boersma et al., 2015). This is to date one of the best examples where nexus challenges have incentivized industry to develop alternatives and create synergies, moving beyond trade-offs for resource usage. It remains to be seen whether, absent financial incentives, industry will be incentivized to apply these practices on a larger scale.
China’s quest for shale gas faces both of these challenges, and in an accentuated form (Enoe et al., 2012; Gunningham, 2014). The most favorable geological conditions appear to lie in Sichuan province and the neighboring municipality of Chongqing. This region is home to more than 100 million people, about 50% of whom live in rural areas with intensive agriculture. Any significant contamination of surface or near-surface waters could undermine agricultural productivity and local livelihoods. Further, although Sichuan has historically been blessed with abundant rainfall, recent years have seen occasional dramatic droughts (Krupnick et al., 2014). Many of the other prospective areas for shale gas in China lie in the far north and northwest of the country, regions already suffering from drought.

Aforementioned risks related to water resources can be substantial, but it is important to note that all can be dealt with using existing technologies under proper regulations. Avoiding stray gas contamination for instance could be enforced by installing safe zones between new shale gas sites and already existing drinking water wells. In addition, to increase transparency regarding naturally occurring methane in water resources vis-à-vis contamination, baseline monitoring could be considered. Disclosure of the content of fracking fluids and chemicals used in operations is also preferable. Regarding wastewater, not allowing discharge without proper treatment is advisable, but discharge cannot always be prevented, surely in cases where injection of wastewater into saline aquifers may induce seismicity (see the subsection ‘Seismicity’).

We now turn to the risks of greenhouse gas emissions that have been linked to unconventional oil and gas extraction.

Greenhouse gas emissions

The effects of unconventional oil and gas in terms of greenhouse gas emissions is decidedly a mixed bag. On the one hand, energy resource extraction is an industrial process, which comes with air pollutants throughout the production and transportation process. At the same time, replacing coal with natural gas for electricity generation has had a downward effect on emissions of several pollutants.

As Jackson et al. (2014) describe, GHG emissions typically occur throughout the shale gas supply chain, from preparing a well pad, installing processing facilities and compressor stations. Then once drilling starts, wastewater is stored in open-pit tanks on site, from which other GHG emissions can flow. Then during the processing of natural gas, vapors may flow into the air, and in the case of oil production in some instances methane is flared, or even vented. The EPA estimates that 58% of methane leakage occurs during field production (leakage from the wells, gathering pipelines, or gas treatment facilities).

Howarth et al. (2011) published a study suggesting that fugitive methane leakage from shale gas wells (between 3.6 and 7.9%) was substantially higher than conventional gas wells (between 1.6 and 7.0%). As a result, they concluded that the carbon footprint of shale was potentially comparable to that of coal. Since then several studies have emerged that have questioned the data used in this paper, and by now it is safe to conclude that shale gas has not fundamentally altered the carbon footprint of the gas industry (Cathless et al., 2012; O’Sullivan and Paltsev, 2012; Heath et al., 2014; Levi, 2015). One reason for this is the increased application of green completions technologies, and increased availability of infrastructure in places where the primary focus is on crude oil production (but a lot of associated gas is produced). In addition, the EPA started regulating emissions from new wells starting January 2015, and rules for existing wells are expected in the future.

Addressing midstream and downstream emissions has proven to be more difficult. One reason may be that leaks are complicated to measure, and data can therefore be incomplete (Boersma
Unconventional oil and gas production

and Ebinger, 2014; Larsen et al., 2015). However, detailed studies at the US city level provide worrisome data, with methane emissions often substantially higher than local authorities believe (McKain et al., 2014). There can be several reasons for this, such as inadequate access to emissions, inadequate measuring, and higher-than-expected leak levels from aging pipeline systems, in particular in major urban areas. None of these arguments however should prevent serious thinking and action about how to reduce methane emissions from midstream and downstream gas systems. In many cases that would likely mean major investment in new pipeline systems. Logically, it would in turn mean that household rates are going up, but it is worth keeping in mind that someone is paying for that fugitive methane as well, and that is the customer. Cost arguments come on top of arguments over air quality (ozone formation), climate change, jobs creation, and overall safety.

On the upside, the US has experienced significant overall carbon emissions reductions, and these were partly the result of fuel switching in the electricity sector. It is unrealistic to point to a singular reason for this drop in emissions. Instead, a mix of factors is more likely, including the economic downturn, increased energy efficiency standards and continued investments in renewable energy, particularly solar and wind (due to federal tax breaks and renewable portfolio standards at the state level). Yet natural gas undeniably played an important role in this drop in carbon emissions as well, which according to the US Energy Information Administration in 2015 reached the lowest level since 1993, and was 21% below the 2005 level (the baseline used in the US pledge for Paris). Next to carbon emissions, burning natural gas in comparison to coal comes with significantly less emissions of other GHGs, such as SO₂, H₂S, and NOₓ and particulates, and thus in some places improves local air quality (Jackson et al., 2014).

The central argument that continues to fuel lively debate in the US is whether natural gas can indeed play the role of bridge fuel, as proponents like to claim. Though some have disputed this, as touched upon before, the reality seems to be that natural gas already is a bridge fuel, based on the very significant investments that have been made, and the fact that 60% of current domestic natural gas production comes from shale rock layers. The more relevant question seems to be what actions are required now to reconcile the expansion of the share of natural gas with the goal of deep decarbonization in 2030 and beyond (Boersma, 2016). Initial studies suggest that natural gas helps to reduce carbon emissions, but that additional targeted climate policies are required to drive down emissions substantially after that initial bump provided by fuel switching (Newell and Raimi, 2014; McJeon et al., 2014). Continued uncertainties about actual methane emissions throughout the supply chain (see e.g. Omara et al., 2016) further underline the need for continued empirical analysis of GHG emissions related to shale gas extraction, and the need to further curtail emissions where possible.

In the medium to long term, technologies like carbon capture and sequestration for gas-fired power plants seem a necessity if countries are to reach levels of what is often called deep decarbonization. Although the focus of this chapter is on unconventional oil and natural gas, it is important to note that the continued cost reduction for some renewable technologies, in particular solar photovoltaics and onshore wind, make these options increasingly attractive for investments in new electricity generation capacity. This does erode the possible market share for fossil fuels in electricity generation, even though it will take decades to make a transition in which renewables comprise the majority of the global fuel mix, especially as long as fossil fuel prices remain relatively low, and negative externalities are not adequately priced. In addition, it is worth considering that in most discussions about renewable energy, little if any time is spent contemplating that resources like oil and natural gas are used in a wide variety of applications, including industrial processes, cooking and heating, and transportation.

Two other forms of unconventional hydrocarbon deserve mention in the context of greenhouse gas emissions. The energy needed to exploit oil sands necessarily involves incremental
production of greenhouse gas emissions, notably carbon dioxide, and these emissions are generally greater for in situ recovery than for surface mining. However, technological progress has led to a steady decline in emissions per unit of oil produced (Gosselin et al., 2010). In the case of methane hydrates, the potential emissions arise not from the extraction process itself but from the accidental and catastrophic release of methane from these giant accumulations during production. This could cause catastrophic instability in overlying marine sediments as well as the release of a powerful greenhouse gas into the atmosphere (Khameneh et al., 2012).

Land degradation and societal disturbance

Another environmental aspect of shale gas extraction is land-use changes from production processes. Cumulative risks of clearing existing land cover can be significant, most notably during the site identification and preparation phase and during production. In addition to direct effects on land usage, indirect effects (such as clearing for gas infrastructure construction, intensive truck usage for water transportation, and noise pollution) can be substantial as well.

Jenner and Lamadrid (2013) concluded that in Pennsylvania a range between 34,000 and 82,000 acres of land could be cleared for shale gas production (see also Jantz et al., 2014). They suggest that shale gas extraction turns large areas into industrial zones, creating brownfields that presumably will be left to localities to deal with when producers leave. Pierre et al. (2015) in their study of landscape impacts of oil and gas extraction in La Salle County in Texas, concluded that the disturbance from infrastructure development (3% of the county area) decreased the available core areas by almost three times the area of disturbance, with effects for habitats and local wildlife. Similarly, Moran et al. (2015) in their measurement of land-use changes within the Fayetteville Shale gas region in Arkansas between 2001/2002 and 2012 conclude that considering the large number of wells drilled in other parts of the country, shale gas development will likely have substantial negative effects on forested habitats and organisms that depend upon them.

Land disturbance is much greater when the hydrocarbon is extracted through surface mining, as has been the case for the oil sands in Alberta for decades. Although land reclamation has taken place and continue, the companies struggle to keep up with the pace of disturbance (Gosselin et al., 2010) and, in some places, there are serious conflicts of interest with indigenous Canadian communities (Paskey et al., 2013).

Seismicity

In recent years, scientists have learned more about possible linkages between unconventional oil and gas production and seismic activity, or induced seismicity. Various anthropogenic applications (such as dam impoundment, mining, and wastewater disposal) have long been known to, in some circumstances, potentially accelerate seismic activity (Schultz et al., 2015). USGS data demonstrate that in the period between 1973 and 2008, on average 21 earthquakes with a magnitude of 3 and larger took place annually in the central and eastern US. In the period from 2009 until 2013 this number jumped to 99 earthquakes of the same magnitude or larger and this number reportedly continues to rise.4

Studies have focused predominantly not on hydraulic fracturing itself, but the reinjection of flowback water, a very common practice in unconventional oil and gas producing regions in the US. The most important conclusion, however, is that there are several major unanswered questions. For instance, Keranen et al. (2013) studied the impacts of wastewater injection and their links to induced seismic activity in Oklahoma. Their research suggests that time delays can
exist between the start of injection and induced seismicity, as it may take time for pressure at the fault to build up. Rosen (2015) reports that the rate of fluid injection into the well, rather than other factors such as volumes of fluids or depth of injection, may play a more prominent role. Next to injection of flowback water, hydraulic fracturing itself in rare circumstances has also been linked to induced seismicity, though mostly these tremors cannot be felt (e.g. Jackson et al., 2014; Schultz et al., 2015). A widely reported case is that of Blackpool in the UK, where in 2011 two relatively small earth tremors halted the emerging unconventional gas industry in its tracks, and operations were suspended for over one year. Hereafter a traffic light system was introduced which the state of Oklahoma also adopted. Essentially, it means that earth tremors are monitored and the regulator can summon operators to stop their activities if considered necessary. It is important to keep in mind though that examples of seismic activity that are attributable to hydraulic fracturing and wastewater injection are small in comparison to other anthropogenic triggers such as mining and dam impoundment (Jackson et al., 2014, p. 345).

Conclusions

From this analysis, we derive the following lessons. Similar with more conventional extraction processes for oil and natural gas, relatively new technologies or a combination of existing technologies (often labelled unconventional oil and gas extraction) can have major consequences for other resources. This is particularly the case when best practices are not applied. As we have shown, price incentives often stimulate companies to further refine extraction techniques. In parts of Texas where (access to) water resources are relatively scarce, and water rights therefore increasingly expensive, the industry developed alternatives to freshwater to be used in fracking fluids, such as brackish water, or gels. We also observe that at least a substantial number of oil and gas companies are concerned with their corporate image in an age where fossil-fuel production is under public scrutiny, adopting best practices as a result. Other behavior has been enforced by regulations, such as the traffic light system monitoring seismic activity in Oklahoma. Thus, we observe that over the course of the last decade, both industry and regulatory authorities cross the board have gone through a steep learning curve, and many important lessons were learned.

However, that is not the full story. As described, several unconventional techniques, such as oil sands production, come with substantial trade-offs. Extracting oil through a process that involves surface mining comes with significant land disturbance, and GHG emissions. To counter negative externalities like these, production processes must be regulated, and more accurately priced than we often do today. Another solution that a part of the environmental lobby proposes is to leave the resource in the ground. The reality seems to be that it will likely take decades before we phase out fossil fuels, and therefore a more pragmatic approach in the short and medium term appears useful. As we described, unconventional oil and gas has only just begun to expand globally, and we expect more countries to follow suit. Applying best practices in both technology and governance are therefore the way forward.

Although unconventional hydrocarbons are seen as playing a negative role in the resources nexus, an important geographic feature distinguishes them from conventional hydrocarbon accumulations; namely, that many accumulations of unconventional hydrocarbons occur in areas with limited reserves of conventional hydrocarbons. Consequently, countries that have long relied on coal for the bulk of their energy supply may have an opportunity to replace a proportion of the coal supply with unconventional gas. If managed well, this would in the short and medium term reduce carbon emissions, land degradation, and pollution of water and air. In some cases, unconventional gas could also increase access to modern energy. China, India, South Africa and Poland are examples of countries with potentially large unconventional gas resources,
but all of them face geological, technological and regulatory obstacles to realizing this opportunity. Each case requires coordinated policy analysis across the relevant resources to decide if the short-term benefits outweigh the long-term costs.

Notes

References


