Report

Can fracking green China’s growth?

Opportunities, risks and recommendations for unconventional gas in China’s environmental transformation

Ilmi Granoff, Sam Pickard, Julian Doczi, Roger Calow,
Zhenbo Hou and Vanessa D’Alançon

April 2015

Overseas Development Institute
203 Blackfriars Road
London SE1 8NJ

Tel. +44 (0) 20 7922 0300
Fax. +44 (0) 20 7922 0399
E-mail: info@odi.org.uk

www.odi.org
www.odi.org/facebook
www.odi.org/twitter

Cover photo: Shell: Checking gas detectors at Changbei, China.

Contents

List of tables, figures and boxes

Tables

Figures

Boxes

Acronyms

API	American Petroleum Institute
ARI	Advanced Resources International
ASrIA	Association for Sustainable and Responsible Investment in Asia
Bcm	Billion Cubic Metres
BCOGC	BC Oil & Gas Commission
BIFF	Britain & Ireland Frack Free
BJMEMC	Beijing Municipal Environmental Monitoring Centre
BP	British Petroleum
CAAC	Clean Air Alliance of China
CCGT	Combined-Cycle Gas Turbine
CCP	Chinese Communist Party
CCS	Carbon Capture and Storage
CH_4	Methane
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
COP	Conference of the Parties
CTI	Carbon Tracker Initiative
DOE	US Department of Energy
DSIRE	Database of State Incentives for Renewables & Efficiency
EDF	Environmental Defense Fund
EDSAP	Energy Development Strategy Action Plan
EIA	Energy Information Administration
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EPB	Environmental Protection Bureau
FAO	Food and Agricultural Organization
FYP	Five-Year Plan
GAO	Government Accountability Office
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GNI	Gross National Income
Gt	Gigatonne
GW	Gigawatt
Hg	Mercury
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPE	Institute of Public and Environmental Affairs
kWhe	Kilowatt Hours
LNG	Liquefied Natural Gas
MD	Measured Depth
MEP	PRC Ministry of Environmental Protection
MLR	Ministry of Land and Resources
Mt	Megatonne
MWR	Ministry of Water Resources
NBS	National Bureau of Statistics
NDRC	National Development and Reform Commission
NEA	National Energy Administration
NETL	National Energy Technology Laboratory
NGCC	Natural Gas Combined Cycle
NO_x	Nitrogen Oxide
NRDC	Natural Resources Defense Council
NSPS	New Source Performance Standards
OECD	Organisation for Economic Co-operation and Development
PM	Particulate Matter
PRC	People's Republic of China
REC	Reduced Emission Completion
RPS	Renewable Portfolio Standard
RSC	Regional Supervision Centre
SNG	Synthetic Natural Gas
SO_x	Suphur Oxide
SPE	Society of Petroleum Engineers International
tcf	Trillion Cubic Feet
TVD	True Vertical Depth
TWh	Terawatt Hour
UK	United Kingdom
UN	United Nations
UNEP	UN Environment Programme
UNFCCC	UN Framework Convention on Climate Change
US	United States
VOC	Volatile Organic Compound
WHO	World Health Organization
WRI	World Resources Institute

Acknowledgements

This report draws on research and contributions from across the Overseas Development Institute (ODI) and was made possible as the result of an Accountable Grant from the UK Department for International Development (DFID). We are grateful to all those who contributed to and commented on the draft of this report, including Andrew Norton, Tom Mitchell, Caroline Haywood, Nat Mason, and Hanna Alder. We are particularly grateful to our peer reviewers, Alvin Lin and Briana Mordick from the Natural Resources Defense Council and Jeffrey Logan and Ella Zhou from the National Renewable Energy Laboratory for their copious and invaluable recommendations. Further thanks go to Mr Jiaofeng Guo of the Development Research Centre of the State Council, Matthew McFeeley, Fuqiang Yang and Amy Mall from the Natural Resources Defense Council, Jenna Brown of the University of West England, Heather Payne, Center for Law, Environment, Adaptation, and Resources (CLEAR) at the University of North Carolina School of Law, and Alex Kazaglis of the UK Committee on Climate Change for insightful guidance. Responsibility for the content of the report rests solely with the authors.

Executive Summary

Following decades of unconstrained growth in which protection of the environment took a distant second place to economic development, environmental objectives are gaining much greater prominence in China. The country has set itself the goal of becoming an 'ecological civilisation', against a background of serious and well-documented air, water and soil pollution and an international reputation tarnished as the world's largest emitter of greenhouse gases (GHG). Its energy sector is at the heart of its transformation towards sustainability. Greening China's growth necessitates that it dramatically reduces the air, water, land and climate impacts of its development path and energy mix.

China is estimated to have the world's largest technically recoverable shale gas reserves. While coal and renewable energy stand on obvious ends of the spectrum from environmentally 'brown' to 'green', the potential for natural gas to facilitate a green transition is a highly polarised question. This is all the more true for unconventional sources like shale gas and tight gas, which require hydraulic fracturing ('fracking') for their production to be economic. Proponents highlight the materially lower air and GHG pollution from gas-fired energy when compared with coal and the flexibility of gas-fired power to support an energy grid dominated by renewable energy. Detractors suggest the climate impacts of methane leakage, water consumption and pollution, and local and land use impacts from fracking outweigh any purported environmental benefits.

This paper analyses whether shale gas, and by implication other unconventional sources, can materially improve the quality and sustainability of China's economic growth. We take a measured, empirical approach, analysing the best available technical, scientific and engineering literature on the risks and opportunities posed, and also analysing what policy environment could maximise the opportunity and minimise the risk. We then turn our attention to China's current policies and practice to understand whether the conditions for greener growth are in place. Although the technical analysis considers China in particular (such as its available water resource estimates), much of the analysis in Sections 1-4 would be relevant to any country with a nascent shale gas industry.

We conclude that many of the environmental risks shale gas poses are manageable, and amenable to conventional environmental law and policy tools. Its development could in principle offer significant net environmental benefits if the gas produced permanently replaces coal and helps set China on a pathway to a renewable-dominated energy system. The greater impediment is political, hinging on whether China has the political will and capacity to dramatically cap coal generation, invest in renewable energy and enforce strong environmental regulations and targets. An increasing portion of Chinese policymakers in Beijing indicate seriousness about a transition towards an ecological civilisation and the desire to balance the trade-offs in greening China's growth, but the political impediments between theoretical and practical green growth should not be underestimated. We therefore emerge from our analysis with a healthy dose of scepticism about unconventional gas greening China's growth: truly making it work requires a broader set of practical commitments to sustainability, pollution control and low-carbon energy.

This paper is aimed at those who are interested in China's green energy transition, and the scope and limitations for unconventional gas in that transition. We hope it will be of interest to policy decision-makers and advocacy groups, financial and legal specialists interested in the developing industry and its associated risks, technical specialists wanting to better understand the Chinese context and those with an interest in energy transitions in the world's largest energy consumer. Our analysis of the environmental impacts of the developing industry and subsequent findings are split between implications for air and climate (Section 2) and for water resources (Section 3) and local and land use impacts (Section 4). This is followed by an analysis of current policy progress (Section 5) and a conclusion and recap of recommendations (Section 6).

Ensuring shale gas reduces air and GHG pollution

Substituting coal with shale gas in the energy system can realise significant net reductions of emissions of GHGs and air pollutants. Permanent, effective substitution will rely mainly on bigger questions of climate and energy policy, rather than the market effects of expansionist gas policy alone. To achieve lasting and significant emissions reductions, shale gas must be constrained by an overarching energy transition that initially supports gas generation to permanently replace unabated coal but ultimately yields to a system where truly low-carbon energy sources dominate.

To serve as a bridge fuel, it must be both a bridge away from coal and towards renewable energy, initially requiring exploitation of the opportunity shale presents to aggressively and permanently limit the role of coal in the energy mix. This will require policies that prevent coal from simply being inventoried or exported for use later or elsewhere. Renewables expansion may need to be insulated from short- and medium-term competition with gas-fired developments; ultimately, gas capacity will be expected to serve as idle back-up (‘firming’) capacity in a renewables-dominated system.

Methane leakage from shale gas production significantly diminishes the GHG benefit of a fuel switch from coal to gas, but it is a risk that is manageable by available and affordable technology. This will not, however, address any systematic leakage risk in China’s wider gas transmission and distribution network. While this may be an equally important climate policy challenge, it is a problem not unique to unconventional gas, thus beyond this paper’s scope. Also beyond our scope is the concern that the technology for gas production may also be used for shale oil development: a corollary increase in oil supply would have none of the potential for pollution reduction of an increase in gas supply.

Understanding and managing shale’s water impacts

The biggest water management risks from shale gas development arise from contamination of large volumes of water in the fracking process, which can in turn contaminate other water bodies. As with other extractive industries, the challenge is made more difficult because treatment and management of such water can be costly, creating pressure to discharge it in surface waters or deep underground.

Other water resource risks will depend on the local environmental context and the regulations and incentives in place to understand and manage its risks. The need for a large volume of water over short periods of time means opportunity costs can be high in circumstances where peak withdrawals coincide with other demands. However, water demands are typically modest compared with total resource availability at national, regional and even basin levels and are comparable with the demands of other industries, including coal. However, the proportion of water lost to further use may be higher since contaminated water, if discharged, can diminish the availability of other water bodies for economic uses.

To control water-related risks, China will need to bring shale gas development under its increasingly extensive environmental regime. This will involve the monitoring and control of water withdrawals, effective treatment and/or reuse of contaminated water to prevent pollution and land use controls that limit exposure to risk of populations and ecosystems. Although China’s environmental performance has improved significantly over the past decade, major obstacles remain. Both the system of cadre evaluation against environmental targets and conventional regulatory control through line agencies will need to be strengthened to avoid or mitigate problems, particularly for pollution.

Handling impacts and trade-offs for land use and local populations

Developing a shale gas industry also creates a number of more localised environmental risks: air, noise and light pollution; land erosion and compaction; and increased seismicity, particularly where wastewater is re-injected for disposal. These may substitute for worse harms at the site of coal mining production, making the aggregate impact smaller, but this has little significance for the scope of local impacts except where these alternatives are at the same site. Further, proliferation of wellheads across a landscape can result in bigger aggregate impacts.

Any sensible gas development strategy will moderate local impacts. Of course, any sensible environmental governance regime should have environmental management requirements to allow regulators to review the geological and technical aspects of the site and permit on the basis of specific impacts. Above and beyond standard environmental management measures, three traditional land use planning tools in particular may facilitate better local environmental management and improve on early-stage shale gas policy in the US: land use planning, compact siting and introduction of public disclosure and participation. Most industrial activities are locally noxious even when well-managed, but even locally noxious land uses may sometimes be desirable in the context of larger environmental protection and management. Land use planning that clusters extractive operations, and sites them away from vulnerable populations and environments, can be an effective practice for environmental management. Clustering of well siting also offers significant opportunities to reduce the regulatory burden stringent environmental governance poses.

Given the potential harms to and trade-offs for local communities, decision-making for siting should involve their material participation, transparent explanations of the likely trade-offs and a respected system to monitor and evaluate the potential impact of any harms arising. Such approaches to noxious land uses are a common component of environmental law and policy, but a patchwork of state-level approaches in the US has led to poor local environmental protection, resulting in significant backlash against the industry. China has the opportunity to do better from the outset.

Creating and enforcing a robust policy framework

A substantial body of evidence suggests the Chinese leadership is keen to reshape the country’s energy sector. This is reflected in its most recent national target-setting, the principal public policy tool through which it pursues its development strategy and translates central government objectives into subnational action. It has identified a number of targets that are relevant to managing climate, air and water risks related to shale gas development.

With respect to the energy and climate targets and policy, the government has sent mixed signals regarding whether it is taking a strategy that will harness shale as a bridge fuel. While it has established explicit coal caps for energy generation, it continues to pursue expansion of coal production. Renewable energy capacity development is ambitious, but may not reflect the full potential of a renewable-dominated grid that harnessing gas-fired power may offer.

Meanwhile, subnational governments' pursuit of urban air pollution targets risks driving the development of coal-to-gas projects that will reduce such pollution but worsen climate pollution.

No industry-specific regulatory regime has yet been developed in China. However, the broader environmental governance system – including cadre performance targets and the regulatory framework – continues to evolve and strengthen. It remains to be seen whether these tools will be applied to an emerging and strategically important shale gas industry.

Progress to date has been achieved largely through a performance appraisal system for leading cadres that has elevated environmental goals to 'hard targets'. The system has leverage because of China's vast bureaucracy (more than 40 million members strong), and the fact that a significant amount of pollution and energy consumption is directly within the control of government and corporate leaders subject to cadre evaluation. This system has advanced a number of new environmental hard targets related to climate change and air pollution, and could in principle advance environment performance on further issues like methane leakage, water quality and water management. The system, however, generates many perverse outcomes, and leads to widespread manipulation or falsification of information and, in the absence of meaningful public scrutiny, a culture of cover-up and secrecy over sensitive issues. Further, both the system of cadre evaluation and conventional environmental regulation can still be distorted by imperatives such as energy security; the risk is that shale gas development may be exempted from the checks and balances applied to less 'strategic' industries. In summary, China has the ability to regulate the industry and mitigate or avoid many of its environmental risks, but not necessarily the willingness to apply controls that might be perceived as slowing its development and undermining strategic goals.

While commitments at the top of the ruling party lend cautious optimism to the fact that China is intensely concerned with greening growth towards an ecological civilisation, translating central government commitment into national and subnational environmental governance is a formidable challenge. In addition to considering the dichotomy between governance at the national and local levels, and the opportunities for performance evaluation to improve performance, we make a number of recommendations specifically relating to extracting the greatest net benefits from the development of its shale gas industry.

Many readers will wish us to conclude shale gas is either an environmental boon or bane. We have avoided such a conclusion, as we do not believe it reflects the nature of China's choice. The feasibility of gas development occurring as part of a green transition will instead depend on China being able to utilise it as a bridge fuel and seriously prioritising management of water pollution risks and water resource management. A series of recommendations for opportunities to improve the shale gas industry's green growth potential are noted in Table 5, divided into those actions that are relatively easy and those that are important but that will be challenging to implement.

1. Introduction: China's push towards an ecological civilisation

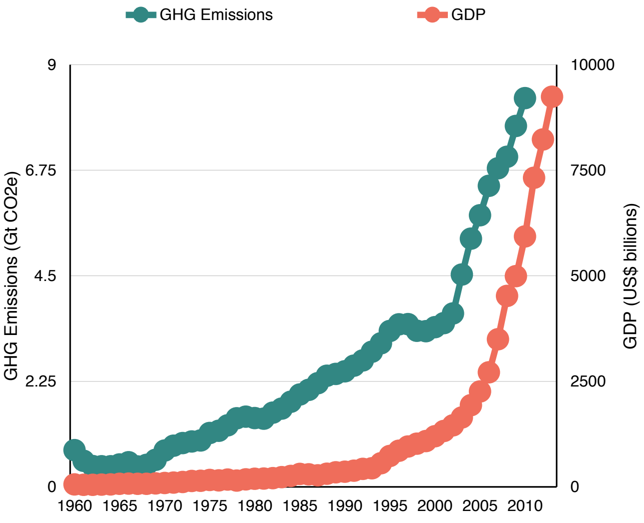
1.1 China confronting the need for greener growth

China's policymakers have recently begun to confront the environmental costs of unconstrained growth to seek a more sustainable development model. The report of the 18th National Congress of the Communist Party calls for the development of an 'ecological civilisation' – a pathway towards greener growth with distinctly Chinese social, political, economic characteristics (Kai, 2013).

Much of the attention to date, both domestically and internationally, has been on air pollution. And, rightly so, as air pollution from fossil fuel combustion is a major public concern, estimated to cost the economy some 10% of gross domestic product (GDP) (Global Commission on the Economy and Climate, 2014). But air pollution should be understood as symptomatic of a larger set of pollution challenges, including pollution affecting climate, air, water and soil. China is the largest emitter of greenhouse gases (GHGs). A total of 30% of decadal river water samples taken in 2012 from 10 of China's major basins were classified as 'heavily polluted' (MEP, 2012). Urban groundwater sampling found 60% of tested wells were polluted (Kaiman, 2014), while a recent government report found 16% of the country's soil was contaminated (MEP, 2014a). Collectively, the costs of environmental degradation and resource depletion amount to roughly 9% of gross national income (GNI), more than 10 times higher than corresponding levels in Korea and Japan (World Bank, 2014).

Improving the quality of economic growth implies improving some or all of these environmental metrics. And, as income levels rise, people are demanding improvements. Growing discontent with 'growth at all costs' development has not gone unnoticed at the highest levels of the Chinese Communist Party (CCP). In March 2014, Premier Li Keqiang announced a 'war on pollution', vowing to move away from the current 'model of inefficient and blind development' (Bloomberg, 2014). Such announcements have been accompanied with substantive shifts in the performance of local officials, the 'cadre evaluation system', that some regard as the primary driver of policy outcomes including environmental performance (Wang, 2013).

Figure 1: Historic correlation and growth of China's economy and emissions, 1960-2010



Source: World Bank (2014).

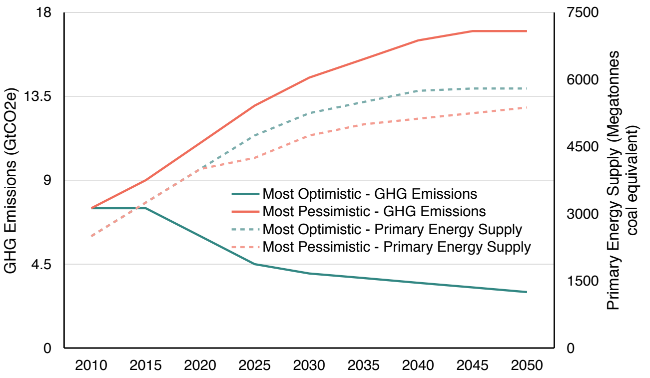
Many of China's pollution challenges come to a head in the energy sector. Although China's growth has historically been fossil-fuelled – creating a host of environmental and human health impacts – Chinese policymakers have expressed a desire to break the link between emissions of air and climate pollution and economic growth.[1] Accordingly, the Chinese government has committed to a number of climate and air pollution-related 'hard' targets in the 2011-2015 12th Five-Year Plan (FYP12),[2] and to a GHG emissions peak (at an unknown level) by 2030 (Taylor and Branigan, 2014), showing this is also now a political goal. Debates as to how China's energy portfolio will change in coming years vary significantly. This is illustrated by the range between the 'most

---

[1] For example, an explicit target in Five-Year Plan (FYP12) is to decrease China's energy and CO_2 intensity.

[2] **See English translation at:** http://www.britishchamber.cn/content/chinas-twelfth-five-year-plan-2011-2015-full-english-version

Figure 2: NDRC's optimistic and pessimistic energy and GHG scenarios



Source: Inferred from data in China 2050 Pathways Development Group (2014).

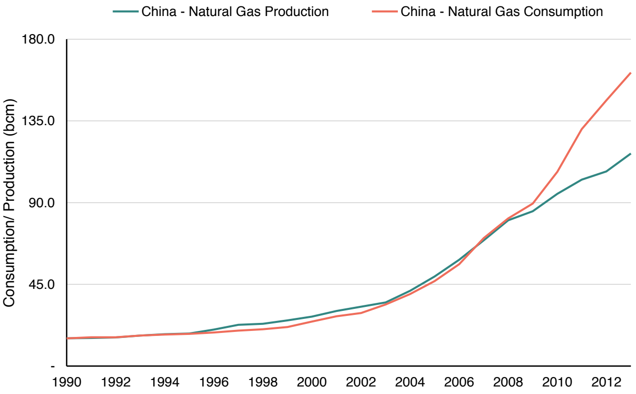
optimistic' and 'most pessimistic' scenarios identified by the Energy Research Institute of the National Development and Reform Commission (NDRC), shown in Figure 2. However, there is wide agreement that, for China to improve its air quality, it will need to reduce its reliance on unabated coal (as shown by the recent declaration to limit coal use by 2020) using low- and lower-carbon alternatives to make up the shortfall in supply.

1.2 Unconventional gas in the energy transition

1.2.1 Natural gas is a growing part of China's energy sector

Consumption of natural gas has grown six-fold in China since 2000 as energy demand has increased and as, within the energy sector, the demand for cleaner fuel options has also grown. Supply matched demand until 2008, when growth in production began to tail off and China started importing gas (Figure 3). Projected demand for natural gas and a desire to improve the country's energy security have led China to promote domestic production and agree to long-term deals on pipeline imports (see Section 5.2.1 for more details). Most of China's current production comes from conventional and tight gas reserves, although there is a strong desire to exploit its vast unconventional shale gas resources to reduce dependence on international markets.

Figure 3: Growth in China's natural gas consumption and production, 1990 to the present



Source: BP (2014).

1.2.2 China is estimated to have the largest global shale resources

China is estimated to have the largest technically recoverable shale gas resources in the world (1115 tcf), in addition to the third-largest shale oil reserves (32 billion barrels) (EIA and ARI, 2013).[3] To put this in context, these unproven gas resources are approximately nine times larger than China's proven conventional gas resources (124 tcf) (ibid.).[4] China is keen to develop shale gas: it is a domestically abundant fuel that is cleaner-burning than coal. China's 12th Five Year Plan identified shale gas as a policy priority and sets out to 'promote and accelerate the exploration and utilisation of shale gas and other types of unconventional gas and oil resources' (PRC, 2013b). This is purported to aim at increasing sources of natural gas supply, easing the pressure on domestic natural gas supply, improving energy consumption, domestic energy structure and reducing carbon footprints.

In the 13th Five Year Plan (2016-2020), shale gas production in China is expected to reach 30 bcm by 2020 – this represents 15% of total natural gas consumption in the country. Within the 30 bcm production target set for 2020, 25 bcm is set to come from Sichuan Province and its neighbouring areas alone.

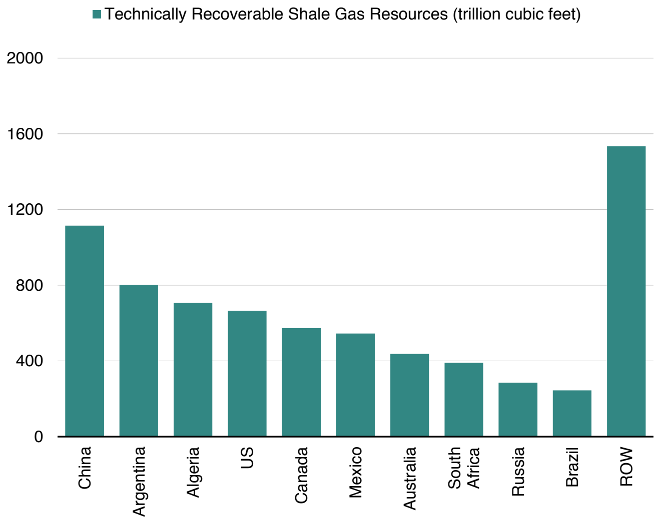
The majority of China's shale gas production in 2015 will come from the two largest state owned enterprises: about 4 bcm and 1.5 bcm from Sinopec and CNPC respectively. With another 0.1 bcm from other companies, the total production of shale gas in China for 2015 is expected to be just above 5.5 bcm (PRC, 2013b).

---

[3] The Energy Information Administration's (EIA's) 2013 estimates are recognised as based on very limited available data, although they remain the most significant global attempt to estimate technically recoverable reserves. Because China's shale resources have not been fully explored, the data used in the assessment are incomplete and further exploration should decrease associated uncertainty. However, the report highlights China's large potential for development.

[4] See SPE (1997) for clarity on the differences between proven and unproven resources.

Figure 4: The world's technically recoverable shale gas reserves



Source: EIA (2013c).

What the falling oil price means for shale gas

Global crude oil prices have fallen in mid-2014 from more than $100 to $50-60 a barrel. There is evidence that these lower prices have been a factor slowing the rate of shale gas production in China (Hornby, 2015). However, it should be remembered that the global decline in oil prices has been brought about in large part by the glut of oil and gas reserves, itself caused by shale development in the US (*The Economist*, 2014). Even shorter-term impacts of over-production highlight the relevance of unconventional gas in the future of the energy mix, and warrant deeper analysis of the industry. At most, current prices are creating a pause in shale's development that may give Chinese policy-makers a chance to catch up to the rapid growth rate that has characterised the industry to date. This reinforces the value of a timely, deeper policy analysis of shale gas's role in China's greener growth.

1.2.3 Chinese unconventional gas production is likely to remain substantial through the medium term

Early shale gas annual production targets of 60-100 bcm indicated the major potential contribution of unconventional production to China's supply (Reuters, 2014). However, in 2014, the government revised its earlier targets down to the current target of 30 bcm per year by 2020, citing technical obstacles. Some have suggested this signifies that the development of China's unconventional gas is stalling. We disagree. It is important to view these shale gas targets alongside those for other unconventional sources: tight gas[5] and coalbed methane. Production of unconventional sources, when assessed together, is likely to be at least as large as the earlier shale gas targets of 60-100 bcm/y by 2020. For example, while shale gas estimates for 2020 were being revised down, independent analysis of tight gas production suggested this resource would grow from its current 30 bcm to 80 bcm/y by 2020 (Chen, 2013). Tight gas is therefore likely to make up a large portion of the 185 bcm government target for total gas production by 2020 (ibid.). In addition, coalbed methane is also targeted to reach annual production of 30 bcm by 2020, according to the recently released Energy Development Strategy Action Plan (EDSAP) (2014-2020) (PRC, 2014).

We view the development of these smaller, but more easily accessed, tight gas reserves as a stepping stone towards the development of China's far vaster, but more difficult to access, shale gas reserves. The government is currently focused on comprehensive surveying of reserves, commercialisation of the industry, and development of core technologies and equipment to ensure accelerated development of shale gas industry between 2020 and 2030 (China Shale Gas Net, 2015).

From an environmental perspective, extraction of tight gas, like shale gas, typically involves hydraulic fracturing.[6] Coalbed methane extraction may also involve hydraulic fracturing in some cases, along with other specific processes, such as dewatering of coalbeds. Although each of these bear some materially different production methods, they also carry most of the significant risks that are related to hydraulic fracturing which this paper discusses at length, such as methane leakage, water diversion and contamination, and further local impacts,. Thus, the scale of environmental risks, trade-offs and opportunities in China in the coming years is at least as great as that of the earlier shale gas targets.

This paper discusses the environmental implications of the development of shale gas, but many, if not all, of them apply equally to the development of other unconventional gas resources, and particularly tight gas.

1.2.4 The implications of shale gas are clouded by polarised debate in the US

Despite global distribution of shale resources, most development has occurred in North America, where the industry has grown at a staggering rate over the past

---

[5] Government targets do not separate out tight gas targets specifically. We therefore conclude China considers it part of its 'conventional' reserves for policymaking purposes (e.g. PRC, 2014). Because of the unconventional nature of production, including fracking, we and other authors refer to it as an unconventional source (see Shell, 2014).

[6] In the case of tight gas, the target formation is not source rock but a more traditional reservoir rock, like sandstone or limestone, but with low porosity and permeability.

decade. Although direct comparison between the US and China has limitations, the US experience is the best source of data when attempting to understand how China's (or any other nation's) shale gas industry may develop.

Shale gas has transformed the US energy sector in recent years. This transformation has provided a number of economic benefits, including significant reductions in the domestic price of energy (and therefore electricity), reduced present and planned dependence on imports (for oil and gas, respectively) and associated balance of payments gains.

Perspectives on the environmental implications of shale gas are particularly polarised, though. The US example shows natural gas has the potential to replace coal in the energy system. Proponents of its development point to reductions in GHG emissions due, in part, to substitution of coal for cleaner-burning gas in the US power system (e.g. Trambath, 2013). They also note that natural gas-fired power generation produces less air pollution than coal-fired generation.

Proponents also observe that the flexible nature of natural gas-fired generation can support the expansion of renewable energy by providing dispatchable capacity to 'firm' the electricity grid to account for the variable generation of some renewables (Bazilian et al., 2014).

Shale gas's detractors suggest the environmental impacts of fracking outweigh any environmental benefits. A widely made criticism is that the leakage of methane (a considerably more potent GHG than CO_2) offsets the benefit of a switch from coal to gas, and in some cases may even lead to higher GHG emissions (e.g. Howarth et al., 2011). Detractors also fear shale gas production will simply delay the transition to truly low-carbon energy generation, and a switch from coal to gas will result in a pyrrhic victory as we further lock our economies into a combustion-based, high emissions energy system that is incompatible with climate change goals (e.g. Broderick et al., 2011).

Detractors also point to the intensive water demands of hydraulic fracturing, and the contamination of water that means reuse is impossible or very expensive. Water is typically mixed with chemical additives and used over a very short period of time. Particularly in areas where water is scarce and competition for water is growing, opportunity costs can be high. Considerable concern about the risk of wastewater, or the gas itself, leaking into existing water sources has also been raised.

These concerns, combined with local land use issues associated with the trucking of water and waste, the 'footprint' of proliferating wellheads and the risk of inducing seismic activity, have created strong opposition to shale gas production.

1.3 Understanding the risks of shale gas in China is important for China and the world

Setting out the evidence in a balanced way is key for China, given the potential growth of the industry and the impact of its energy system. China continues to rely on coal to service its massive and growing energy demand, with consequences to climate, air, water and land. Gas may have the potential to facilitate a faster transition to a lower-carbon, more environmentally sustainable energy system. However, interrogating the US experience suggests rapid, poorly regulated development of the industry could undermine these benefits and create other harms.

Most of the differences between the Chinese and US context relate to the structure and nature of the government and economy, which affect everything from how wells are sited and regulated to how new generation capacity is priced. However, it is worth noting that the development of China's shale reserves also engenders a more complicated technological endeavour: most of the resource is deeper underground and in formations that are less amenable to clean and safe extraction than US formations. Understanding these differences in geology and mode of operation is important to highlight the limitations of transposing the US experience to potential development in China.

Better insight into how the technology has developed in the US, the risks and benefits involved and how China's situation differs, allows regulators some appreciation of the challenges that lay ahead if they are to ensure the development of shale gas really does allow China to foster greener growth.

1.4 Structure of the analysis

This paper aims to provide a clear analysis for those interested in understanding the potential for shale gas to make China's energy sector, and thus its continued growth, greener than may have otherwise been the case. To develop this analysis, we provide a rigorous review of the evidence for the main environmental impacts associated with shale gas development: impacts on climate, air, and water, as well as those the land use and other impacts local to shale gas wells.[7] A number of studies have carried out similar rigorous analyses in the US context, and others have assessed some of the environmental aspects in a China-specific context. However, the novelty of this paper is two-fold.

We first provide a systematic analysis of the potential impacts in a Chinese context, using the most up-to-date science. We consider, on the basis of this science, the environmental impacts, risks and benefits associated with shale production and consumption. Then, having established the range of impacts that might occur, we draw on regulatory and policy experience from the US to suggest recommendations on how to oversee the industry to ensure the least negative environmental impacts ensue and to

---

[7] These three distinct categories have been decided on by synthesising analysis in the US (DOE, 2014a; Jenner and Lamadrid, 2013) and, where available, in China (Farah and Tremolada, 2013).

maximise the environmental opportunities shale gas may present.

This paper does not aim to provide a roadmap for shale gas development or a gap analysis of knowledge. Instead, it aims to provide a science-based assessment of the environmental risks and opportunities, and to provide practical advice for policymakers and regulators on how they might develop a shale gas industry that sets China on a path to greener growth. In so doing, we seriously consider the proposition that shale gas could theoretically bring about 'greener growth' (if not some ideal of 'green growth'), but aim to identify the policy circumstances that would move China from theory to practice. Noting the aims of our paper, we assume some basic prior knowledge of shale gas production methods, in particular of hydraulic fracturing and horizontal drilling.[8]

A note on data confidence

Our conclusions in this piece are based on an analysis of the best available data which could be sourced from desktop research. We are, however, acutely aware that much of the polarisation surrounding the shale gas industry in the US is buoyed by a lack of data availability with highly conflicting measurements being discussed at all levels.

At one end of the scale, proponents for the shale gas industry cite industry-sourced data that typically highlight the best-performing examples of technology and practices used in shale gas development. Indeed, the majority of publicly available data has been, often voluntarily, provided by shale gas operators. Given the usual reticence of such companies to divulge data, this has raised suggestions of potential bias in reporting that we are unable to quantify or counter directly. Conversely, opponents of the industry typically use ambient atmospheric measurements to infer the characteristics of the worst-performing sites. Both groups then tend to scale their results from a handful of points up to the wider industry, creating significantly different outcomes and conclusions on the relative merits and harms associated with the industry. In this first wave of US shale development, federal and state regulators have failed to collect and report, or ensure companies collect and report, accurate and complete data. It is therefore impossible to accurately describe the situation which has developed in the US, but it is likely that the true environmental impacts of the industry lie somewhere between the extremes, as a number of academic and governmental analyses have suggested.

To make accurate, even if not precise, assessments, we have been forced to judge the most representative data to inform our analysis. Wherever possible, we have tended to favour the most recent, independent, meta-analyses of primary data that have undergone rigorous scientific review (see for example, our analysis of methane leakage in Section 2.1.3). Where such analysis is not available – as is often the case for any China-specific data – we have tended to describe the possible range of impacts based on similar available data, analysing best- and worst-case scenarios to question our conclusions of high, and low, impact. (see, for example, our analysis of the impact of water extraction detailed in the Annex).

In light of the paucity of characteristic data, and noting that the US situation will likely differ from that in China, we can only form conclusions that are the most likely, given the data we have been able to source. While we are confident in the conclusions we have drawn from the data and have attempted to engage in a precautionary principle, overcoming this frustrating data deadlock between proponents and detractors is key to rigorously analysing the environmental impact of China's shale gas industry as it develops. For this reason, one of the key recommendations of this paper is for China to enforce strong data collection and disclosure requirements from the outset.

---

[8] For those unfamiliar with the shale gas production process, the following sites provide a detailed and more high-level description, respectively: http://fracfocus.org/hydraulic-fracturing-how-it-works/hydraulic-fracturing-process and http://www.halliburton.com/public/projects/pubsdata/hydraulic_fracturing/fracturing_101.html#

2. Air and climate: ensuring shale gas has real benefits for air and greenhouse gas pollution

Summary: air and climate

Substituting coal with shale gas in the energy system can realise significant net reductions of GHG emissions and air pollutants. Permanent replacement, however, hinges on broader climate and energy policy decisions rather than the market effects of expansionist gas policy alone. To achieve lasting and significant emissions reductions, shale gas must be constrained by an overarching energy transition that initially supports shale gas to permanently replace unabated coal but that is ultimately dominated by truly low-carbon energy sources.

To serve as a bridge fuel, it must be both a 'bridge away' from coal and a 'bridge towards' renewable energy, which will require exploiting the opportunity shale gas presents to aggressively and permanently limit the role of coal in the energy mix. This will require policies that prevent coal from simply being inventoried or exported for use later or elsewhere. For shale gas to serve as a bridge towards renewable energies, renewables expansion will need to be insulated from competition with gas-fired developments, and, ultimately, gas will be expected to serve as idle back-up capacity in a renewables-dominated system.

Methane leakage, particular to shale gas, poses a material risk to the benefits of a fuel switch, but risks specific to fracking can be mitigated through available safeguards, particularly at the well completion stage. These will not, however, address any systematic leakage risk in China's larger gas system, which must also be addressed.

One of the foremost reasons for pressing ahead with the development of shale gas is that it may offer a method of delivering electricity while producing fewer emissions of GHGs and air pollutants than generation from coal-fired power plants.[9] This is particularly important in the wider context of international climate change mitigation efforts under the United Nations Framework Convention on Climate Change (UNFCCC). Under the Copenhagen Accord to the UNFCCC, the international community set a limit for global temperature rise to 2°C, and each country is required to reduce their national GHG emissions to achieve this goal. Under the Accord, China has committed to reduce its CO_2 emissions per unit of GDP by 40-45% from 2005 levels and use non-fossil fuels for about 15% of its energy under the Copenhagen Accord to the UNFCCC (NDRC, 2010).

The claim that shale gas may produce fewer GHG emissions than coal-fired electricity has been the subject of much argument, with published work supporting both sides of the argument. Our interrogation of the existing data concludes that, while risks exist, well-managed shale gas production and the resultant increase in gas supply can displace coal generation and lead to significant reductions in domestic GHG and air pollution in comparison with a coal-fired baseline.

While this provides some basis for optimism about the potential for shale gas to improve GHG emissions

---

[9] In this study, we focus solely on the opportunity for gas to replace thermal coal in China's electricity sector. While potential exists for substitution in other sectors, the higher thermal efficiency of natural gas combined cycle (NGCC) generation suggests the benefit here is greater than simply substituting coal with another heat source, as would be the case in many industrial situations (see, for example, the comparisons on a heat basis and electricity basis in Mackay and Stone, 2013). Despite this, we are acutely aware that both thermal and metallurgical coal-firing in other sectors must also be curtailed if China is to experience greener growth, but an analysis to define these sectors is beyond this project's scope. Such a scenario is well documented to have occurred in the US, where gas-fired generation undercut many coal-fired plants.

scenarios and urban air quality, the combined effect of technological potential and market forces from competitive gas prices alone is not sufficient to transition an energy system from coal to lower-carbon sources. In addition to the differences between the energy industry in China and that in the US, we also note that available technologies are not always those applied, and, while favourable market conditions may promote the expansion of gas generation, they do not necessarily keep coal in the ground permanently or pave the way for a low-carbon energy mix absent other conditions. To serve as a 'bridge away' from coal, development of unconventional gas must be complemented by other green growth policies if it is to serve as a fuel that permanently transitions an energy system away from coal.

Equally important, for unconventional gas to serve as 'bridge towards' a climate-compatible energy system, it must ultimately be replaced by even lower emissions technology in the decades that follow. Here, too, there is little evidence that available technologies and market forces alone will forge a pathway to a green energy system. Instead, an overarching policy and planning is required to ensure the development of shale gas supports the development of renewable energy sources in the medium term and yields to it in the longer term, rather than competing with and delaying the expansion of renewable energy generation. In a sense, the story of whether natural gas will benefit or harm the climate is less about gas policy itself and more about the broader framework of energy and climate policy context in which it operates.

2.1 Risks and opportunities: the climate and air impacts of shale gas

2.1.1 Using shale gas for power generation carries about half the climate impact of using coal

Independent rigorous investigations in the UK (MacKay and Stone, 2013) and the US (DOE, 2014b) conclude most of the GHGs emitted from fossil fuel-based energy production, including from unconventional gas sources, are emitted during combustion of the fuel at the energy or electricity generation stage, and that the lower CO_2 intensity and higher thermal efficiency of gas compared with coal results in lower total GHG emissions. The range for the UK study showed shale gas produces 37-63% of the GHGs produced by coal-firing.[10] These ranges are likely to be comparable to power plants in China. The central values for the US study found unconventional gas-fired production emitted 43% of the GHGs of coal.[11] These findings are in line with the vast majority of other well-accepted data (e.g. Sathaye et al., 2011), although they represent larger gains in switching between coal and shale gas than are shown in some studies that assume higher rates of methane leakage (e.g. Howarth et al., 2011). The following section discusses these higher leakage rates but they have been widely contested, with academic papers (Brandt et al., 2014; O'Sullivan and Paltsev, 2012), including the UK and US studies cited above, strongly suggesting they should be considered outliers.[12]

2.1.2 Substituting coal with gas is likely to bring net reductions in most air pollutants at the point of use

In addition to net reductions in GHG emissions, substituting coal with gas as the fuel for energy production significantly reduces the emissions of many air pollutants. Fossil fuels combustion produces a wide range of air pollutants, including oxides of sulphur (SO_x) and nitrogen (NO_x), and volatile organic compounds (VOCs), particulate matter (PM) and mercury (Hg). In China, ambient atmospheric concentrations of these pollutants often significantly exceed thresholds the World Health Organization (WHO) deems safe and are the major driving force behind China's desire to reduce urban coal consumption. Table 1 presents the range of emissions expected from coal- and gas-fired power plants used in electricity generation.[13] It shows that, for most of these pollutants, natural gas poses a significant air pollution reduction benefit, but may increase concentrations of non-methane VOCs (NMVOCs) at a local scale.

The difference in minimum and maximum NO_x, SO_2 and PM emissions from coal-fired plants indicates the availability of pollution control measures to improve the performance of coal capacity relative to what is currently installed. However, on their own, these measures alone appear to have been ineffective at solving the urban pollution crisis in China's largest cities, requiring action by the government to replace coal-fired generation with gas-fired power stations.[14] The impact of switching from coal- to gas-firing has the likely potential of decreasing pollution levels at the generation site, although an increase in gas-fired generation may also increase localised emissions of VOCs.

---

[10] Shale gas produced 423-525 gCO_2/kWhe with 837-1139 gCO_2/kWhe for coal-fired electricity.

[11] Using unconventional gas to generate electricity produced 488 gCO_2/kWhe compared with 1124 gCO_2/kWhe for coal-fired generation using current technology in the US.

[12] If nothing else, this combination of measurements of high leakage rates and the availability of technology that minimises leakage highlights the need for universal technological mandates.

[13] Again, we focus on electricity generation for comparison, although natural gas can be used for other forms of energy generation, such as household thermal energy needs.

[14] For example, Beijing has targeted replacing all of its coal-fired power generation with gas-fired options by 2020 and aims to limit emissions from coal to 10Mt-CO_2 by then(People's Daily, 2014; Shanghai Daily, 2015)

2.1.3 Methane leakage may erode the comparative benefit of shale gas-based energy generation over coal

The release of a leaked cubic metre of methane to the atmosphere exerts a global warming potential (GWP) that is nine times larger than would have occurred had the methane been combusted (e.g. during electricity generation) (IPCC, 2007).[15,16] Leakage can occur during the shale gas production, processing, transmission and distribution stages. Until very recently, accurate data were unavailable on leakage rates from the wider shale gas sector. Operators have not historically been required to either measure or disclose methane leakage rates from their facilities. Two recent studies have increased knowledge in this area: the first reported the largest collection of measured leakage rates from shale gas production facilities in the US (Allen et al., 2013), and the second analysed the wider natural gas system (Brandt et al., 2014). The first showed that, where best practices were employed, emission of methane at unconventional gas production sites was approximately 0.5% of the extracted gas. The second showed that, while these best practices may not apply at all sites of natural gas production, transmission and distribution, even the higher leakage rates remained insufficient to erode the GHG benefit in switching from coal to natural gas.[17]

It also showed market forces were material in reducing leakage, since leaked methane is itself natural gas (see also EPA, 2006). However, the second study also noted that, in the US, market forces failed to incentivise all actors: a small number of 'super-emitters' were likely responsible for a disproportionate amount of the methane leaked (Brandt et al., 2014; Harvey et al., 2012; and inferred from high emitters cited in Allen et al., 2013). Further work on better quantifying leakage data in this area is ongoing (EDF, 2013, in Brandt et al., 2014), but this is expected to continue to suggest that higher leakage rates – of up to 12% from the well cited by previous studies – are not representative of the current technology in use in the US.

2.1.4 Expanded natural gas supply from unconventional sources can displace coal by out-pricing

Although it is difficult to disentangle relative prices from other market factors, econometric studies have found shale gas substituting coal has led to 35-50% of the CO_2 reductions (an 8.6% fall between 2005 to 2012) seen in the US power sector in recent years (Afsah and Salcito, 2012; Lu et al., 2012).[18] A higher estimate of the impact suggests fossil fuel emissions from the US power sector fell by 13% between 2008 and 2012 owing to shale gas substituting coal (Logan et al., 2013). It is reasonable to expect price signals from a cheap gas supply will not be as strong in China's more structured energy market than in the US market, but analysis suggests a number of drivers may cause coal to be displaced in the coming years (CTI and ASrIA, 2014).

Table 1: Lifecycle emissions for electricity generation from coal and gas

Pollutant (g/kWh$_e$)	Hard coal		Natural gas (CC)	
	Best performing	Worst performing	Best performing	Worst performing
NO_x	0.5	4.5	<0.5	<0.5
SO_2	<0.5	27	<0.5	<0.5
$PM_{2.5}$	<0.05	1.85	~0	~0
NMVOC	<0.05	0.2	0.25	0.25

Source: Sathaye et al. (2011).

---

[15] Based on the 100-year GWP values used by the Intergovernmental Panel on Climate Change (IPCC) in the Fourth Assessment Report and the relative masses of methane and CO_2 (16 and 44, respectively), i.e. $GWPCH_4/GWPCO_2$ on a molar basis = 25 × (16.04/44.01) = 9.11.

[16] For comparison, recent modelling in the UK suggested, '*For it to have higher lifecycle emissions than coal per unit of energy contained in the fuel, the methane leakage rate during shale gas production [and transmission/distribution] would need to exceed 11%*' and, '*This also doesn't account for the fact that gas-fired power generation is generally significantly more efficient than coal-fired, so for power generation the break-even methane leakage rate would be even higher*' (Joffe, 2013).

[17] In their work, the total leakage on an end-use basis ranged from 1.8% to 7.1%, with this upper bound being described as unlikely as it required all leaked methane in the US to have been generated by the natural gas system and required high-end assumptions for observed excess emissions. They compare this figure with previous work by Alvarez et al. (2012) that suggested for the US a leakage rate of 7.6% was the threshold for no net climate benefit, suggesting even at the worst case 'robust climate benefits' remained. This threshold is lower than the UK example and represents different assumptions regarding efficiencies in the power sector.

[18] It is worth noting that arguments continue as to whether the increase in gas-fired generation also displaced renewables. Section 2.2.3 discusses this in more detail.

2.1.5 Switching to shale gas does not guarantee coal is permanently displaced

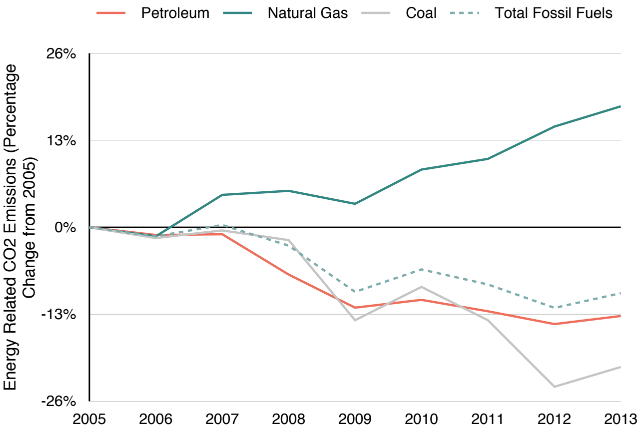
Coal can be burned later in time: inventory and refiring

A decrease in natural gas prices as a result of expanded production from unconventional (or conventional) sources can make power generation from existing coal-fired capacity uneconomic, as seen in the decline in coal use in the US since 2005. But natural gas prices are subject to both short- and medium-term volatility.[19] Unlike many other fuel sources, coal is also exceptionally amenable to long-term, low-maintenance storage that makes it easily inventoried. Any increase in either the shale gas price or the inability of shale gas to meet market demand may bring retired, but functional, coal plants back online or make use of large coal stockpiles that energy companies may use to bear the economic risks of variable gas prices.

This risk was demonstrated in the US in mid-2012, when 'a combination of higher prices for natural gas and increased demand for electricity' led to coal reclaiming some of the US electricity generation market and US emissions from energy increasing after several years of decline (EIA, 2013a). Expanded natural gas production pressed US domestic power generation costs down in particular because the expanded US gas inventory was used exclusively in US energy markets. US gas production could not be exported, with insufficient liquefied natural gas (LNG) export facilities in place, which caused the price of natural gas available to power generators to fall[20] – that is, GHG emissions were sensitive to the price of the source fuels. In the absence of material GHG or coal generation limiting policies, increases in marginal gas prices – caused by either increased exports, increased demand or reduced domestic supply – can cause a shift back toward coal-fired generation, increasing GHG emissions.

Of course, even a temporary reduction in domestic coal demand from expanded natural gas supply and energy generation could reduce the political power of the coal sector and thus create the political space for regulatory action. It is a reasonable hypothesis, although difficult to test, that the role of shale gas in mothballing marginal coal-fired power facilities in the past several years created the conditions for the Obama Administration to advance further regulation of coal-fired power plants. This, however, only further highlights the need for regulatory action to lock in the benefits of shale gas as a 'bridge from' to permanently lower-carbon energy systems.

Figure 5: Percentage changes in US CO_2 emissions for coal, gas and petroleum, 2005-2013



Source: EIA (2014c).

Coal can be burned elsewhere: exports

Broderick and Anderson (2012) found a significant amount of the coal displaced by the shale gas revolution in the US was sold elsewhere around the world. Their analysis suggests 52% of the emissions reductions in the US may have been unrealised at a global scale because coal was being exported.[21] Indeed, as Figure 6 shows, while coal production in the US decreased by 15% between 2006 and 2013, this was largely caused by the financial crisis that hit coal markets in 2009. Indeed, 2009 aside, the general trend in coal production has been to increase (despite the fact that gas production has expanded rapidly and coal generation has decreased, because of unconventional gas). The increase in coal production since 2009 is largely due to an increase in coal exports, which has occurred alongside a decrease in US demand for coal on the international market.

2.1.6 Shale gas generation without an overarching climate policy is ultimately not compatible with climate change ambitions

The 2011 *Golden Age of Gas* report showed at a global level that, without further climate policies, simply substituting coal with gas would set the world on a trajectory towards at 3.5°C rise in the long term, in breach of the climate commitments agreed at COP15 in Copenhagen (IEA, 2011; UNFCCC, 2010). More recent quantitative modelling has assessed the impact of increasing gas reserves on GHG emissions at national scales, mainly for the US. These studies also show that, without a stringent climate policy, abundant gas reserves

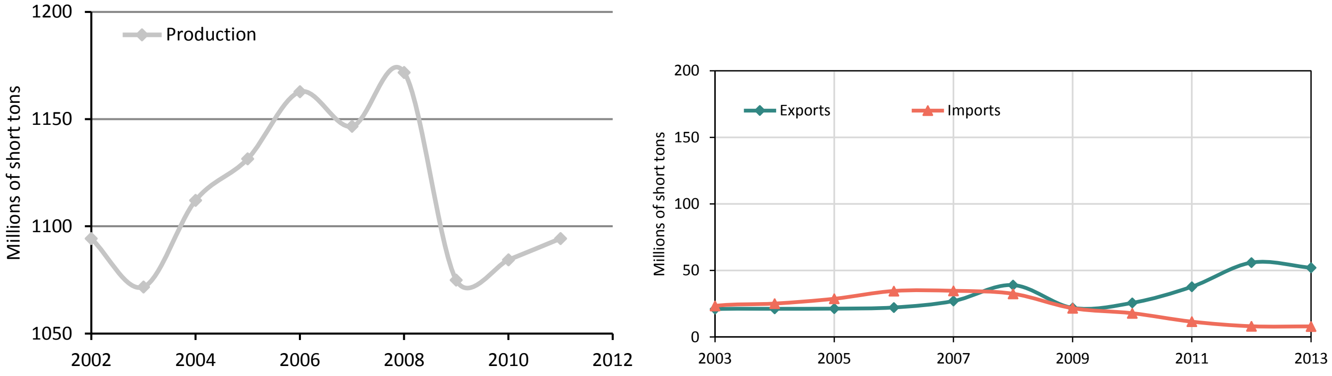
---

[19] For example, consider Henry Hub prices, which in 2011 fell 32.4%, in 2012 grew 10.6% and in 2013 grew 31.7% (*Financial Times*, 2014).

[20] This is clearly seen by the divergence in price for natural gas in the US (Henry Hub) and the price in Europe and Japan over the previous decade.

[21] The uncertainty surrounding this figure owes to all of the other issues with influence on energy markets, and, implicitly, actual reductions in emissions during the period during which the switch to shale gas occurred.

Figure 6: Changes in US production, imports and exports of steam coal, 2002-2011 showing recent increases in coal production have led to increased coal exports



Source: EIA (2014a).

may have only limited benefits for global GHG emissions, or may even bring about an increase in total cumulative emissions. This increase is explained by an excess of supply leading to a 'rebound effect' that caused more energy to be consumed overall. The increase in emissions associated with this overall increase in energy consumption may partially offset net emissions reductions observed when gas substitutes for coal (Brown et al., 2010; Jacoby et al., 2012; McJeon et al., 2014).

Understanding cumulative emissions is especially important for shale gas that is produced with shale oil (associated gas) and other condensable hydrocarbons (wet gas). The cost of exploration and production is shared between the resources so an expanded supply of gas is accompanied by an expanded supply of oil. Alternatively, high gas prices may lead to exploration that leads to increased oil production, with associated increases in GHG emissions. Although the Sichuan Basin, where most of China's shale industry is concentrated so far, holds dry, non-associated gas, a number of the other shale formations in China contain liquid hydrocarbons (EIA, 2013c). While the two fuels may be used in different markets, empirically speaking, the application of fracking for shale gas may correlate with greater oil production and consequent oil-derived emissions. While this paper has not analysed the GHG implications of this correlation (which would require significant new modelling), we note that this is an additional risk from a climate perspective.

2.2 Recommendations: managing shale gas' climate and air impacts

2.2.1 Coal must stay in the ground permanently

Because cumulative emissions drive the impact on the global climate, any shale gas burned in addition to rather than replacing coal simply exacerbates the problem of stabilising CO_2 emissions or mitigating air pollution. Here, the impact of shale gas on emissions of GHGs and other air pollutants is dependent on what happens to the coal that would have been burned were shale gas not available. In short, policy must ensure the coal must not be (i)burned later in time or (i) exported and burned elsewhere; it must stay in the ground permanently.

2.2.2 Install a credible pathway for permanently phasing out unabated coal

Policy that either implicitly or explicitly limits the building of new coal-fired plants and the steady reduction in coal use over time should be installed at a national level.[22] Although a number of policy options offer the opportunity to remove coal from the energy system, any effective approach must be national in scope. This prevents a reduction in coal-fired generation in one region causing an increase in another region, as may occur if policy were introduced at a subnational level. Explicit policy could range from outright prohibition of the construction of new unabated coal plants to specifying a decreasing fraction of the energy portfolio that can be met by coal supported by higher priority targets in short- and medium-term plans. Examples of implicit policy include introducing a nationwide price of CO_2 or a nationwide GHG emissions

---

[22] We note carbon capture and storage (CCS) offers the potential for significantly reducing GHG emissions from all fossil-fuelled plants. However, given that no commercially viable project yet exists at scale, we do not see CCS as yet having sufficient potential to mitigate all coal-generated GHG emissions. Thus, we feel policy related to reducing the impact of coal-firing should be made regardless, with any benefits from CCS accruing additionally to those from phasing out coal, for example by accelerating the phase-out of unabated coal.

[23] Including the outlawing of coal for power generation in Beijing and Shanghai, and regional cap and trade programmes.

cap and trade system that increases or decreases, respectively, year-on-year, making both the expansion and the continued use of unabated coal-fired capacity uneconomic. Examples of both implicit and explicit policy options have already been employed at a subnational level;[23] however, these must be applied at a national level to prevent the further shifting of coal consumption to other regions within China.

Addressing air pollution does not necessarily address climate change worries

Reducing coal consumption reduces air pollution. Therefore, any permanent reductions in coal-fired generation from climate policy automatically convey net air pollution benefits.[24] Unfortunately, the reverse is not true: air pollution impacts can be reduced, by either moving the pollution from urban areas or through producing synthetic natural gas (SNG) by coal gasification, without reducing GHG emissions. In fact, SNG use results in more intensive GHG emissions than from coal-based generation. This allows the broad conclusion that, while a coal phase-out owing to a desire to cut GHG emissions will yield a net reduction in emissions of other air pollutants, an air pollution reduction target will not guarantee GHG emission reductions.

Use extraction or export controls/duties to prevent coal being diverted abroad

To ensure the GHG benefits of replacing coal plant are realised, disincentives to production need to be put in place before a production surplus can be created that may encourage coal exports. China imports a significant amount of the coal used in its energy system. Therefore, using domestically produced shale as a substitute for imported coal could initially reduce its dependence on foreign energy sources and improve its balance of payments. However, as China's coal consumption peaks and relative consumption of alternative energy sources increases, without any decrease in coal production, the country may at some point begin to see a domestic surplus in coal stocks.

Again, this outcome can be targeted explicitly or implicitly. Explicit methods could take the form of a roadmap to phase down coal production alongside consumption and include options such as restricting the output of existing mines, accelerating China's mine closure plan (Tse, 2013),[25] outlawing the permitting of any greenfield mine development and enforcing a coal export cap in addition to a cap on domestic consumption. Implicit options include increasing extraction taxes, royalties or export duties to disincentivise further mining by making it uneconomic. Many of these operations may already be uneconomic: 70% of the country's coal firms are reportedly running at a loss even without the associated externalities being internalised (Stanway and Hardy, 2014). Current implementation of a permanent moratorium on coal exports would, notably, have little political cost now because all production is currently domestically consumed, and would send a strong signal about China's objective to reduce its role in global GHG emissions.

Fugitive methane emissions can and must be significantly reduced

Fugitive methane emissions can substantially erode, and theoretically could even reverse, the GHG emissions reductions realised by switching from coal- to gas-fired power. Natural gas in general faces leakage risk across the entire system of production, transport and use, and data in the US show a variety of leakage rates within the wider natural gas system.[26] Shale gas in particular poses some unique methane leakage challenges during the production phase. Fortunately, from a technical and regulatory standpoint, these appear to be amenable to specific technical requirements at that stage. More broadly, gas systems should of course also be subject to rigorous monitoring and upgrading for the wider gas grid. Indeed, recent work in the US has shown a significant amount of leakage and combustion emissions result from the subsequent gas processing, transmission and distribution systems (McCabe et al., 2015; ICF International, 2014). Thus, although applicable to the wider natural gas infrastructure rather than specific to shale gas, maximising shale gas' GHG advantage over coal requires significant policy attention to this wider system. This is unfortunately beyond the scope of this paper, as it is not particular to shale gas but applies to all gas transmission and distribution. However, we note that methane emissions regulation is amenable to the target-setting approach that is central to China's system of governance.

Minimum technology standards for well components and completion significantly reduce methane leakage during production

Enforcing minimum technology standards offers a relatively simple way of mitigating the largest potential for methane leakage during production. This is particularly true of venting of methane during the completion stage of the hydraulic fracturing process. Figure 7 shows that, for the worst case scenario, the well completion for a typical

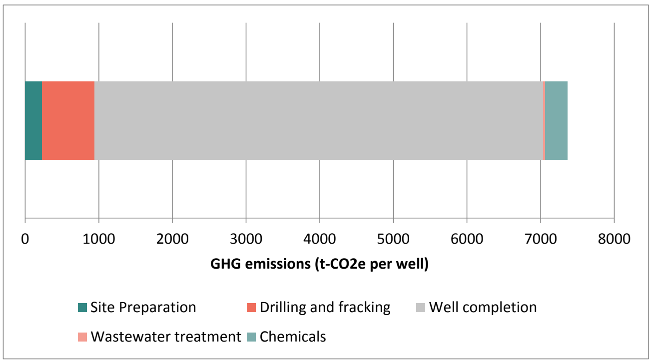
---

[24] Similar comparison has recently been identified for the co-benefits for indoor air pollution and GHG reduction (Schmale et al., 2014).

[25] 1,256 mines were due to be closed in China in 2013.

[26] The lifecycle emissions are unique for each unit of gas and depend on where it is produced, through which system it is transported and where and how it is consumed. Similar variation exists for coal.

Figure 7: Unmitigated sources of GHG emissions during extraction of gas using hydraulic fracturing



Source: MacKay and Stone (2013).

shale gas well could potentially release 83% of the total emissions associated with the production of gas from shale formations.[27,28]

Employing 'green' or 'reduced emission' completions (RECs) targets this largest source of easily mitigated methane leakage by collecting water and gas produced during completion, storing it and then separating the gas out and adding it to the product pipeline. For example, data from the Mackay and Stone (2013) study suggest RECs reduce these emissions by 90% against a worst-case scenario, reducing the total emissions from the well by 81%. The report also shows that, in the UK case, if RECs are used then emissions from the production of shale gas are lower than those related to production of LNG.

In addition to the large episodic emission potential during completion, a number of components used in the early stages of production also exhibit leakage risks that can be easily countered by better technology choices. In the US, the EPA released the New Source Performance Standards (NSPS) in 2012, which aim to reduce emissions from completions, compressors, pneumatic valves, and storage tanks by 95% compared to worst-case scenarios (US EPA, 2012).

In addition to reduced emissions completions, sealed storage tanks and updated components for compressors and valves are now voluntarily widely adopted in the US to minimise methane leakage. Prior to the introduction of the NSPS, there was still strong market pressures on the industry to improve methane capture since the by-product was itself saleable natural gas (McCabe, et al., 2015; ICF International, 2014). This was likely spurred by innovation caused by competition between numerous shale gas operators. However, despite the financial incentives to install emissions reduction technologies driving their rollout, they did not achieve universal coverage under voluntary arrangements (Harvey et al., 2012).

Failure to achieve universal application best practices has had material consequences because of the disproportionate impacts of 'super-emitter' wells and facilities (Brandt et al., 2014; EPA, 2006). Because technologies that reduce methane leakage are already in place in the US, forward-looking analyses (e.g. McCabe, et al., 2015; ICF International, 2014) that target leakage across the wider natural gas system do not recognise emissions during completion and production as particularly significant contributors to total system GHG emissions. However, we are not aware of regulations in China that mandate the use of these low-leakage components and practices during the production stage, nor whether companies are employing such components and practices voluntarily. In light of this, for China's shale gas production facilities specifically we prioritise these emissions reductions measures that have largely already been adopted in the US.

For China, further, it is unclear whether the market signals that assisted methane capture in the US, and also paved the way for regulation to universalise these practices, will be as clear. Innovation and uptake of efficiency measures may not occur in the same way, given differences in the structure of the industry forces acting on it. In China, unlike in the US, only a small number of large (mainly state-owned) companies are currently involved in shale gas exploration and development. We have also not been able to find any evidence of monitoring or public disclosure of methane emissions, either directly via bottom-up methods or indirectly via top-down methods. Finally, it is unclear whether the economic driver that permeated the US market will exist in China (for example, whether it will be as easy or cheap to sell the gas or install the equipment to separate it), especially since China's natural gas market is less liberalised than that in the US.

Because the industry is only just beginning to expand, China has an opportunity to ensure RECs and other methane-minimising choices are the industry norm. One study has suggested the cost-competitive installation of components that reduce leakage could reduce China's GHG emissions by 36 $MtCO_2e$ per year by 2030 (Brink et al., 2013). In the US, it has taken over a decade of drilling (and tens of thousands of wells with only voluntary emission reduction measures) to enforce RECs and techniques to reduce leakage at production sites.[29]

---

[27] Data are for the UK but are considered representative for China. Note that this is not the total emissions, but just the emissions associated with the production of the gas – that is, it does not include emissions associated with the ultimate combustion of the gas (which is responsible for the majority of the lifecycle emissions).

[28] This is also the main reason for differences in lifecycle emissions between the production of gas from conventional and unconventional sources.

[29] Note also that the NSPS does not cover associated activities such as well work-overs or liquid unloading.

Action by regulators now to require RECs and low-leakage components and practices at every production site offers an opportunity to minimise emissions during the production stage.

Methane leakage will also need to be reduced in the wider gas distribution system

While such an approach offers an opportunity to significantly reduce leakage compared with a worst case scenario, recent work in the US has highlighted that, once these measures are taken, there is a need to focus on other GHG emissions (leakage or combustion emissions) within the transmission and distribution system (Alvarez et al., 2012; Brand et al., 2014; McCabe, et al., 2015; ICF International, 2014). As noted above, analysis of the wider system is beyond the scope of this paper and applies to the entire gas sector, although we reiterate that we recognise that efforts to minimise emissions during the production stage – such as those exemplified by the NSPS in the US – are only the first of several necessary steps in limiting emissions from the wider system.

Any development of the wider gas network should be accompanied by a drive to decrease leakage of natural gas across the network. Gas can leak from an enormous number of points between the production site and burner tip rendering inspection and monitoring at a device scale uneconomic and likely too burdensome to be practically enforced. A recent meta study on leakage rates across the natural gas system in the US (Brandt et al., 2014) reiterated an earlier finding of the need for better data to reduce the uncertainty in estimating natural gas leakages (Alvarez et al., 2012), with at least one programme to satisfy this need ongoing in the country (EDF, 2014). Nevertheless, the study made two important conclusions from North American data. First, that the current estimates for natural gas leakage from devices across the natural gas technology chain underestimated actual leakage. And second, that it was unlikely that the high leakage rates reported at some sites were representative of the wider gas industry, finding instead that a disproportionate amount of leaked methane was released from a few sources.

Because the opportunities for leakage are so numerous downstream of the wellhead and no single stage is likely responsible for a large amount of emissions (as for the case of completion), the most practical way to reduce leakages is likely by designing a monitoring strategy that begins at regional-scale atmospheric measurements, with a protocol that then drills down on any anomalous readings to pinpoint any leakage and compels operators to stem the flow. To identify methane leakage that can be addressed requires baseline data that include appreciation of other sources of methane (both anthropogenic and natural), which ongoing research into 'fingerprinting' to identify sources may aid with (Rich et al., 2013).

Clustering of wellheads can facilitate monitoring and enforcement and reduce the regulatory burden

Advances in horizontal drilling allow multiple wells to be drilled from a single well pad. These advances allow shale gas wells to be clustered together in order to reach more distant reserves and formations. Concentrating shale gas extraction within a specific industrial zone both reduces the land use footprint of a project (discussed in Section 4) but also can reduce the regulatory burdens related to land use planning and monitoring and enforcement by regulators.

From a regulatory point of view, concentrating shale gas activity into fewer sites exerts a far smaller monitoring burden. Such a set-up is also likely to benefit operators who can take advantage of economies of scale, for example, reusing sealed tanks and gas–liquid separation systems for completion stages on many wells.

2.2.3 Shale gas must not be a destination fuel

The development of shale gas can serve the development of low-carbon energy sources if deployed within a credible overarching policy that has a sustainable, low-carbon energy system as its goal. The climate compatibility of shale gas development is dependent on the decline of more carbon-intensive energy sources and the growth in low-carbon energy. Sections 2.2.1 and 2.2.2 describe shale gas' potential to form a bridge away from an energy system dominated by high-carbon sources (such as coal); this section clarifies that any development in shale gas must be managed to effect the transition as a bridge towards a truly low-carbon energy system.

Although the majority of this analysis has compared the impacts of shale gas with those of coal in generating electricity, understanding whether shale gas represents a bridge or a destination fuel requires appreciation of the wider energy system. The following quote from Bazilian et al. (2014) captures the complexity of this issue 'the 'environmental benefits from natural gas are a property not just of technologies, conversion efficiencies, and leakage rates, but of the interaction of natural gas with the rest of the energy system and the broader social and political system'. Such a multitude of interactions has spurred a continuing debate as to whether substituting coal with shale gas is likely to result in a sustainable energy system that is compatible with stabilising the climate at safe atmospheric concentrations of GHGs. On one side of the debate, proponents argue development of gas can aid the development of renewable technologies; opponents suggest gas and renewables compete, meaning any gas development hinders that of renewables.

Wellhead clustering in Wyoming, US

Photo: Fracking in Wyoming: Simon Fraser University, 2006.

Gas development is not itself a low-carbon energy plan, but can be a complement to aggressive renewables expansion

Increasing the amount of spare installed capacity of gas-fired plant firms the grid allows for greater penetration of variable renewable energy.[30] This is because the power many renewable technologies supply is variable and difficult to predict accurately across short periods of time. Thus, as electricity grids are increasingly supplied by such renewable energy systems, the potential for a supply shortfall – which would destabilise the grid and is highly undesirable – across an electricity grid increases. While other technologies are being developed[31] or used on a smaller scale,[32] gas-fired power generation is flexible and dispatchable, and is currently widely used to compensate for shortfalls in energy supply over small periods. In light of this ability, a number of modelling studies have shown that an expansion of natural gas capacity for 'grid firming' could represent the least-cost option of accelerating the deployment of renewable energy technologies in the coming decades (Lee et al., 2012; Wolak, 2012).

Just because gas can be a bridge fuel doesn't mean it will be

Without a credible framework towards a climate-compatible energy system, shale gas offers a short-term convenient option to reduce coal dependence but may delay or prevent the development of more climate-compatible solutions. Despite the current benefits of firming, a number of analysts have suggested aggressive development of gas infrastructure now may lead to nations being technologically locked into a high-carbon future, noting that 'climate-relevant emissions trajectories [i.e. a product of energy policy decisions] [are] heavily dependent on system inertia, positive feedbacks, and path dependencies' (Bazilian et al., 2014). Decisions to invest in gas-fired generation capacity can reinforce dependence on gas-fired generation in the future, 'locking in' a fossil-fuel component to the energy system (Bassi, 2013; Chignell and Gross, 2013; Jacoby et al., 2012; Schrag, 2012). Such a premise could be further compounded as operators seek to maximise their return from investment sunk into plants by maximising load factors throughout their lifetimes.

It is, however, not possible to predict accurately how energy systems will evolve over the coming decades. At one extreme, gas becomes the favoured fuel, replacing coal and setting in trend an energy system that depends on the gas grid. This is essentially the scenario the International Energy Agency's (IEA's) *Golden Age of Gas* describes. At the other extreme exists an energy system that does not invest in enough grid-firming (of which gas is likely the lowest-cost option for the scale of an energy system)[33] and the development of further variable renewable energy generation is slowed because there is insufficient flexible capacity to cover supply shortages. Neither of these extremes is likely to be compatible with stabilising global GHG emissions at agreed levels.

2.3 Implications for China

2.3.1 Understanding the opportunity that gas poses

The future of gas, coal and China's energy mix may be heavily influenced by global agreements on GHG emission reduction strategies, most notably a global carbon price that plots a trajectory to a globally sustainable future, which is adopted transparently into national energy markets. If this were implemented globally in a sufficiently stringent fashion, it would ensure that substituted coal could not resurface elsewhere in the global energy system and would go a significant way towards reducing the risk of being locked into a fossil fuel-dependent system. Within China, a national development plan that sets prescriptive targets, similar to those in the most recent FYP, to transition towards a sustainable energy future could also reduce the opportunity for coal to re-enter the energy landscape elsewhere within China and create a basis for the gradual superseding of shale gas-powered electricity generation by lower-carbon sources.[34]

By 'firming' the grid, natural gas-generating capacity can help overcome some of the variability in generation associated with renewable technologies. Energy storage and better grid interconnectivity may diminish natural gas' 'unique' ability to provide this firming role as the technologies develop. However, until that time, a strong argument exists for the co-location of renewable energy

---

[30] We distinguish between 'controllable renewable energy', such as from hydroelectric or geothermal sources, and 'variable renewable energy' that is derived from other renewable sources such as wind or solar.

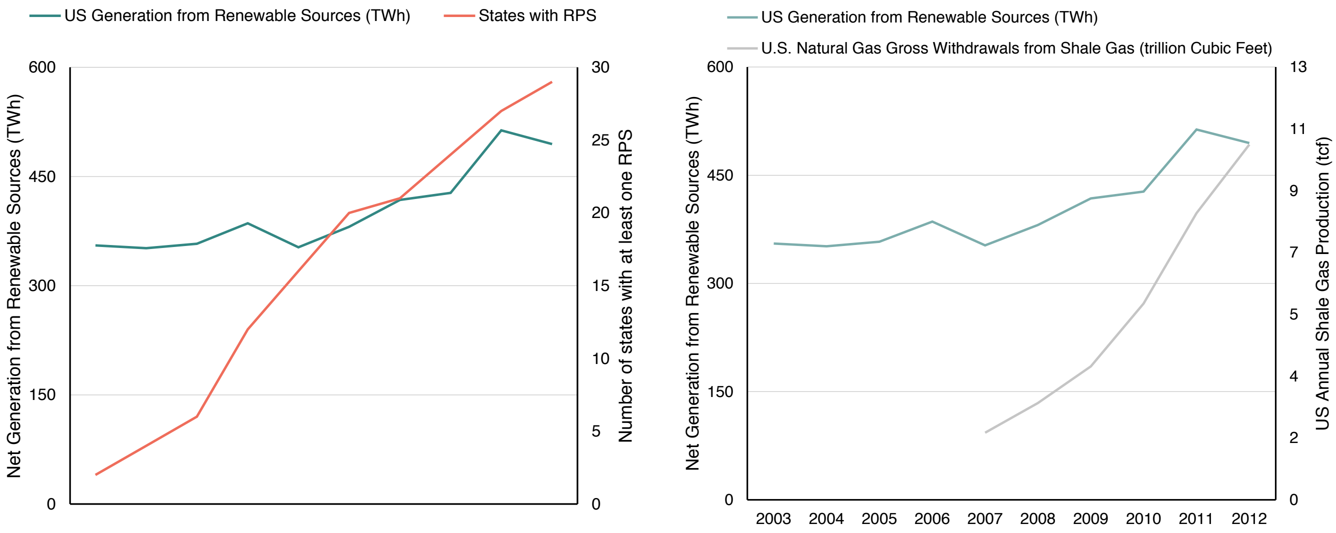
[31] For example, liquid air energy storage or integrated and flexible smart-grids.

[32] For example, pumped hydroelectric power or demand management – that is, curtailing supply of intensive users at peak times.

[33] Although EDSAP contains a goal of building more pumped hydro energy storage sites, we are not convinced sufficient proven capacity will exist to firm the grid to the extent required to effect a shift towards being renewably dominated. We also note demand management (curtailing heavy industry) and creating a fully integrated grid could technically stabilise the grid sufficiently to enable high renewable penetration, but we feel neither of these is currently achievable in China, given its strong commitment to economic growth and the significant investment and time required, respectively.

[34] Although we do not consider shale gas use outside of electricity generation in this paper, were it to replace coal in industrial applications we expect we would make similar recommendations to those made here.

Figure 8: Comparison of US growth in renewable electricity generation and number of states with renewable portfolio standards, 2003-2012



Source: DSIRE (2014); EIA (2013b, 2013c).

technologies with the grid-balancing, responsive, flexible generation gas-fired offers. However, this simple conclusion belies the complexity of the delicate balance that must be struck between provision of enough gas-fired capacity to accelerate the deployment of renewables but not so much as to tip the energy sector towards being locked into gas-fired generation that is incompatible with climate change goals.

A bridge towards renewable energy capacity expansion also requires that gas-fired generation does not undercut the financeability of renewable energy options. Bazilian et al. (2014) note that, historically, renewable energy capacity expansion successfully weathered the shale gas boom in the US. The limited effect of natural gas power development on renewable energy development is likely a consequence in part of the 'renewable portfolio standard' (RPS) incentive structure implemented in most US states. RPS programmes essentially mandate that utilities purchase a minimum percentage of renewables-based generation. This locks in demand and shelters renewable energy generation from fluctuations in prices from other sources. Any system in which natural gas expansion is expected to complement renewable energy generation will require a policy framework that similarly insulates demand for renewable energy capacity and generation from being outcompeted by natural gas itself. Other factors may have contributed to renewable energy performance as well, such as companies diversifying their portfolios for risk mitigation and to improve their public image.[35]

2.3.2 What might China's energy future look like?

Prescribing China's entire energy system is beyond the scope of this paper.[36] However, the process below highlights the primary plausible scenario under which the shale gas industry will be developed in China in a climate-compatible manner (Levi, 2013; Trambath et al., 2013). This is not to say this is certain or even likely, but that each of these elements is necessary for shale gas to serve to bring about a truly low-carbon energy mix. It both highlights that shale gas has the potential to fuel a low-carbon transition but equally that failure to guide policy and planning towards the identified steps will likely mean failure to enable such a transition.

An important point that arises from the scenario below is that, initially, gas plants operate at high-capacity factors, which results in rapid recovery of capital expenditure in building new gas-fired plants. These plants would then eventually generate at low-capacity factors. Investment recovery early in the lifecycle of power plants is a common feature of energy investment, but it is possible that shifting gas to an auxiliary role in the energy mix would require some public financial support.[37]

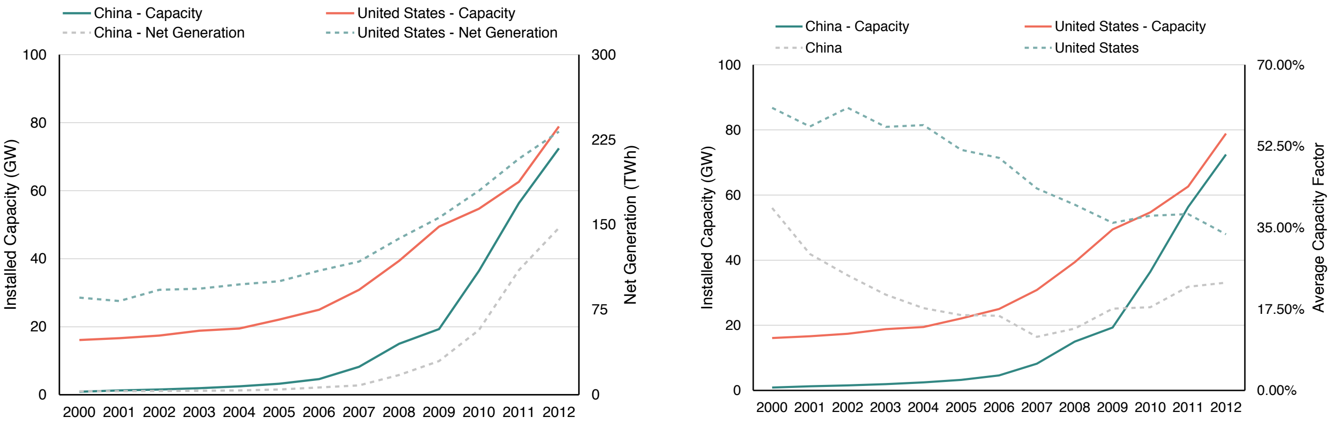
---

[35] With thanks to J. Logan for this suggestion.

[36] Kahrl and Wang (2014) provide a compelling and more technically detailed analysis of integrating renewables into China's power system

[37] Perhaps similar to the capacity payments in the UK's Electricity Market Reform (see UK Government, 2014), which have generally had a minimal role in increasing the cost of renewable energy in the grid.

Figure 9: Comparison of installed capacity, net generation and average capacity factor for non-hydro renewable electricity in China and the US, 2000-2011



Source: EIA (2014b).

Step 1: Shale gas develops and increasingly directly substitutes coal-fired energy. Gas-fired plants are built and operate at high-capacity factors to substitute the most coal. This should occur alongside China's current trend for rapid development of renewable energy sources, with a small portion of gas used to 'firm' the electricity grid to account for the inherent variability in renewable energy generation. To achieve the greatest climate benefits, this step involves a 'smart' use of gas to replace coal to ensure the largest net GHG reduction compared with using coal. [38,39] Accelerating a 'smart' use of gas could be achieved through a number of policy tools. Again, most efficient among them would be an explicit economy-wide pricing of CO_2 emissions via a tax or tightening cap and trade system.

However, for specific sectors such as electricity this may include managing the system itself, for example by changing the priority of dispatching different electricity generation technologies to ensure coal is always the last choice that is economical (perhaps having incorporated the externalities associated with different electricity and energy generation technologies) (Alberici et al., 2014; NRDC, 2014). Prioritisation is also crucial to the effective integration and expansion of renewable energy. China has been criticised for, on the one hand, greatly expanding renewable energy capacity while, on the other, failing to rely on it for generation because of its failure to prioritise its dispatch when available. Figure 9 shows this scenario: although the installed capacity of non-hydro renewable energy generation in China now exceeds that in the US, actual generation from these sources in China in 2011 was approximately half that generated in the US.

Low capacity factors are particularly felt in China's wind industry (the largest component of the non-hydro renewables). In 2013, China's installed wind capacity stood at 77.16GW, and 134.9TWh were generated in that year (average capacity factor of 19.9%). The China National Renewable Energy Centre (CNREC) (2014) reports that 11% of China's national wind power was curtailed in 2013, with the proportion hitting 20% in some provinces. This is a reduction from the 2012 level (20% national average), although continuing this drive for procurement of wind energy is likely to entail substantial costs in upgrading the electricity grid to accommodate it.

Step 2: Gas capacity begins to decrease as it changes from substituting coal to supporting renewables. As coal-fired generation reduces significantly through the retirement of coal plants and the proliferation of low-carbon electricity sources, the primary role of gas capacity begins to change from substituting coal to supporting the development of further renewables. This sees the capacity factor of natural gas power stations begin to decrease as more of the total demand is met by renewables and more 'capacity backup' is required (i.e. more gas-powered generation must be idle in case it needs to be ramped up).

Step 3: Gas-fired plants' capacity factor reduces even further. This trend of reducing the capacity factor for gas-fired plants continues as the amount of renewables on the system increases to very high levels, resulting in a relatively high installed capacity of gas plants running at a low load factor.

---

[38] For example, if given the choice between using gas for electricity generation and using it for providing heat, the considerably higher thermal efficiency burning gas in combined-cycle gas turbines (CCGTs) offers to generate electricity suggests this would be the better use of supplanting coal use of these options. It should be noted that the decision to replace coal with gas may also be made according to other drivers, which may preclude this. For example, replacing coal-fired domestic cooking appliances with a domestic gas network or LPG cylinders may not generate the same benefit as choosing to use gas instead of coal for electricity generation. However, such a change may be driven by a desire to improve indoor air quality.

[39] Perhaps similar to the capacity payments in the UK's Electricity Market Reform (see UK Government, 2014), which have generally had a minimal role in increasing the cost of renewable energy in the grid.

3. Water: understanding and managing the water impacts of shale gas development

Summary: water impacts

The biggest water management risks from shale gas development arise from contamination of large volumes of water in the fracking process, which can in turn contaminate other water bodies. As with other extractive industries, the challenge is made more difficult because treatment and management of such water can be costly, creating pressure to discharge it in surface waters or deep underground. Other water resource risks will depend on the local environmental context and the regulations and incentives in place to understand and manage its risks. The need for a large volume of water over short periods of time means opportunity costs can be high in circumstances where peak withdrawals coincide with other demands. However, water demands are typically modest compared with total resource availability at national, regional and even basin levels and are comparable with the demands of other industries, including coal. However, the proportion of water lost to further use may be higher since contaminated water, if discharged, can diminish the availability of other water bodies for economic uses.

To control water-related risks, China will need to bring shale gas development under its increasingly extensive environmental regime. This will involve the monitoring and control of water withdrawals, effective treatment and/or reuse of contaminated water to prevent pollution and land use controls that limit exposure to risk of populations and ecosystems. Although China's environmental performance has improved significantly over the past decade, major obstacles remain. Both the system of cadre evaluation against environmental targets and conventional regulatory control through line agencies will need to be strengthened to avoid or mitigate problems, particularly for pollution.

3.1 Risks and opportunities: the water impacts of shale gas

3.1.1 Water consumption risks are primarily those of acute local water stress from intensive use during the production phase

Several million US gallons of water are needed to frack an individual well, and much used water becomes contaminated. Fracking multiple wells (or single wells multiples times) therefore has the potential to exacerbate water scarcity and cause pollution, depending on where, when and how many times the process occurs.

In the US, aggregate estimates from the various shale basins suggest shale gas development contributes to less than 1% of total water demand in these areas. At a local scale, however, and at peak production times, the impact on water balances can be significant. Some US counties report demand rising to anywhere from 30% to >100% of total water demand over shorter timeframes, posing a major risks to water resources and other water users (Zammerilli et al., 2014). We expect a similar situation in China.

Attempting to understand the impact of demand on aggregate water resources requires an estimate of how many wells are likely to be drilled to meet shale gas production targets. Representative data from the US applied to the UK context suggest an economically competitive, fracked shale gas well can produce anywhere from 50 to 140 million cubic metres of gas over its lifetime (MacKay and Stone, 2013). In comparison, the US Energy Information Administration (EIA) estimates that the total volume of recoverable shale gas reserves in China and the US is 31.6 and 18.8 trillion cubic metres, respectively (EIA, 2013c). This implies it would require hundreds of thousands of wells to exploit these resources fully in either country, with risks of pressure on local water resources in areas where more wells are drilled than the existing water resources could supply. In addition to the number of wells required, their impact on water resources is also dependent on the location, timing and frequency of the fracking operations, as Table 2 describes.

The water resource risks from fracking activities therefore accrue mainly at the local level, and their impact on water availability for other uses will vary significantly between different local contexts. Simply put, the response to questions about the risks of a fracking activity on water resources is: 'it depends'. It depends on the location, timing and frequency of the activity in relation to the available water supply and other competing human and environmental demands on the resource.

Table 2: Variance in water demands for fracking

Factor	Description	Examples of variance
Location	The water used for fracking is usually trucked into individual well sites, although water is heavy and trucking is expensive. This gives shale gas companies the financial incentive to find surface or groundwater sources near to the point of operation, with major impacts on local water balances.	A fracking job undertaken in a desert may pose greater risk to water availability than one undertaken in a rainforest.
Timing	A fracking job requires large volumes of water in a short period of time – the fracking process lasts from three to ten days (Sovacool, 2014). As a result, fracking activities could stress local water resources during periods where supply is low or other demands are high.	A fracking job undertaken during a month of local drought may pose greater risk to water availability than one undertaken during a month of heavy rainfall. However, the same high-risk fracking job could proceed without concern if the company had withdrawn its water during a wet period and had stored it for use during the drought period.
Frequency	Shale gas production at scale via fracking requires the establishment of many well sites within the area of the shale basin, which multiplies their water demands accordingly.	An area suffering from low water supply owing to drought and other demands may be able to accommodate the additional water demand from one or two fracking operations, but not from ten or fifty such operations.

Water withdrawals from shale gas are modest in relation to total water availability and other industrial demands

China suffers from existing problems of water scarcity, raising concerns that shale gas development could exacerbate them further (Hoffman et al., 2014; Reig, Luo and Proctor, 2014). The country contains only 6% of the world's total freshwater resources, but 21% of its total population (FAO Aquastat, 2011). As discussed previously, the country's current shale gas target is 30 bcm of production per year by 2020, from its total estimated reserves of 31.6 trillion cubic metres (Chen et al., 2014; EIA, 2013c). To date, most production is taking place in the Sichuan shale gas basin of Chongqing, although the Tarim and Junggar basins in the autonomous region of Xinjiang are among other basins slated for development. Chongqing's main Fuling shale gas field is currently targeting an annual production of 10 bcm per year by 2017 (Hua and Chen, 2014).

Table 3 displays the annual renewable water resource situations in 2012 at national and provincial level for China's main shale gas regions. These provinces/regions vary in their water resource endowments. At province level, Chongqing and Sichuan are relatively water abundant in terms of supply and demand: existing uses account for about 17% of Chongqing's renewable resources and about 8.5% of Sichuan's. By contrast, Xinjiang is less water-abundant, with existing uses accounting for about 66% of current resources. Note that these are national government data, and water resource assessment and accounting in China is rudimentary (Calow et al., 2009; Doczi et al., 2014). Local-level data are not easily available for these areas.[40]

We use the most recent (2013) primary data on water resource availability and withdrawals from the Chinese National Bureau of Statistics (NBS) to allow for more nuanced discussion of the country's water risks. In contrast, a recent report by Reig et al. (2014) depicts a broad-scale water security crisis in the country, with shale gas activities threatening to exacerbate this. Using data on national water use/resources from older and less granular secondary sources, Reig et al. then combine the data with a number of other indicators (like rainfall variability, threatened amphibians and water-related media coverage) to create a metric on 'overall water risk'. Our analysis suggests this assessment of water stress is based on data that are inappropriate to the scale of the risks shale gas development creates and fails to recognise the unique contexts of the individual provinces/regions/localities where shale gas development is occurring. This conclusion – that fracking presents very material water resource risks at a highly localised level – is also emphasised by recent work in the US (e.g. Freyman, 2014).

With this table and a few simplifying assumptions and calculations, we can roughly estimate the magnitude of the fracking-related water resource risks that might arise if China meets its production targets. We detail these assumptions and calculations in Annex A. We find China's 2020 production target could require the drilling of about

---

[40] It is important to note that these national data on water use do not distinguish between consumptive and non-consumptive uses of water. A consumptive use of water is one that results in freshwater losses downstream (e.g. via evaporation or pollution), whereas a non-consumptive use is one where its freshwater withdrawals flow back into the downstream hydrology. These national government data on water use should therefore be interpreted as total water withdrawals, both consumptive and non-consumptive. The fracking process is a consumptive user of water, since the freshwater it uses becomes polluted or is removed from the hydrological cycle entirely. Other industrial water uses vary in this regard. Coal mining pollutes its water and is therefore a consumptive user, while the cooling water used in power plants usually does not become polluted and is therefore a non-consumptive use.

Table 3: Annual water resource and water use data for China and relevant provinces/regions

Location	Annually renewable water resources (million m^3)	Total water use (withdrawals) (million m^3/year)	Total industrial water use (million m^3/year)	Total agricultural water use (million m^3/year)	Total domestic/ service sector water use (million m^3/year)
National	2,952,600	614,100	142,300	388,000	72,800
Chongqing	47,600	8,200	3,900	2,500	1,700
Sichuan	289,200	24,500	5400	14,500	4200
Xinjiang	90,000	59,000	1200	56,100	1200

Source: NBS (2013).

8,400 wells and the fracking of 160 million cubic metres of water. This would constitute about 23 million cubic metres per year if production were evenly spaced. We similarly find Fuling's 2017 production target could require drilling about 1,600 wells and fracking 30 million cubic metres of water – about 7.5 million cubic metres per year.[41]

In both cases, these volumes are small in relation to the volumes of China's national and regional aggregate water withdrawals summarised in Table 3. In the likely scenario where most production happens in Chongqing, the yearly water resource requirements from fracking activities would account for less than 1% of the province's industrial water withdrawals, less than 0.5% of total water withdrawals and less than 0.05% of total water resources. These small percentages may be more significant than they appear, since much of the water needed for the fracking process is lost to further use. Nevertheless, many of the other industrial and agricultural processes that withdraw water in this context (e.g. coal mining) also involve non-recoverable losses. Similar results apply even when we test more extreme production scenarios and when we attempt to factor in hydraulic fracturing for tight gas as well, as our simple sensitivity analysis in Annex A shows. This supports our earlier assertion that the water resource consumption risks from fracking accrue mainly at the local level, rather than at the provincial or national levels.

Local risks could be particularly important in Xinjiang, which contains the Tarim and Junggar shale basins. In extreme production scenarios, fracking could comprise a more significant proportion of industrial water use in the region. The added complexity for Xinjiang is that it is China's largest administrative region by land area and its water resources are distributed very unevenly (as opposed to the small and relatively uniform land area of Chongqing). Assessing potential water resource stress from shale gas development in Xinjiang is therefore much less informative than it is for Chongqing and Sichuan. Fracking activities in the water-scarce desert areas could pose a significant pressure on other water users. Even in the river valleys, fracking could create allocation tensions between agriculture (still the dominant withdrawer and consumptive user of water) and industry, since it would drive up industrial use as a whole. Without a strong system in place to balance demands between users, water demands for fracking could dominate those of rural farmers and threaten their livelihoods. It is important to put this in context: the nature of shale gas in terms of water demand is not unique: large-scale expansion of any heavy industry can create significant demands on water resources that need management in the context of local populations' demands.

Non-recoverable water losses from fracking strengthen the need to monitor resources and assess cumulative impacts

Sound water accounting is based on information on where water is going, where it is being consumed, where it is being reused, what is happening to salt and pollution loadings and the timing and location of return flows as others recycle and reuse water. This means, for example, that losses at the scale of an individual farmer or enterprise are not necessarily losses in the hydrological sense, because the lost water may be available for use at some other point in the basin, or from an aquifer. When evaluating the impact of a new industry, or a technical change in an existing one, this makes it important to 'follow the water' to determine its fate and disposition, especially when claims are made about water saving and efficiency (Perry, 2013).

In the absence of detailed water accounting data for fracking, 'following the water' is difficult. However, we do know that mixing water with chemical agents as part of the

---

[41] Note that we attach no certainty to these figures other than providing the magnitude of fracking-related water resource risks. We understand that using the data from the US as an analogue for China is imperfect and unlikely to be representative and strongly caution against the further use of these figures outside of the context that we use them in here, which is to test the usefulness of assessing water resource impacts of fracking at a regional or national scale.

fracking process both demands a lot of water and means a significant proportion is lost from further use, at least in an economic sense. During the fracking process, some water is dissipated into the shale rock, and contaminated flow-back water is often injected into sealed geological formations. This water is unrecoverable, at least in an economic sense.

The proportion of water permanently removed varies significantly between projects (Zammerilli et al., 2014). It is technologically possible, if economically expensive, to treat and reuse water, or return it to a water source. Data for China – on water accounting and economics – are not yet available, but it is reasonable to assume non-recoverable losses will comprise a significant proportion of total water use, highlighting the need to monitor the cumulative impact of fracking on resource conditions.

3.1.2 The water use of fracking is significant but comparable with other industrial uses

We can further contextualise the water use of fracking by comparing it with other industries. The Chinese pulp and paper industry is another water-intensive industry with major non-recoverable losses, and thus provides a useful comparator. The comparison illustrates that shale gas operations are not unique in the type and magnitude of water risks they create. This is not to minimise the risk, but it contextualises fracking in China's larger challenge of water risk from industrial activities.

Several of China's major paper mills are located in the provinces of Sichuan and Chongqing, where much of the near-term shale gas production will take place. Production data were found for three of them, for which we established estimates of water used.[42] If we apply a low-end estimate for water use of 75 cubic metres per ton, three mills in Chongqing producing 1,000 tonnes of paper per day would require about 78 million cubic metres of water per year.If we apply the high-water use figure of 500, the result is 519 million cubic metres of water per year.

These pulp and paper figures are much higher than those highlighted in the previous section for fracking, and comprise a much larger percentages of total available resources and withdrawals in the province. Nevertheless, they are likely an underestimate, as there are probably more than three paper mills in the province: our cursory internet research suggests there are at least four or five. This further supports our analysis that shale gas production will pose relatively low water resource risks at provincial level when compared with existing uses, at least in terms of its water (versus potential pollution) footprint.

3.1.3 Management of contaminated water before and after the fracking process is a critical issue, posing risks to both surface and groundwater resources

The fracking process both uses and produces large volumes of contaminated water that can be expensive to manage and pose a pollution threat to other resources

The large water demand and dispersed nature of fracking activities together create a challenge for managing the contaminated water the process requires and produces. Drilling and fracking use water mixed with an amount of sand and proprietary chemical additives prior to injection that is a relatively small proportion of the consequent solution but may be large in absolute terms. These chemical additives can include toxic and carcinogenic compounds, creating a risk to water quality if some of this injection water spills or is discharged inappropriately (Shonkoff et al., 2014). Mixing usually occurs on site, which makes spills a real risk, as we discuss further below.

Once injected for drilling and fracking, a portion of this water returns to the surface with even higher levels of contamination and cannot be used for any other purpose without expensive treatment (apart from being recycled into other fracking jobs). Of the 3-8 million US gallons on average used to frack a well, anywhere from 20-80% of this will flow back out of the well in the weeks immediately following the fracking as 'flow-back water', depending on the geological properties of the rock formation (Zammerilli et al., 2014). More water (some of it naturally occurring within shale formations) will then flow out gradually from the well as it begins to produce the shale gas, known as 'produced water'.[43] Both types of water are always polluted, though their level of pollution varies between different shale basins, as mentioned earlier in the context of their potential to be recycled.

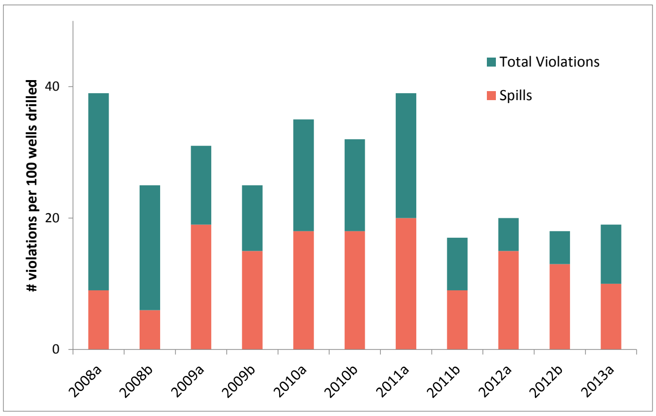
In any case, fracking will generate a large volume of flow-back and produced water that will damage the environment if it is discharged without treatment. The water contains high amounts of dissolved solids, salts, heavy metals, oil, grease, shale gas, naturally occurring radioactive materials from the shale rock and chemical additives from the fracking process, among others. These often occur at levels that are toxic to microorganisms in standard laboratory

---

[42] Production data for the three mills identified in Chongqing suggest average production of around 1,000 tonnes of paper per day (CLPIC, n.d.; NDPHL, 2007; Sanderson, 2014). Alongside this, data on the water use of Chinese paper mills suggest it varies between 75 and 500 cubic metres of water per tonne of paper produced (Carmody, 2010; Xie et al., 2009). Mill activity pollutes this water and we assume Chinese mills still discharge most of this polluted water without treatment – essentially a non-recoverable fraction of withdrawals. We assume mills operate for 346 days of the year (OECD, 2004).

[43] The remaining water left in the shale formation is theorised to absorb into the shale rock in most cases (Vidic et al., 2013).

Figure 10: Number of violations issued by Pennsylvania's Department of Environmental Protection that represent individual events of concern with respect to risks to water resource, by six-month time increments



*Note: * Violations normalised to number of wells drilled within the same six-month period.*
Source: Rahm and Riha (2014).

tests and are able to cause adverse health effects to humans (Alley et al., 2011; Colborn et al., 2011).

The potential for this wastewater to cause harm in the environment if directly discharged is difficult to estimate but probably substantial. Commentary by Al et al. (2012) speculated that a 100:1 dilution factor of freshwater with this wastewater would be insufficient to protect the environment from its negative effects. Jiang et al. (2014) estimated that if all the flow-back and produced water from an American Marcellus shale gas well were released into the environment without treatment, the water would have high potential for carcinogenic effects, eutrophication, ecotoxicity and non-carcinogenic effects. It would be equivalent to releasing hundreds of kilograms of benzene, hundreds to thousands of kilograms of nitrogen and herbicides and millions of tonnes of toluene into the environment, respectively. In addition, the Marcellus shale is known for better wastewater quality than other US shale basins (Zammerilli et al., 2014), which implies the magnitude of this risk is even higher elsewhere.

There is good evidence to suggest these large volumes of contaminated water are difficult for the industry to manage on site. A review by Rahm and Riha (2014) found surface-level spills of contaminated water (either prior to or after the fracking process) were the most common industry violation, with 5-20 violations per 100 wells drilled in the US from 2008 to 2013. Figure 10 displays this. Most of these spills are likely small in volume, but could pose a cumulative risk. Spills are not unique to shale gas operations, but the potential pace and scale of fracking activities could cause them to become a significant water quality risk at the local scale if not appropriately managed (ibid.).

Wastewater injection creates risks of groundwater contamination and induced seismicity, although it is inexpensive for the developer and reduces the risk of surface water contamination

Methods to manage the wastewater from fracking carry their own risks. Rather than treat this water, many of the shale gas companies in the US simply inject it into porous rock formations deep underground, to save money.[44] The companies either drill wells specifically for this purpose or use those from other expired oil and gas plays (Zammerilli et al., 2014). Clark and Veil (2009) report that the US shale gas industry injected more than 98% of its produced water in 2007. The Wilson Center (Marsters, 2012) reports that Chinese companies in Sichuan are also beginning this practice. This need not be the only option, though: recent work by Freyman (2014) in the US context shows that, in some regions, up to 100% of produced water can be recycled.

The practice of deep injection creates three main environmental risks. The first is that it results in the permanent loss of the produced water: several million US gallons of water are removed from the near-surface water cycle. In other words, the practice decreases the amount of readily available water for other uses and users.[45]

The second is the risk of aquifer contamination. If disposal wells are not adequately sealed or are isolated from other aquifers, the injected water could migrate toward these aquifers and contaminate them. This has been recorded in the US, although debates continue regarding the extent of the problem. The US EPA regulates the wells and insists its approach is safe, but faces an immense workload in doing so, with nearly 150,000 existing injection wells in use by the oil and gas sector (EPA, 2014). The situation is complicated by the fact that individual states hold much of the responsibility for oversight. A review of inspection records in 2012 found high rates of well failure, with one in six well inspections identifying an integrity violation between 2007 and 2010 (ProPublica, 2012). A recent US Government Accountability Office (GAO) report (2014) supports this, finding failures in this regulatory approach and recommending significant improvements.

The third is that the practice has raised concerns about its potential to trigger earthquakes. A review of the evidence by Zammerilli et al. (2014) suggests deep injection

---

[44] Other options include evaporating this water and disposing of the leftovers as solid waste; sending it to conventional water treatment plants; or discharging it to the surface environment. The first option is expensive and works only in hot climates, the second is legally insufficient in the US because conventional water treatment does not remove some of the contaminants and the third is usually forbidden in the US without expensive treatment (Zammerilli et al., 2014).

[45] That said, the injected water could still be recoverable if it is pumped back out of the disposal well. It is not gone 'forever', but simply physically removed from the water cycle.

may, under certain circumstances, induce seismic activity. Most of this evidence suggests earthquakes become more likely if the deep injection relieves the pressure on a nearby fault that is already under tectonic stress. Experience to date suggests the hydraulic fracturing process is not widely thought to lead to induced seismicity unless the drilling or fracturing processes connect with an existing stressed fault (e.g. DOE, 2014a; Jackson, 2014). Research in Canada demonstrated both fracturing itself and wastewater injection highlighted that both processes were linked to induced seismicity (BCOGC, 2014). However, this was true in only a small number of cases (approximately 2% of hydraulic fracturing activities) and none of these observed episodes were strong enough to cause damage at the surface (ibid.). In the US in particular, disposal of water by underground injection is thought to pose more of a risk owing to the long period over which stress is exerted on the formation, with a number of wastewater injection facilities linked to induced seismicity (Jackson, 2014).

The high-pressure fracking process also poses a contamination risk to groundwater, through the technological failure of the fracking wells or neighbouring wells

The fracking process itself, with its high pressures, can create a risk to groundwater quality when industry best practices are not followed. However, our research indicates this is not as significant a risk as that posed to surface waters. Most evidence suggests the short-term pressures created during the fracking process do not induce seismic activity (Zammerilli et al., 2014). However, there have been a few recorded instances of the fracking process resulting in contaminated water and methane migrating up into the shallow groundwater zone near the surface (ibid.). This has occurred when the vertical wellbore has had inadequate or improper casing and cementing. It has also occurred when the fractures from fracking have connected with existing fractures, faults or other neighbouring wells in the local geology that were not accounted for, or when the fractures from fracking grew over time to connect with the overlying aquifers (ibid.). In all three cases, the risk of upward migration decreases as the depth of the well increases, since any pathway must cross an increasing number of rock strata, some of which are likely to be impermeable. This suggests the risk will be greatest in fewer sites, but equally emphasises the importance of identifying geological risks at the feasibility and design stages and empowering regulators with the ability and incentives to change or even prevent sites where groundwater risk is too high. Since Chinese shale reserves are generally several thousand metres deeper underground than US reserves, we would expect these risks to be lower, even if best practice is not followed. A clear exception to this is where previous oil and gas exploration and production have created man-made pathways. Here, potential connection with these pathways and their ability to withstand the pressures sustained during hydraulic fracturing also need to be assessed.

Leakage of fracturing fluid from the vertical section of the wellbore may occur if poor construction techniques are used during the drilling, lining or cementing of the well (e.g. Darrah et al., 2014). Conventional well design involves a number of concentric layers of steel and cement that isolate protected groundwater from deeper water-, brine- or hydrocarbon-bearing zones (Zammerilli et al., 2014). If these layers are designed and constructed correctly, they should withstand multiple exposures to the high-pressure fluid during the multi-stage fractures of the well in the vicinity of the shale rock. Adequate construction of such wells and monitoring of a well's integrity during high-pressure operations is a common practice in the extractive industry. Thus, this suggests there is no technical reason why this risk should not be easily mitigated if the correct construction and monitoring procedures are required to be in place. However, the ongoing problem of well failures suggests non-technical challenges remain, such as general negligence and cutting corners by industry owing to a lack of regulatory oversight (Jackson et al., 2014; Mordick, 2014; ProPublica, 2012; Rahm and Riha, 2014).

We do not have enough data from the nascent Chinese shale gas industry to quantify its risks to water quality

We can run a simple analysis to assess the fracking-related risks to water quality from China's shale gas production targets. Few locally-specific data are available to talk sensibly about the cumulative risks from surface discharge or subterranean injection of fracking wastewater. We know volumes of wastewater generated will be similar to or less than volumes of freshwater withdrawn, but we do not know how the toxicity of fracking wastewater ranks in comparison with the wastewater of other industries, beyond a rough assumption we make for coal (see Section 3.1.5 below). We have no data on the mix of industries in these provinces/regions and the volumes and strengths of their wastewater discharges with which to compare fracking. Without these data, we can only guess that the impact of fracking wastewater discharged to the environment may be proportional to the impacts of other industrial wastewater in the same ratio as their freshwater withdrawals.

If the Chinese shale gas industry will rely heavily on subterranean injection, then this raises concern about non-recoverable losses of water. If we assume 100% of

---

46 This is probably achievable, since the EPA (2014) reports that the US oil and gas industry injects about 7.6 million cubic metres of wastewater per day into subterranean wells – about 2.7 bcm per year – much of which is used for enhanced oil recovery. This takes place mostly in the states of Texas, California, Oklahoma and Kansas, which present a geological land area of similar size to Sichuan, Chongqing and Xinjiang. However, its achievability does not negate the risks it poses, as we discussed earlier.

fracking's freshwater withdrawals are permanently 'lost', then China would need to inject about 23 million cubic metres of wastewater per year into subterranean wells by 2020. This is probably achievable,[46] but introduces risks related to permanent water consumption, groundwater contamination and seismicity that would otherwise not occur.

Overall, the wastewater from fracking and the methods used to manage it create risks for water quality, as does the fracking process itself. These risks persist for most fracking activities and are less dependent on the local context than the water resource risks. We view these contamination risks as potentially more difficult for China to manage than the water use risks, especially since the prevailing management technique of subterranean injection carries its own set of hazards.

3.1.4 If shale gas development can displace coal-fired electricity generation, it may reduce pressure on water resources

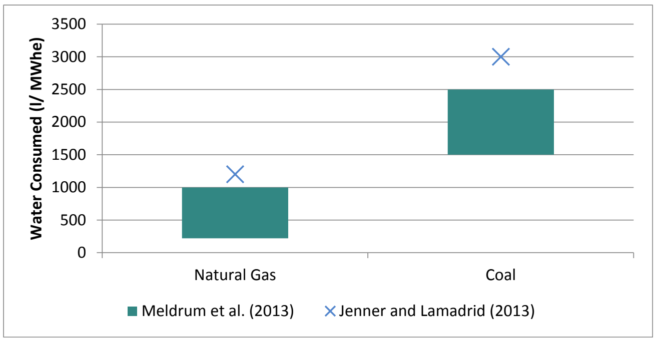
Shale gas development is not exclusively a risk-bearing activity – it could result in net water savings if it offsets a *status quo* of coal-based energy production. Fracking will clearly create risks to water resources and quality, but these may be lower than those existing energy sources like coal pose.

The comparison is particularly relevant for China, which is the world's largest coal consumer and plans to construct several hundred more coal-fired power plants in the coming years. A recent analysis found China might build more than half of its proposed plants in areas with high water stress (Luo et al., 2013). If shale gas could supply the same amount of energy with less water, this could help reduce the otherwise major risks to water security that this coal expansion will bring.

In terms of water resources, most authors agree shale gas as an energy source will 'consume' (through evaporation) less water overall than coal. In both cases, most of the water consumption comes at the combustion and generation phase rather than at the extraction phase. Jenner and Lamadrid (2013) found the water consumption requirements for coal and shale gas were similar at the extraction and processing phase but significantly lower for shale gas at the combustion phase. On average, coal combustion consumes nearly 2.5 times more water than natural gas combustion: ~3,000 litres per megawatt hour of electricity generated compared with ~1,200 for natural gas. A Meldrum et al. (2013) provide similar estimates, giving ranges for lifecycle water consumption of between ~220 and ~1,000 litres per megawatt hour for natural gas and between ~1,500 and ~2,500 for coal.

We can consider the implications of a switch from coal to natural gas for China's water resources with a few simplified calculations. We use the forecast from Luo et al. (2012) that China is proposing to construct an additional 557 GW of coal-fired energy capacity as an illustrative example, although this may now be an overestimate, given recent environmental commitments. If we examine only the water requirements for combustion (which composes about 98% of the lifecycle water use of coal and about 91% for shale gas), this would require about 14 bcm of water consumption,[47] which would constitute more than 2% of the country's total water use in 2012 (NBS, 2013). Shale gas, by contrast would require only about 6 bcm and constitute less than 1% of this total water use. Replacing this coal capacity with shale gas is possible – it would require about 1 trillion cubic metres of shale gas to be extracted in the aggregate,[48] while China's total reserves are estimated at around 31.6 trillion cubic metres (EIA, 2013c). At least at the aggregate level, therefore, shale gas seems to offer a 'greener' alternative for water resources compared with 'business as usual', although this will depend heavily on how the local risks from fracking are managed and whether it actually displaces coal generation, as discussed earlier.

Figure 11: Estimates of lifecycle water consumption for coal and shale gas used to produce electricity



Sources: Jenner and Lamadrid (2013); Meldrum et al. (2013).

The large volume of contaminated water produced by fracking also continues to pose a pollution risk, particularly to surface water. In terms of water quality, we have not seen a study that attempts to rigorously compare the pollution risks from coal mining and fracking separately for China, although examples exist for the US and we expect issues to be similar (Grubert et al., 2012; Jenner and Lamadrid, 2013). Coal mining uses water for cooling, cutting and suppressing dust in the mines and for washing the coal once removed from the mine, to remove impurities like sulphur and mercury. Wastewater from these processes can contain heavy metals, sulphurous compounds, other chemicals added to the water during the washing process and other acidic compounds that can create the pollution effect known as acid mine drainage.

---

[47] This assumes each power plant would operate for 350 days of the year.

[48] This assumes 1,000 cubic feet of natural gas can produce 127 kWhe (EIA, 2014d).

Spills of this wastewater in the US have resulted in significant environmental damage (Allen et al., 2012).

The wastewater from fracking contains a variety of differing compounds, making the nature of its risk difficult to assess fully or to compare with alternatives like coal mining. This difficulty should be cause for heightened rather than lessened concern. Further, the volumes of wastewater that both fracking and coal mining processes generate will be similar, because both processes consume a similar amount of clean water. Therefore, in terms of water quality, fracking does not appear to offer a 'greener' opportunity as compared with coal mining, and poses considerable risks of its own.

3.2 Recommendations: managing shale gas' water impacts

3.2.1 Regulators must be empowered with the appropriate authority, data and institutional capacity to manage water allocation

Managing water resources effectively first requires reliable and comprehensive data collection and dissemination

Assimilating water measurements and providing them at a level that is useful to regulators is key to ensuring water resources are well managed during the development of a shale gas industry. In addition to sound accounting data on flows and losses (see above), baseline data on water resource conditions – both quantity and quality – are needed for benchmarking.[49]

Although fracking will create acute risks to water resources predominantly at local level, it will be possible to better control these risks by understanding water resource flows at larger scales. When water resource and usage data are detailed and easily accessible, project developers and regulators can take better account of this reality in their decisions. Just as fracking creates risks based on the location, timing and frequency of its withdrawals, these variables can also be used to manage the risks. As a simple example, a proposed shale gas project may pose high risks to a local water-stressed river, but could achieve the same level of production at much lower risk if relocated a few miles to a nearby river with less existing water stress.

In China, it is currently unclear whether regulators at various scales are able to access and use data in this manner to respond to water resource risks. To investigate this, we reviewed a variety of publicly available industrial project approvals by the Yangtze River Basin Commission, as well as different project approvals by the environment department of the Chongqing regional government within this river basin. In both cases, project approval documents did not appear to use water resource and usage data to assess the relative scarcity risks posed by the new project and any potential mitigation measures. While we cannot conclude from these two samples what are the broader availability and use of water data in project planning, we equally cannot conclude, given the absence of these data, that they are generally applied. Indeed, it is unclear whether water resource regulators are ever able to consider the full extent of basin-, provincial- and local-level withdrawals in their decision-making. Different line departments at different levels of government take responsibility for different types of project approvals, and a centralised database of all individual users was not readily identifiable from our research.

New project approvals should be based on assessment of existing water demands and potential trade-offs

Water resource issues are rarely the main determining factor in the planning and siting of an industrial development, whether shale gas or otherwise. However, this does not mean they should be overlooked or considered only after all important development decisions have been made. Water allocation management is improving, as Section 5 discusses.

We conclude that China needs to manage the water quality risks of fracking more urgently than the risks to water resource availability. Whereas issues around competing water demands can be dealt with at the design and planning stage of a fracking project, water quality risks persist throughout the project cycle and require a more interventionist regulatory approach. Although the mechanisms for contamination of freshwater and groundwater resources differ, dealing with these risks broadly requires the same two-pronged approach: standards must be enforced at the site where the risk may occur while also monitoring the ambient resource to detect whether contamination occurs.

Managing water quality is an urgent issue for China beyond just fracking activities. Surface water quality has reportedly improved since 2003, but about 30% of river samples from 10 of China's major river basins were still classed as 'heavily polluted' in 2012 (MEP, 2003, 2012). Meanwhile, the country's groundwater quality is steadily worsening, with recent reports finding that 60% of sampled urban groundwater wells were polluted and 16% of the country's soil was polluted (Kaiman, 2014; MEP, 2014a). China's government is working hard to address this problem, recently declaring a 'war on pollution' and investing heavily in new environmental policies and industrial inspection programmes (Doczi et al., 2014). However, the government has sometimes struggled to

---

[49] For example, seasonal variation in river flows or reservoir levels.

translate national ambition into local results, even through the ‘target responsibility system’ (see Section 4).

Table 4: An overview of the potential types of standards China should develop to prevent surface water contamination from the various steps of the fracking process

Process step	Potential standards
Water withdrawal	Type of withdrawal device, method, location and timing
Water transport, mixing and storage	Type of containment device and transport methods for water, sand and chemical additives Location, process and method of mixing Type and location of storage container prior to injection For all three, sub-standards on specific technologies or practices, e.g. on above-ground pits
Water injection for drilling and fracking	Method of transferring water from storage containers to the well Method, volumes and pressures of injecting the water to the well
Collection and storage of flow-back and produced water	Method of capturing and separating flow-back and produced water from the shale gas Method of transferring water to storage containers Method of tracking the movement of wastewater from collection to treatment and discharge, e.g. via manifest forms Type and location of storage container
Treatment and discharge to surface water bodies	Method of transferring water from storage containers to treatment facility Minimum necessary treatment processes/sites permitted to treat shale gas wastewater Timing, volumes, monitoring and quality of discharge of the treated water, depending on the type of receiving surface water body
Throughout	Spill response measures in place and staff adequately trained on them Regular safety and process quality checks Regular environmental quality monitoring, including a baseline study prior to the start of site development, with monitoring data to be made publically available Environmental management systems (e.g. ISO 14000 series) in place

Managing surface water contamination risks requires site, effluent and ambient standards and monitoring and robust response procedures

An effective system for managing the risks of fracking to surface water quality will need to implement a combination of appropriate industry standards, monitoring systems and incident response procedures. These should work together to promote industry best practice and minimise risks that arise throughout fracking, which include those from withdrawal, storage, mixing, injection, collection, treatment and discharge of contaminated water. Standards should include a mix of:

- Technology standards;
- Process and performance standards;
- Discharge standards and monitoring requirements for different types of surface and groundwater bodies and monitoring of downstream environmental quality.

Table 4 provides an overview of the types of standards an effective regulatory approach may apply to various stages in the fracking process. A factsheet by the Natural Resources Defense Council (NRDC) (2012) provides a similar overview of recommended standards to avoid water contamination.

As we discussed earlier, Rahm and Riha’s (2014) review of US fracking violations emphasises the importance for Chinese regulators to focus on spill prevention and response for protecting surface water quality. Since spills are a persistent problem even for the mature shale gas industry in the highly regulated US context, we anticipate them to be a major problem for China’s younger and less regulated industrial context. China will need to empower its regulators to manage this risk, but also to evaluate regulators on the basis of industrial environmental performance and ambient water quality.

Managing groundwater contamination requires well integrity and drilling standards, and robust procedures to assess the sub-surface environment prior to, during and after the fracking or wastewater disposal process

China will need to make use of a similar set of regulatory tools to manage the risks of fracking to groundwater quality as for surface water quality, though, in this case, the risks are less well understood. As such, China’s regulatory approach will need to be more pragmatic and reliant on the precautionary principle,[50] while updating standards regularly to account for new advances in sub-surface monitoring and assessment.

As we discussed earlier, risks to groundwater occur in both the fracking process and the process of wastewater disposal via subterranean injection, so both processes need to be adequately regulated. The potential regulations are similar for both. In both cases, the most significant risk is that of contaminants migrating from their intended

---

[50] The precautionary principle is a risk management approach that emphasises the avoidance of potential harm in the face of uncertainty. If an action has a suspected risk of causing environmental harm and if there is no scientific consensus that the action is not harmful, then the burden of proof that it is not harmful falls on those taking the action, else the action should not proceed.

location to aquifers and other surface water that supply other users. This can occur if the wells are poorly designed or constructed, or if the deep formation where fracking/disposal occurs contains fault lines or other pathways for contaminated water to migrate upwards. Unless shale drilling occurs in an area that already has a number of known migratory pathways[51] – where it may be preferable to avoid drilling altogether – the latter risk is probably lower than in the US, given that most of China's shale reserves are much deeper underground than those in the US. This geological fact certainly does not eliminate the risk: we suggest Chinese regulators focus their efforts on ensuring good awareness of potential migration pathways and well integrity at the project scoping and design phase, and during permitting.

Likewise, despite relatively tight regulation and a well-established industry, well casing violations continue to occur in the US shale industry (Jackson et al., 2014; ProPublica, 2012; Rahm and Riha, 2014), so we expect even more to occur as the new industry develops in China unless regulations keep pace. Current industry best practice recommends a multi-barrier design in vertical well construction, including several concentric layers of concrete and steel, with the outer layer cemented firmly to the rock face (Zammerilli et al., 2014). The cement and layers should be allowed to adequately dry and harden before further work begins, and the well should also be pressure-tested for leaks. A regular monitoring regime should inspect wells for integrity violations thereafter. Embedding such practices as industry norms now, particularly the cycle of regular monitoring and reporting, will avoid the need to impose changes on the industry in the future. Here, as with many other aspects of environmental protection, China has the potential to learn from the experience of the US and avoid the same levels of environmental damage.

Although it may pose a smaller risk in the Chinese context, the industry should still be required to undertake careful assessments of the sub-surface environment prior to and after the fracking or disposal process. Doing so can help identify potential fault lines or other geological features that could threaten surface aquifers or the integrity of the well. Water quality in the surface aquifers should also be regularly monitored, ideally with the data made publicly available. In doing this, Chinese regulators should understand that monitoring techniques to detect groundwater contamination from fracking wastewater are still evolving and should give their monitoring systems the flexibility to advance along with new research in this area, while incorporating the decades of experience gained from conventional oil and gas production.[52]

Data on additives used in hydraulic fracturing must be disclosed to regulators and to the public

The US shale gas industry initially kept secret the identities of many of its chemical additives in fracking water, although now it is simply the 'recipe' of these additives that is unknown (McFeeley, 2014; US House of Representatives, 2011). Disclosure laws vary significantly between states. Some states mandate the release of general information on the types of compounds added and their general functions (e.g. API, 2014; FracFocus, 2014), although full disclosure of additives and their concentrations is not yet widely carried out. In part, this is because the ingredient lists and concentrations differ for every fracking operation, depending on local site characteristics. However, most companies have not been willing to voluntarily offer this information either. They argue unique formulations of additives affect shale gas yields and are a source of competitive advantage.

However, this secrecy creates a challenge for water quality regulators. Without knowing the specific recipes of chemical additives in fracking water, these compounds cannot be accurately tracked in the event of a discharge of wastewater. This is problematic for two reasons. First, it makes it harder to track the source and either apply measures to stem the discharge or undertake remedial measures to the environments and populations the discharge may have affected. Second, a failure to disclose the additives used prevents identification of which well or company was responsible and the apportioning of liability and imposing of punitive measures. By knowing effluent composition, regulators know what to look for when monitoring and can perhaps trace spills back to their source. In addition, since different contaminants require different water treatment options, knowing what is in place when the water goes into the well helps decide whether the treatment options and risk mitigation strategies proposed are suitable.

For these reasons, we support the open, mandatory publication of additive recipes used in fracking operations. This would ideally occur on an independent, accessible portal. The US has historically relied on a self-reporting system, FracFocus, that a number of fracking operators have endorsed but the environmental organisations have criticised (McFeeley, 2013) for failing to meet minimum standards for managing government records and public access to information.

---

[51] For example, if drilling is in an area where a number of previous wells have been drilled for prior fossil fuel extraction, or if the geology of the area is known to be heavily faulted.

[52] For example, a recent advance by Warner et al. (2014) proposes a new method of monitoring particular isotopes of lithium and boron to identify the presence of fracking flow-back water in a water sample. Such a technique highlights the technical feasibility of identifying, tracing and prosecuting contaminating operators by regulators where there is adequate political and fiscal commitment to do so.

In addition to avoiding the problems mentioned above, data disclosure presents a number of opportunities for the industry as a whole. For regulators, disclosure provides enough information to update water quality monitoring regimes and to inform assessments of company wastewater treatment and risk mitigation proposals. For central government, it allows more confidence in the reliability of evaluation measures, by assuring underlying data are accurate. For companies, the process does not necessarily involve sacrificing competitive advantage and instead creates a pressure to innovate and move towards 'cleaner' operations. Together, these factors contribute to building public confidence in the credibility of the industry. Positive engagement with the local population is essential for successful industrial development, particularly in areas where shale basins neighbour population centres.

4. Land and local impacts: handling impacts and trade-offs for land use and local populations

Summary: land and local impacts

The development of a shale gas also creates a number of more localised environmental risks: air, noise and light pollution; land erosion and compaction; and increased seismicity, particularly where wastewater is being re-injected for disposal. These harms may substitute worse ones at the site of coal mining production, making the aggregate impact smaller, but this has little significance for locally affected communities, except where these alternatives are at the same site. Further, while the impacts at individual well sites may be small, proliferation of wellheads across a landscape can result in bigger aggregate impacts.

Any sensible gas development strategy will moderate local impacts and consider the equity implications they create between local and regional or national interests. Of course, any environmental governance regime should have environmental management requirements to allow regulators to review the geological and technical aspects of the site and permit on the basis of specific impacts. Above and beyond such management measures, three traditional land use planning tools in particular may facilitate better local environmental management and improve on early-stage shale gas policy in the US: land use planning, compact siting and public disclosure and participation. Most industrial activities are locally noxious even when well managed, but even locally noxious land uses may sometimes be desirable in the context of larger environmental protection and management. Land use planning that concentrates extractive operations, and sites them away from vulnerable populations and environments, can be an effective practice for environmental management. Clustering of well siting also offers significant opportunities to reduce the regulatory burden stringent environmental governance poses.

Given the potential harms to and trade-offs for local communities, the decision-making process for siting should involve material participation of local stakeholders, transparent explanations of the likely trade-offs and a respected system to monitor and evaluate the potential impact of any harms arising during operations. Such approaches to noxious land uses are a common component in environmental law and policy, but a patchwork of state-level approaches in the US has led to poor local environmental protection, with these harms resulting in significant backlash against the industry. China has the opportunity to do better from the outset.

4.1 Risks and opportunities: the impact of shale gas on local populations and environments

Developing an unconventional gas site creates a range of consequences, some of which have negative impacts for local communities, environments and ecosystems, although these depend on when, how and for how long the negative outcomes are felt. For example, consequences for aquatic environments may be more impactful during times of drought or in areas with lower water availability; the impact of a consequence of developing a fracking site on a given ecosystem depends on the ecosystem's resilience; and impacts on local animal populations may more pronounced during specific periods of vulnerability such as breeding or migratory seasons. Given this, as Brittingham et al. (2014) point out, the following section can provide only general coverage of potential impacts. China's prioritisation of national developmental and industrial considerations may also dwarf these concerns from a policy perspective. However, it is important to highlight the nature and presence of some of the more prominent local impacts to help identify what we take to be sensible policy and management approaches.

4.1.1 Local air, noise and light pollution can be acute during fracking shale wells

Air pollution is material during production but comparable with other gas operations

At the production site, emission of air pollutants is likely to increase. While material, these are likely to be in line with those from conventional gas production. Moreover, their impact depends on the proximity of vulnerable populations. Emissions of air pollutants at the site may arise from multiple sources, including, but not limited to, machinery used in drilling or hydraulic fracturing, compressors or gas separation equipment employed prior to transport by pipeline or the many engines used in transporting materials and machinery to or from the site. One study (Litovitz et al., 2013) suggested the absolute magnitude of emissions of air pollutants was small (less than 1% of industrial emissions of VOC, PM and SO_2 and 2.9-4.8% of NO_x emissions in Pennsylvania – where shale gas extraction is a large industry – were attributed to shale gas production), but was concentrated according to well density and at high densities could be comparable with emissions from a power station.[53]

These figures may be in addition to the exhaust emissions from trucks delivering and removing equipment and materials (primarily water and fracturing additives) to/from the well site, which will be emitted along transport routes. Estimates for the number of truck movements vary, though an average 5 million gallons of water would alone require approximately 1,000 movements per well (Stark et al., 2014), which may correspond to significant localised emissions depending on the transport infrastructure in place. Again, the impact of these emissions is highly dependent on the location in which they are emitted.[54] Concentrated episodes of noise and light pollution can be severe and negatively impact the health of local populations and environments.

Intense light and noise pollution can occur during fracking operations

Particularly during drilling and hydraulic fracturing, relatively intense activity occurs non-stop at the well site. The activity itself creates noise pollution and sites are typically lit through the night to permit continuous operation. Although in the US the combined period of these activities is normally considerably less than a month for a single well, in China, where the technology is less mature and the geology more challenging, such operations currently persist for longer, particularly while the technology is still maturing. Similarly, the drilling of multiple wells from a single site in a consecutive fashion would extend the period accordingly. Both noise and light pollution have a disruptive impact on both local human and animal populations (Brittingham et al., 2014).

4.1.2 The aggregate effects of shale production can lead to significant land use impacts

The construction of hydraulic fracturing sites and associated infrastructure leads to direct habitat destruction and fragmentation

Brittingham et al. note (2014) that, although the size of a typical well pad is only 1.2-2.7 ha, an extra 2.9-3. 6 ha of habitat per well pad is either lost or converted because of infrastructure development (pipeline and road access). While the establishment of the well pad and pollution (noise, air and water) directly affects ecosystems in the very localised area, the impact of infrastructure development is more likely to cause fragmentation of ecosystems. Fragmentation can occur if, for example, land is cleared for a pipeline, road or seismic pathway[55] that bisects a forest, or if such a development crosses existing streams or rivers and blocks or impedes their pre-existing passage. This has been shown to be responsible for a number of negative impacts for sensitive species (ibid.). Further fragmentation occurs with the establishment of numerous wellheads across a landscape.

A large number of movements by trucks and heavy machinery can lead to land erosion and siltation of water courses

Hydraulic fracturing requires delivery and removal of large quantities of water across short periods, even with temporary storage on site (which brings its own risks). With 1,000-1,600 truck movements per site in a short period of activity, significant erosion and siltation impacts have been widely observed in areas without adequate road infrastructure in place to protect against these impacts. Compaction of road surfaces and the removal of stabilising vegetation can lead to erosion (directly and following enhanced water runoff), while siltation can occur when eroded material is transferred to water courses. Studies have documented increases in these phenomena, with the lack of baseline data in the US thought to have largely prevented a fuller analysis of these impacts. Nonetheless, both well pads and unpaved roads have been found to

---

[53] Brittingham et al. (2014) also emphasises the need to appreciate the cumulative effect and concentration of well sites.

[54] For example, if the emissions occur in a location that does not lend itself to rapid atmospheric mixing (which would help disperse the pollution) and is close to sensitive ecosystems or dense human populations, then the impacts will be substantially larger than for a well in an open, flat, unpopulated area with few local ecosystems.

[55] A 'seismic pathway' is the surface route along which subsurface seismic measurements are taken.

increase runoff and affect the volume and characteristics of local water courses (Brittingham et al., 2014).

4.1.3 If coal is displaced by gas production, it is likely to reduce associated environmental impacts at coal mines

To fairly compare the net aggregate impacts of a development in shale gas production, if it is to substitute coal any increase in shale gas production should be met with an associated decline in coal production, particularly if the approach outlined in Section 2.2 is implemented. In such a case, the local impacts associated with coal mining and processing should also be taken into account. The negative impacts of coal mining on air, water and land resources are well documented (UNEP, 2000), with any decline in this activity expected to yield a benefit at the mining and processing sites.

However, even if aggregate local impacts may be smaller if gas production replaces coal production, this has little significance for the scope of local impacts except where these alternatives are at the same site. Sensible environmental governance of local risks will still have to take into account the effect of development on populations directly affected by individual mines. Even if much of the impacts are comparable with other industrial uses, this may constitute a significant impairment of ambient environmental quality where, for example, no industrial activity previously existed.

4.2 Recommendations: managing shale gas' impacts on local populations and environments

4.2.1 Many regulatory tools that apply to existing industry can be effectively employed to oversee the development of shale gas

Many of the potential local impacts that may arise from a developing shale gas industry can be controlled or mitigated through existing frameworks designed for similar industrial activity. Indeed, one may attribute a significant proportion of the worst environmental impacts in the US to the fact that the activity was exempted (by the 2005 Energy Act and a number of prior laws) from complying with a number of federal environmental protection laws (Brady, 2012; Kosnik, 2007).[56] It is, however, important to note that, while it is possible that a developing shale gas industry may be largely well regulated 'on the books', the effectiveness of oversight hinges on the fiscal and technical capacity, and empowerment and independence, of the regulator tasked with implementing that structure, and in the priority it is given in targets and cadre evaluations.

4.2.2 Balancing oversight of land use planning between regional technical expertise and local knowledge is key to ensuring impacts are minimised

Advances in horizontal drilling permit use of conditional zoning, which is key to separating and reducing the risks of any industrial activity from those most vulnerable to its effects

Empowering local authorities to use conditional zoning laws to determine shale gas well locations can complement regional technical expertise for resource targeting, but the balance of power between the two must be shared. Directional drilling allows companies drilling unconventional wells to design their well trajectories to minimise interference both above and below ground. Below ground, wells may be directed to avoid connection with faults and previously drilled wells. Above ground directional drilling allows operators to site their wells in places that create the least impact, segregating them from local populations and environments, while still having access to the resources. This zoning of shale gas wells will not likely change the immediate local consequences of shale gas development, but it can ameliorate the impact of those consequences by designating industrial zones and buffering them from activities. There are inevitable trade-offs in the context of Sichuan in particular, because of its densely populated agricultural landscape.

Ensuring wells are drilled in locations that are optimal, given technical and local geographical conditions, requires both local, site-specific knowledge and technical expertise. Shale plays stretch across entire regions; it is unlikely every municipality will have the technical expertise and capacity to assess geological data to inform the siting of a shale well. This degree of expertise and resource is likely to be concentrated at a regional level (in the US normally at state level). Conversely, regulators at the regional level cannot be expected to have sufficient local knowledge to inform the impacts of siting a well in a given location; this requires input from municipal authorities on which areas are most compatible with local populations' desires and least disruptive of vulnerable environments.

Given this, most shale gas development in the US initially occurred by way of a dual-permitting system, with state authorities overseeing the technical section and municipal zoning laws used to involve municipal planning authorities. However, recent legal challenges in some states suggest attempts to 'streamline' the process resulted in state legislators pre-empting local lawmakers'

---

[56] Exemptions for hydraulic fracturing included for the Safe Drinking Water Act; the Resource Conservation and Recovery Act; the Emergency Planning and Community Right-To-Know Act; the Clean Water Act; the Clean Air Act; the Comprehensive Environmental Response, Compensation and Liability Act; and the National Environmental Policy Act.

ability to decide on well location (Horner and Clark, 2012). Given the various regional and local expertise and drivers,[57] it is essential that both authorities be involved in the permitting process.[58] As well as defining well location, municipalities may be given the option to grant conditional permits that require mitigation measures to be taken for any well development. Conditional permitting allows local authorities to manage risks that zoning alone cannot mitigate and may engender stronger public support if the local authority requests concessions benefiting the local community (Adair et al., 2012).[59] Clustering will intensify operations and associated emissions but can reduce landscape-level impacts and makes managing the impacts of these outputs less of a regulatory burden.

As with any industrial land use, clustering such operations together, away from densely populated areas, and other land uses not compatible with the inherent impacts of industrial activity (such as reservoirs, agricultural land, etc.), is a standard method to manage industrial environmental risk. Where operations are effectively zoned away from areas they may impact, intensification of drilling at each well pad could lead to a number of options for net reductions in negative environmental impacts compared with the same number of wells drilled at disparate well sites. Potential net benefits include an overall smaller environmental footprint of both well pads and associated infrastructure; a greater incentive to reuse water for fracking operations, thereby reducing local water withdrawals and the need for treatment of contaminated wastewater; and sufficient economies of scale to invest in technologies and infrastructure that improve the environmental performance of the well site, including for water treatment and handling, for improving gas handling and limiting fugitive gas emissions and for developing infrastructure, such as paved roads in a way that creates a lesser impact on environments and ecosystems overall. From a regulatory point of view, perhaps the largest benefit is that concentrating wells in specially designated sites can significantly reduce the burden of permitting, monitoring and regulating shale gas production.

4.2.3 Establishing the requirement for data collection before drilling begins

Collecting detailed geological data before drilling to highlight and avoid existing subterranean infrastructure and faults that may induce seismicity if activated or provide a route for leakage of gas or polluted water

Carrying out detailed seismic surveying before drilling starts can avert many serious risks related to subterranean issues. As well as using seismic analysis to highlight major faults that, if reactivated, may induce seismicity, analysis of previously drilled oil and gas infrastructure may highlight leakage pathways for shale gas or fluids used in the hydraulic fracturing process. Understanding the potential impact of these risks requires a much wider analysis involving community engagement and developing risk-mitigation plans (Committee on Induced Seismicity Potential in Energy Technologies et al., 2013, e.g. ‘Steps Toward a “Best Practices” Protocol’).

Risks associated with permanent disposal of water into geologic wells may also be reduced by seismic monitoring or negated if this is not permitted as an option to deal with wastewater.

Provide baseline data to regulators that subsequent monitoring and evaluation programmes can be compared against to identify any leakages

For monitoring and evaluation to be effective, the collection of representative baseline data prior to activity onset is essential to provide the control for comparison (Allen et al., 2013; Brandt et al., 2014; Brittingham et al., 2014). Although the method, frequency and location of measurements will vary between variables (Brittingham et al., 2014),[60] baseline data should be collected so they are directly comparable with the proposed measurements in a monitoring and evaluation programme while also being sufficiently granular to take into account other potential reasons for variability.[61]

Ensure trade-offs are articulated and explained to local stakeholders and seek their participation

Management of local impacts is about managing trade-offs. Any new economic development activity, shale gas extraction included, can bring direct and indirect

---

[57] Regional authorities are likely more focused on issues such as energy security and jobs, whereas local authorities are likely more attuned to local issues such as pollution levels near schools or congestion on local highways.

[58] Local officials not being involved in the US has created friction and exposed local populations to unwarranted risks. Similarly, outright bans by local authorities on any industrial practice – including hydraulic fracturing – without due consideration of the potential risks and benefits is unhelpful in achieving broader energy transitions.

[59] For example, erecting noise or light barriers or improving local road infrastructure, or creating designated transportation routes.

[60] For example, Brittingham et al. (2014) recommend five separate types of analysis to provide insight into the potential impacts on species and habitats (spatial analyses, species-based modelling, vulnerability assessments, eco-regional assessments, threshold and toxicity evaluations); assessing water consumption may require measurement of aquifer levels; spotting methane emissions will require background atmospheric measurement.

[61] For example, natural seasons or variable levels of industrial activity and other sources of emissions.

employment and public revenue, even if it also can pose environmental and health risks. 'Successful' management of local environmental risks is therefore about the ability of local stakeholders to participate in development choices. Defining where this balance lies will depend on the characteristics of local situations and the views of local stakeholders, with local communities viewing potential development as either positive or negative. For relatively undeveloped areas, the construction of shale gas wells may bring employment, investment and infrastructure to local communities that would otherwise not have been provided. On the other hand, the added congestion or air pollution from truck movements or destruction of natural habitats during construction of wells and/or pipelines may result in loss of local livelihoods in addition to their associated environmental impact, particularly if the source of employment is generated from the environment (e.g. farming). How or whether benefits are passed on to local communities, or impacts are mitigated, is likely to be unique to each development, although it is considered essential to take time to communicate transparent data and involve stakeholders early in the planning process to alleviate, mitigate or compensate for these issues.

Establish independent monitoring body/mandate public environmental reporting

In addition to safeguards designed to mitigate risks, systems should be in place to ensure that, should unplanned negative impacts occur, they are detected early and containment and remediation strategies are in place to ameliorate their impact. Disclosure of relevant data and ensuring they are accessible allows local authorities and engaged stakeholders to plan response procedures; allows expert researchers to study the impacts of development on environments and ecosystems; and engages companies to innovate and compete to continually reduce their environmental impact (McFeeley, 2014). It also greatly improves the ability of centralised government to evaluate local governments' environmental performance. Noting the potential for conflicts of interest for shale gas operators between reporting any leaks and public support for future development, having monitoring procedures completed or audited independently would be preferable.

5. Governance of shale gas: how is China doing?

Summary: governance

In the face of growing popular disquiet about the state of the environment, China's policymakers have rewritten the narrative on economic growth. In a deliberate break with the past, the 'grow first, clean up later' approach has been supplanted by a new mantra of harmonious development – Chinese policy-speak for sustainable development. This is reflected in the government's most recent national target setting, the principle public policy tool through which it pursues its development strategy and translates central government objectives into subnational action. The government has established targets for benchmarking progress towards climate, air quality and water goals, and Premier Li Keqiang has declared a 'war against pollution'. The elevation of environmental priorities can be viewed as part of the CCP's efforts to bolster its public legitimacy, promote social stability and assert top-down authority.

With respect to energy and climate policy, the government has given off mixed messages about the potential to harness shale gas as a bridge fuel. While it has established explicit coal caps for energy generation, it continues to pursue expansion of coal production. Renewable energy targets are ambitious, but may not reflect the full potential of harnessing gas-fired power for a renewable-dominated grid. Meanwhile, increasingly powerful regional governments are pursuing air pollution targets by developing coal-to-gasification projects that will reduce air pollution but worsen GHG pollution.

With respect to direct management of shale gas and related environmental risks, no national regulatory regime yet exists, but environmental governance more broadly is improving, albeit from a very low level. Water resource management and pollution control, in particular, are handicapped by institutional fragmentation and weak enforcement. It remains to be seen whether an emerging, state-led shale gas industry can be effectively policed by fragmented state agencies that have historically suffered from weak regulatory capacity, poor enforcement and strong pressure to exempt state-owned enterprises from scrutiny.

This section provides a short overview of environmental governance in China, drawing on some of the key observations and recommendations in the previous sections. We begin by looking at China's overarching energy and climate policy, and where shale gas might fit. We then examine the institutional framework, regulations and incentives for pollution control and environmental protection, and ask: are they fit for purpose in dealing with the known risks of shale gas development outlined previously? In particular, we rely on the insights of Wang (2013) regarding the relative importance of cadre evaluation as the interface between national targets and local action, and the driver of environmental performance.

5.1 The role of target-setting in China's development policy

5.1.1 Central government drives policy primarily through a target-setting system

Beijing relies on a top-down system of governance in which the NDRC sets its development agenda centrally through national FYPs. As noted above, FYP12 clearly demonstrates the government's ambition to restructure and 'green' its economy, reduce the carbon intensity of development and enforce a system of performance targets for reducing pollution and protecting the environment.

Following publication of the FYP, responsibilities for implementation are passed down to provincial, prefecture and county government. Specifically, a top-down system of cadre evaluation that has elevated environmental goals into personal assessments for governors, mayors and state-owned enterprise leaders is used to drive progress and cement loyalty to the party-state. It is this target responsibility system, rather than the legal and regulatory regime, that has been most influential in shaping China's environmental performance to date (Wang, 2013).

5.1.2 The target responsibility system translates national targets into subnational targets

The targets span a range of issues, with officials in provincial government in particular tasked with deciding how best to meet and distribute targets among enterprises, departments and lower-level government bodies. In this respect, the system offers local actors a great deal of flexibility in achieving targets – by fair means or foul (Wang, 2013).

The environmental target-setting process began in earnest under FYP11, when Chinese authorities established high-priority, quantitative pollution reduction and energy efficiency targets, including mandates for a 10% reduction in $S0_2$ and chemical oxygen demand (COD) releases, and a 20% reduction in energy intensity (Wang, 2013). This represented a significant elevation of environmental goals, raising them to a level of priority previously reserved for key party-state mandates such as economic growth, social stability and the one-child policy (ibid.). China expanded its use of environmental targets in FYP12, with targets for carbon intensity, renewable energy and water efficiency, among others (see below).

Market-based systems for dealing with environmental and resource allocation problems are also emerging in some areas. These include water trades in Inner Mongolia (Calow et al., 2009; Doczi et al., 2014), and ecological compensation schemes operating between cities and upstream catchments. In addition, environmental laws and regulations are expanding and enforcement is improving. However, most progress to date has been achieved through government diktat and a cadre evaluation system that awards or penalises leaders according to their performance against centrally determined targets.

5.1.3 Environmental targets are becoming increasingly significant

After decades of focusing on economic growth alone, China's highest political office has made transitioning to a more sustainable and environmentally responsible growth path a priority. All energy, climate and environmental policies are implemented through the target responsibility system, which is China's main environmental management tool (Williams, 2014). Prior to FYP11, environmental goals were linked with soft 'guidance' targets – an indication of their secondary importance within the Chinese bureaucratic system. Following FYP11, environmental targets became binding, with achievement linked to promotion, bonuses and prises, and non-attainment linked to penalties, transfers or worse (Wang, 2013). There are currently nine binding environmental targets in FYP12, described further in the sections that follow. These include, relevant to shale gas, reductions in i) carbon intensity, ii) energy intensity, iii) share of fossil fuels in the energy mix, iv) major pollutants and v) water consumption.

While the commitments are a clear indicator of political motivation, whether they are enough to avoid dangerous climate change or address China's growing range of environmental problems is less clear. However, the system has both reach and impact. This is because of China's vast bureaucracy (more than 40 million strong) and the fact that a significant amount of pollution and energy consumption is directly within the control of government and corporate leaders subject to cadre evaluation. Hence, when environmental targets were hardened during FYP11, investment in pollution control infrastructure soared. One province with only two wastewater treatment plants in 2006 built more than 100 facilities over the following four years; another built 119 wastewater treatment plants in three years; and coal-fired plants clamoured to install pollution control equipment to meet targets. At the same time, local governments ordered the closure of many 'worst offender' industrial units to reduce pollution. By the end of 2010, officials had also ordered the shutdown of some 70 GW of small thermal power plant capacity across the country (Wang, 2013).

The focus on environmental targets, prioritised through performance appraisal, has lent weight and credibility to China's long-ignored environmental laws and regulations, empowering local officials in terms of formal governance reform and practice. In terms of formal reforms, the elevation of the MEP to ministerial status and the creation of regional enforcement offices has been significant, and helped ensure cooperation from other agencies, both central and local. In terms of implementation, line agencies are better able to assert the law, at least in some instances. For example, 'regional approval restrictions' have been used to block industrial development in areas that have failed to meet pollution reduction targets, and even China's notoriously weak Environmental Impact Assessment Law has been used to block industries that might jeopardise target achievement.

This fluid relationship between bureaucratic target-setting and law enforcement is evolving, and is not without problems. First, environmental agencies remain weak compared with more established ones, despite their recent elevation in status, and responsibilities for environmental protection and pollution control remain fragmented within and between different institutions. Second, the legal system remains weak, with a focus on principles rather than mechanisms for enforcing compliance. Third, public access to information on institutional responsibilities and accountabilities, behaviours and the performance of water users and polluters is very limited, with a widespread tendency for agencies and enterprises to hide or manipulate information that might cause public dissatisfaction. Beijing's air quality monitoring is a case in point. Finally, the cadre evaluation system, the principal mechanism through which authorities guide officials to implement central priorities, is subject to collusion, data falsification and goal displacement. There have been some perverse outcomes, most notably in the last year of the FYP11, when many local governments, at risk of missing their environmental targets, responded through draconian and often illegal actions, including forced power outages to enterprises, residences and city services such as hospitals and schools.

5.2 China's energy strategy: moving away from coal and investing in renewable energy

We have seen policy must ensure shale gas acts as a bridge fuel. At one end of the bridge, this entails permanently replacing existing or future electricity generation from more carbon-intensive sources; at the other, it requires policy that facilitates electricity generation from even lower carbon sources that will largely replace the bridge fuel itself. For gas-power generation to function as a bridge fuel thus depends largely on the broader climate and energy policy in which it is situated.

5.2.1 Is China bridging away from coal?

China's focus on efficiency goes some way to limiting emissions growth in the short term

In terms of the 'bridge away' from more air and climate pollution-intensive fuels, China has made a number of statements relating to reducing the dominance of coal in its energy mix. The most recent is EDSAP 2014-2020 (PRC, 2014). As well as those explicitly focusing on coal, described below, a number of public declarations have been made that implicitly target coal as a part of wider climate or energy strategy. For example, FYP12 includes a nationwide target for reducing carbon intensity (i.e. tons of $C0_2$ emitted per real RMB 10,000) by 17% during the FYP12 period (2011-2015). However, given that there is also a target of reducing energy intensity by 16% across this period, this appears to more be an attempt at decoupling energy use and economic activity (i.e. boosting energy efficiency) than significantly affecting how energy is supplied in the short term (i.e. only 1% of that target seems to be based on a change in the energy mix).[62] China's goal to peak emissions by 2030 is a good signal of intentions but is still insufficiently detailed to suggest whether it is compatible with bridging to a low-carbon energy structure and averting dangerous climate change.

China has a long-term target to reduce the carbon intensity of the economy by 40-45% from 2005 levels by 2020 (Yingchun, 2013), but by linking emissions to economic growth it is difficult to quantify the absolute impact on emissions. Similarly, although the recent announcement that China will aim for peak carbon emissions by 2030 is very welcome in terms of the message it conveys about China's focus on limiting its climate impact, the amount of that peak, and thus China's precise ambitions and whether they will be sufficient to achieve the 2°C world, is less clear.[63]

China has been piloting a number of schemes to drive emission reductions and increase energy efficiency

In an attempt to begin decarbonising its economy, in August 2013 the Chinese government designated 13 regions as 'low-carbon economy' pilot zones. In addition, China has set up seven cap-and-trade pilot schemes for carbon emissions across cities and provinces. Together, the emissions from these regions make up the second largest amount of regulated carbon emissions after the European Union and plans have been reported to establish a national cap-and-trade policy in 2016.

Alongside national cap-and-trade schemes, the government has also been reported to be considering launching a carbon tax pilot programme (Martina et al., 2014). Furthermore, in May 2014 the State Council released the Energy Saving and Low Carbon Development 2014-2015 Action Plan, which lays out a number of hard targets for phasing out environmentally damaging technologies and practices (China Water Risk, 2014).[64] This also lays out provincial targets for installing pollution control technologies to reduce air pollution by the oxides of nitrogen and sulphur in line with the targets in the FYP12 period.[65]

Energy efficiency is also key to future plans, with FYP13 slated to support continued optimisation of energy efficiency standards. Similar 'energy efficiency drives' are also evidenced by powerful state-owned enterprises; for example, Sinopec announced in late-June 2014 that it would invest RMB 14 billion to double its energy efficiency by 2025, mainly by developing new technologies and optimising environmental management (Xinhua, 2014). Although increasing the efficiency of the fleet does not necessarily mean coal-fired power stations will not be built, given China's current energy supply portfolio a drive for energy efficiency essentially entails closing the most polluting plants first. This premise was strengthened earlier this year when MEP released new rules on water and air emissions related to the power industry that included targets for a reduction in carbon emissions of at least 4% in 2014 and 3.5% in 2015.

---

[62] This is to say that, while we acknowledge that the low efficiency of older coal-fired power plants makes them the most likely be replaced by more efficient plants (perhaps operating on alternative fuels), such similar carbon and energy intensity targets are unlikely to go far enough to restrict the use of coal in the energy system.

[63] China is expected to announce 2030 carbon intensity targets in the spring of 2015 (Lin, A., pers. comm.), around the time of publication of this report. It may make the emissions peak clearer, although only if one makes assumptions about future economic growth rates.

[64] For example, enforcing environmental impact assessments, reducing heavy metal water-borne pollution in various sectors and decreasing coal use in certain regions.

[65] FYP12 targets reductions in NO_2 and SO_2 emissions of 10 and 8%, respectively.

China's 2020 coal cap sends a strong message to develop alternative fuel sources

More explicitly, the Energy Saving and Low Carbon Development 2014-2015 Action Plan limits China's coal consumption to 4.2 Gt and 62% of the energy supply by 2020. This represents the first target for an absolute cap on coal consumption at a national level and builds on the Air Pollution Prevention and Control Action Plan, released in September 2013, which set out to reduce coal consumption as a percentage of primary energy to below 65% by 2017 (PRC, 2013a), with others suggesting it may fall to 60% by the end of FYP13 (Liangchun, 2014). The Action Plan also includes regional bans on new coal plants unless they are combined heat and power or are replacing an equal capacity of smaller, less-efficient coal fired power plants (CAAC, 2013). The Beijing government plans to replace all its coal-fired power plants with natural gas plants by 2017 and to limit its coal burning to under 10 million tonnes (Reuters, 2013). By 2020, annual consumption of coal across Beijing, Tianjin and Shandong is targeted in the Action Plan to be 100 million tonnes less than in 2012.

Despite the cap, a number of simultaneous announcements are designed to incentivise the coal industry and expanded production

While the large state- and privately-owned companies operating in China's coal industry continue to invest in exploration for new resources, the operation of mines is continually being consolidated and focused on larger operations, with over 1,200 smaller mines set for closure in 2013. However, domestic coal production grew from 2.75 to 3.66 Gt between 2008 and 2012, suggesting substantial effort will be needed to curb this sector and avoid China becoming a coal (and thus emissions) exporter even if domestic coal demand can be reduced from 2020 onwards. Indeed, EDSAP also contains a goal to strengthen the transport networks for coal, particularly to and from Inner Mongolia.[66]

China is investing in strategies and policies that incentivise gas production and secure imports

Primarily to reduce urban air pollution levels, China is focused on substituting coal with gas at the point of use in heavily populated areas and increasing domestic supply and guaranteeing imports. Although gas provided just 4.8% of the primary energy supply in China in 2013 (BP, 2014), its development is being vigorously pursued in the country, with projections that gas will supply 10% of primary energy in 2020 (PRC, 2014).

To satisfy this demand, China has been increasing and diversifying its supply options in recent years. From a total gas production of 117 bcm in 2013 (BP, 2014), EDSAP targets 185 bcm of conventional and tight gas (Chen et al., 2014), and 30 bcm each from coalbed methane and shale gas for 2020 (PRC, 2014). China has also signed a number of import agreements, most recently a 38 bcm/y agreement and a 30 bcm/y framework with Russia (Patton and Guo, 2014). In an attempt to further bolster energy security and reduce its demand on imported LNG, the government has also attempted to incentivise domestic development of unconventional gas.[67] Coalbed methane has attracted a subsidy (currently 0.2 RMB/m^3) to stimulate the industry's growth since 2007 (Ling, 2012), while FYP12 lists shale gas a 'strategic emerging industry' and denotes a subsidy of 0.4 RMB/m^3 for its production. EDSAP targets annual production of 30 bcm from coalbed methane and at least 30 bcm from shale gas by 2020 in addition to the 80 bcm expected from tight gas (Chen, 2013). China is contemplating a coal-to-gas alternative, which would be a backwards step for climate change and water stress. Indeed, while the ratio varies depending on the end use of the fuel, the use of synthetic natural gas (SNG) has been calculated to have 20-108% higher GHG emissions than coal would (Ding et al., 2013).

Despite the very high levels of GHG pollution that result from SNG electricity generation, at the end of 2012 projects with a capacity of 120.4 bcm/y were planned or ongoing (Ding et al., 2013). A study in Yang and Jackson (2013) indicated that, as of October 2013 nine projects with a capacity of 37.1 bcm/y had been approved by the national government, with a further 40 projected. The study estimated the 'emissions penalty' of using SNG was 36-82% for electricity generation. There is some indication that central government is slowing the development of coal-to-gas (Bernton, 2014).

Such environmental concerns from a range of actors appear to have tempered some of the pace of development (Larson, 2013), although the industry continues to expand. As recently as September 2014, for example, Sinopec reiterated its intention to invest $10 billion in an 8 bcm/y SNG project (Reuters, 2014), with forecasts that 40-60 bcm/y may be produced in this way by 2020 (Xin, 2014). It has been reported that the unabated growth of the industry is not desired by the central government, but projects are attractive to subnational governments on account of their potential economic impacts (Reuters, 2014). For instance, the municipal government of Chongqing (a mega city in the Sichuan Province) issued its own *Chongqing shale gas industry development guidance (2015-2020)* and set itself an ambitious target of 20 bcm in 2020 (Chongqing Provincial Government, 2015).

---

[66] It is worth noting that China's coal production in 2014 fell a reported 2.5%, for the first time in over 10 years (Myllyvirta, 2015), although it is far to early to establish this as a longer-term trend.

[67] Note that tight gas does not appear to be distinguished from conventional sources in China.

5.2.2 Is China bridging towards renewables?

China is investing heavily in low-carbon capacity and targets significant growth in the short and medium term

Although FYP12 appears to be targeted largely at efficiency measures, it also includes a commitment to increase the share of electricity generated from 'non-fossil' sources (renewable and nuclear) from 8.6% to 11.4% across the period. Responding to soaring electricity demands, the Chinese government has also been investing heavily in renewable energy, with the world's second- and third-largest operating hydropower stations in China (British Embassy Beijing, 2014).

FYP13 targets for renewable and non-fossil energy are already determined, with a steady increase in the importance of renewable energy in the primary energy make-up, reaching 13% in 2017 (BJMEMC, 2014) and 15% in 2020. The recent announcement to limit GHG emissions by 2030 also includes a goal of non-fossil sources supplying 20% of energy needs by this date. EDSAP lays out how the 2020 targets may be split, with targeted installed capacities of electricity generation from nuclear, hydropower, wind and solar PV sources of 58, 350, 200 and 100 GW, respectively.

While capacity is growing, China recognises more work is needed to rebalance the energy sector to prioritise a shift towards low-carbon sources

EDSAP recognises China fails to extract all of the potential renewable energy its capacity can generate, and is seeking to improve this by reducing curtailment of renewable capacity, upgrading the power grids to aid with balancing of renewable energy generation's variability and prioritising the dispatch of low-carbon generation options (CNREC, 2014; PRC, 2014). Some analysts have pushed back on prioritising dispatch of renewable energy, suggesting that dispatch should be conducted purely on a price basis (CNREC, 2014), and EDSAP suggests price comparisons between renewable options and coal should be 'fair'. This, of course, fails to incorporate two considerations: first, by prioritising renewable generation now and thus reducing the levelised cost of installed capacity, it will lower the cost of future capacity. Second, recent work has shown the negative human health and environmental costs of coal-fired generation in China represent large externalities (NRDC, 2014): a truly 'fair' cost system would need to internalise these large social costs from more polluting generation sources. Thus, unless the pricing structure used for dispatch is also able to include such externalities, the system is likely to be unfavourable to renewable energy sources, which carry few external costs.

The current and forecast uneconomic nature of many coal projects (Carbon Tracker Initiative, 2014) does suggest renewable energy expansion will occur under current market conditions. Gas development could, in principle, reinforce this pattern, but it is also likely that aggressive gas-fired generation targets could undercut renewable energy expansion. The fluctuation of gas prices also introduces market uncertainty that can have a chilling effect on renewable energy investment. For example, recent debate over the cost of shale gas production in China has suggested that the unit cost of shale gas in China is between 1.6 and 1.8 Yuan pcm. Opponents argue this price might not have taken account of the cost of pipeline infrastructure and other associated transportation costs, which could drive the cost of domestic production much less attractive, particularly when compared to imported natural gas from Kazakhstan or Russia. Supporters of shale gas expect this price to fall further by 2018 (DRC, 2015).

For these reasons, we believe there is value in providing some policy support for renewable energy expansion that insulates it from direct competition from gas-fired and other sources. These might be akin to the state-level renewable portfolio standards employed in the US or other fixed-demand approaches. The possibility of a similar quota system has been under consideration for quite some time (Karhl and Wang, 2014; Alvin Lin, pers. comm.).

5.3 China's shale gas governance structure and environmental protection

5.3.1 Responsibility for developing shale gas is shared between government institutions

At a national level, China's energy regulator plays the central role responsible for setting China's shale gas development targets, along with input from the Department of Resource Conservation and Environmental Protection and the Department of Climate Change (NDRC) (Chou, 2013). Based on these targets, the Ministry of Land and Resources (MLR) issues drilling rights and MEP and the Ministry of Water Resources (MWR) are responsible for the regulation of the environmental and water impacts of shale gas.

Under MEP, environmental standards set through national policy are enforced at the local level through regional supervision centres (RSCs) and Environmental Protection Bureaus (EPBs), which work across all industries. In other words, there is no specific environmental enforcement capacity for the shale gas industry. These RSCs and EPBs form China's main environmental agencies. EPBs include an environmental monitoring centre and an inspection unit tasked with supervising environmental impact assessments (EIAs), environmental monitoring and reporting, responding to public environmental complaints and instigating punitive action for environmental violations. EPBs also include a research institute and are tasked with coordinating various local government units to endorse environmental regulations and integrating environmental protection plans into local economic and social development plans (OECD, 2006).

For water resources, China's 2002 Water Law marked a shift towards sustainable development, with a focus on water conservation and allocation licensing (Calow et al, 2009). With growing levels of water scarcity across the country, particularly in the north, China has strengthened its regulatory system to control withdrawals better, at least for major users under the control of the state. A system of allocation licensing, in particular, is used by both river basin commissions and water departments and bureaus to control and coordinate withdrawals (Doczi et al., 2014). Working through a well-established network of line departments reaching down to county and township levels, and through river basin commissions, MWR has sought to save water and reallocate savings to growing urban areas and industry, while maintaining food production and farm incomes – a delicate balancing act. The biggest challenge MWR faces lies not in regulating larger, more readily identifiable users, potentially including the shale gas industry, but in attempting to control groundwater withdrawals by hundreds of thousands of farmers self-supplying groundwater in the north of the country. However, it is also unclear whether 'strategic emerging industries' such as shale gas will be subject to adequate controls as well.

No national-scale regulation yet exists for the shale gas industry, but local regulations are beginning to emerge

Currently, no national legislation or set of guidelines specifically regulates shale gas in China. However, the vice-minister of environment has indicated national guidelines on environmental protection are being developed and will consider potential impacts on land use planning, the environment and ecosystems, human safety and the national economy (van Hende et al., 2014). While the formal process underway for setting shale gas environmental pollution standards may take two to three years, there is also consideration of issuing more general environmental management guidelines before the standards are developed and issued (Lin, pers. comm.).

Guidelines for development have appeared at a subnational level, with technical standards on shale gas drilling published by the provincial government of Hunan (Hunan Provincial Government, 2014) and a Usage Implementation Plan published by the Chongqing government that promotes 'ecological management' (Fuling District of Chongqing Government, 2014). The plan set out by the Chongqing authority includes aspects on strengthening research and development on 'green' technology that ensures environmental protection, strengthening monitoring capacity (through an investment of RMB 266 million) and establishing an environmental compensation fund for land reclamation, land restoration and other environmental impacts.

Many existing regulations can equally apply to the developing shale gas industry

Regulation of shale gas can largely be achieved through existing, well-established law and policy frameworks for the management of industrial development. The larger question is whether such tools will be used in China in the coming years in general, and will be applied to shale gas development.

The Environmental Impact Assessment Law requires operators and subcontractors to protect natural resources and prevent the environment from being polluted or damaged before projects can be signed off (often by MLR, local water management bureaus and EPBs). Similarly, for managing potential water pollution, existing regulations and strategies in China applicable to the shale gas industry include the law on Prevention and Control of Water Pollution and the Clean Water Action Plan. A number of other laws exist for other environmental vectors,[68] and MEP has recently issued 73 national standards for environmental protections.

China is engaging in a series of reforms to attempt to achieve the substantial goal of rebalancing subnational priorities towards environmental protection. The central questions will be whether this developing framework, and the target responsibility system used to assess cadre performance, will be applied to shale gas development, and in particular to some of China's most powerful and politically embedded energy companies.

MEP appears to recognise that a weak EIA system creates risks for effective environmental regulation and in 2014 released a report on *Opinions on Strengthening the Management of Environment Impact Assessment Agencies* (MEP, 2014b). This assessed possible reasons for non-compliance by EIA agencies and concluded expertise, management and auditing systems and consistency of approach may all contribute to weak enforcement of the EIA law. These factors were also thought to contribute to the fact that EIA reporting may be completed without sufficient diligence to ensure the data are reliable and representative of the project (in addition to instances of falsifying data). A recent inspection by MEP of EIA agencies resulted in 34 agencies and 58 assessors facing disqualification, rectification or warning sanctions following the provision of false materials (Hu, 2014). Disparate goals between government departments and agencies and a lack of resources and expertise in environmental ministries has led to suggestions that industries often go forward with projects and 'make up'

---

[68] The Air Pollution Prevention and Control Law includes waste gas and coal burning; the Environmental Protection Law covers pollution and liability for pollution; the Promotion of Clean Production Law includes measures to promote the use of cleaner energy and raw materials; the Law on Evaluation of Environmental Effects includes more strategic measures on environmental impacts; a Solid Waste Pollution Prevention Law and a Law on Water and Soil Conservation.

EIAs afterwards with the costs of potential polluting fines insufficient to deter the industries (Marsters, 2012).

MEP had already begun taking steps to strengthen EIA administration and supervision and push for more transparency. As Wu Xiaoqing, vice-minister of the environment, explained, the reform process aims 'to implement the most stringent source protection system, to fully play its role in optimizing economic development, pollution prevention and ecological damage, and to enhance the effectiveness and management of the EIA' (Hu, 2014). MEP also appears to be willing to begin to include the wider public in environmental decision-making and in 2014 released another report titled '*Guidance on Promoting Public Participation in Environmental Protection*' (MEP, 2014c).

As well as attempting to strengthen the enforcement system, MEP has been working to update the regulations to be enforced by updating the Environmental Protection Law. In particular, the law has placed more legal liability on EIA agencies and assessors, changed pollution fines to continue increasing so long as the pollution continues and provided public stakeholders the opportunity to obtain environmental information and legally challenge polluters (Hilton and Geall, 2014).

Providing better access to environmental data is key to increasing transparency and building public confidence, but data disclosure and public scrutiny of government and industry remains weak. A recent report on the Pollution Information Transparency Index used in 120 cities in China found that, despite progress in the disclosure of pollution data and EIA reports[69], improvements in how information is being managed and protected are still needed, with availability of industrial emissions data in particular still very limited (IPE and NRDC, 2014).

Data quality is also a key issue in light of the widespread tendency to falsify or simply hide data that might cause public dissatisfaction and undermine party legitimacy. In 2009, for example, the head of Beijing's environmental monitoring centre admitted to 'engineering' data to meet air quality targets. Local government used 'emergency measures' to manipulate data, including re-siting monitors to local parks away from traffic and closing down construction sites near monitoring stations. Authorities continue to try and hide 'bad news' on air quality, with leaked US State Department cables documenting sustained efforts by officials to stop disclosure of US Embassy air quality data.

Further changes in how environmental protection occurs are expected as MEP undergoes reform, as noted in the 2014 Central Government Work Report. However, other government departments also appear to be moving to strengthen environmental protection standards. For example, as well as bolstering the EIA process and conducting research into market-based carbon reduction schemes, the State Council's Energy Saving and Low Carbon Development Action Plan 2014-2015 includes plans to strengthen punitive pricing for environmental violations.

---

[69] Beijing and other cities publish daily data, 42 cities implemented disclosure of full EIA reports, Shandong and other provinces have online monitoring platforms for hourly updates, Hunan and other EPBs use social media to interact with the public

6. Conclusions and recommendations

6.1 Conclusions

The stage is set for rapid development of China's shale gas industry. If the country can set the development of this industry on a path to environmental responsibility, and wed the industry's growth expressly to a coal phase-out and renewable energy expansion, there is every possibility it can contribute to a climate-compatible future with cleaner skies and lower stresses on the country's water resources. However, it is also possible that, in the short window of opportunity China now has, it could fail to establish environmental safeguards, fail to exploit gas' 'bridge fuel' potential and miss the chance to capitalise on the US experience.

Without a credible framework to oversee the industry, the environmental, economic and ultimately social costs of developing shale gas could outweigh its benefits. While commitments at the top of the ruling party lend cautious optimism to the fact China is intensely concerned with ameliorating its environmental impacts, a host of mechanisms still need to be put in place if this is to be ensured.

With respect to air and GHG pollution, gas development clearly has the potential to improve environmental outcomes. On climate, though, the increasing urgency of the crisis raises the concern that a moderate improvement against business as usual and temporary or marginal displacement of coal will constitute a grave missed opportunity. For this reason we emphasise that development of gas resources, and gas-fired capacity, is not in and of itself a climate-compatible energy strategy. True, gas-fired capacity does effectively complement renewable energy expansion in a truly low-carbon energy strategy, but that it can does not mean it will. Only development of gas in the context of broader phase-out of more carbon-intensive resources, and in the context of aggressive renewables expansion, will enable shale development to reach its potential to facilitate a low-carbon transition.

With respect to many of the other environmental issues discussed in the paper, our findings suggest the system of cadre evaluation linked to environmental targets and the more conventional regulatory approach to environmental governance based on the rule of law are capable of managing risks. The development of shale gas does not present unique environmental challenges: methane leakage can be prevented through enforcement of technical standards; water demands can be dealt with in the licensing system; and pollution risks, though a more challenging issue, can still be managed through land use planning, monitoring and aggressive enforcement of technical and environmental standards.

While China's regulatory framework contains many of the aspects needed to effectively oversee the development of the shale gas industry – suggesting the industry ***could*** be developed in an environmentally acceptable manner – whether the existing structure ***will*** achieve this depends on how well the framework and political motives are enforced. The political power of state-owned energy companies remains a crucial political economic challenge for robust and independent regulation of the sector, China's environment is widely perceived to have lost out in trade-offs with economic development in recent decades and analysis suggests such influence, along with political rivalries between government bodies, high cadre turnover and a disconnect between national and local incentives, hinders the implementation of environmental targets (Eaton and Kostka, 2014). An example of such a disconnect includes how 26 of the 31 provinces set their growth targets for the FYP12 period to above 10% despite the national annual target of FYP12 being at 7%. The Chinese leadership has publicly recognised the dominance of economic growth targets and the environmental impacts the trade-off between the two continues to cause (Stanway, 2013).

Shale gas development could certainly become another major pressure on air, climate, water and land resources. The political obstacles to shifting from a fossil-fuel based economy are formidable. Government can hesitate to implement robust, well-funded environmental protection regimes or make pollution abatement and control a political priority, and can fail to demand accurate data disclosure lest it reveals rampant under-performance. Many readers will wish us to conclude that shale gas is either an environmental boon or bane. We have avoided such a conclusion, as we do not believe it reflects the nature of China's choice.

6.2 Recommendations

Instead of such a forecast, this report concludes by reiterating, in table form, a condensed version of the various recommendations made throughout, along with a rough assessment of what we perceive to be the level of difficulty we think such policy action poses, and the rationale for it. Conclusions about the feasibility of a gas development occurring as part of a green transition will depend largely on whether many of these recommendations will be implemented.

Table 5: Key policy actions to facilitate gas development as part of a green growth strategy.

Policy tool	Policy action	Difficulty	Rationale
Energy policy (bridge away from coal)	Install a coal production export moratorium	Easy	Avoid export of coal-based emissions by eventual export of thermal coal. Moratorium has little current political cost in absence of current exports.
	Scale back (and eventually abandon) future coal-based generation projects	Moderate	May be achieved by multiple policy mechanisms, including carbon pricing, regulation of unabated new coal capacity development or changes to national development plans and targets. Regulatory action necessary to lock in emissions reduction benefit over time.
	Permanently retire existing capacity	Hard	Ideally, gas expansion would accelerate decommissioning of existing coal capacity, beginning with the most-polluting, least-efficient plants. Likely to be politically challenging as energy demand expands and because of vested interests' control in existing capital assets. Most easily achieved and maintained through (direct or indirect) carbon pricing.
Energy policy (bridge towards renewable energy)	Give renewable energy generation grid priority	Easy	Generation from renewable energy capacity should be provided dispatch priority.
	Deploy gas capacity sited to complement variable renewable energy capacity	Moderate	Development and siting of new gas capacity should prioritise its ability to provide flexible, dispatchable power to support variable renewable energy projects.
	Renewable capacity demand protected from gas price fluctuations	Moderate	Incentives for renewable energy capacity development should be insulated from short- and medium-term natural gas price fluctuations (through e.g. state-commissioned projects, renewable targets and quotas).
Mandatory technical standards for certain aspects of shale gas development	Mandate application of green well completion technologies and processes and use of reduced leakage components	Easy	Green well completions, better-sealed components and non-venting practices are generally cost-competitive, but strong mandates are needed to ensure uniform compliance and limit rogue 'super-emitter' sites with outsized negative impacts.
	Prioritise reductions of methane emissions in cadre evaluation system	Hard	As a measure of local government performance this is not complicated and will likely have strong climate benefits, but significant challenges exist to putting in a credible monitoring system that will effectively hold local officials accountable.
	Establish hard methane emissions targets across the gas system	Moderate	System-wide capital investments to improve emissions may be difficult, but are also amenable to performance target-based governance (i.e. cadre evaluation). While not specific to shale gas, system-wide methane control is important to maximise the bridge fuel benefits of a fuel switch.
	Establish minimum technical requirements for well design, drilling and cementing	Moderate	Industrial standard technological requirements are readily available to avoid fluid migration, but robust monitoring can be costly, particularly to ensure plans and specification are applied.
	Establish minimum technical requirements to prevent contamination during handling of fracking fluids, particularly waste water	Hard	Management of wastewater from extractive industries including shale gas can be costly (to both developer and regulator tasked with monitoring and enforcing) but is critical to protecting water resources, particularly surface water.

Table 5: Continued

Policy tool	Policy action	Difficulty	Rationale
Empower local and regional decision-makers to balance competing interests and use scale-specific data to evidence decisions	Implement land use planning that favours clustering of wellheads	Moderate	Permitting processes that consider alternative site planning that clusters well arrangements and relies on horizontal drilling for access to the shale rock may increase marginal cost of operations. However, this has been enabled by improvements in drilling technology, and can reduce both land use impacts and the cost of regulatory monitoring and enforcement of well sites.
	Implement land use planning to site shale gas development and associated infrastructure away from non-industrial land uses	Hard	Land use planning can be employed to avoid siting of industrial and other noxious land uses near vulnerable populations and environments and dense populations. This key environmental governance tool can be used to avoid many of the local impacts affecting US shale development and arising from patchwork application of zoning rules in different US jurisdictions.
	Ensure water resource planning is based on robust spatial and temporal analysis of water availability and designed to balance trade-offs with other users fairly	Hard	As well as the impact of developing individual wells, the cumulative impact of developing multiple wells must be assessed at a variety of scales - spatial (i.e. local, regional and river basin) and temporal (i.e. accounting for seasonal changes in water extraction).
Enforce strong data collection and disclosure requirements, and early public engagement	Application of a robust, independently corroborated data collection system for environmental risks, particularly for i) effluents and emissions and ii) ambient air, water and soil quality	Hard	Effective management of economic development requires reliable data on the impacts of those activities. Effluent data can be collected by the industry itself, but still require independent corroboration. Ambient environmental quality measures should complement effluent measurements. China is good at prioritising measurable goals, particularly through the cadre evaluation system. However, ensuring data are accurate, reliable and independently verified remains a challenge that undermines the effectiveness and credibility of pollution reduction targets.
	Establish a mechanism for communities directly affected by shale gas development to be informed about and participate in decisions regarding siting and development	Hard	Policy choices with the potential for regional and national benefits can have significant local costs. Local communities should have the ability to either directly benefit from shale development through employment and municipal revenue generation or to participate in siting and development decisions. Establishing a more participatory approach to the local resource development choices within existing political structures remains challenging.

References

Abdalla, C.W. and Drohan, J.R. (2010) *Water Withdrawals for Development of Marcellus Shale Gas in Pennsylvania*. State College, PA: Pennsylvania State University.

Adair, S.K., Pearson, B.R., Monast, J., Vengosh, A. and Jackson R.B. (2012) 'Considering Shale Gas Extraction in North Carolina: Lessons from Other States'. *Duke Environmental Law & Policy Forum* 22: 257-301. (http://scholarship.law.duke.edu/delpf/vol22/iss2/2)

Afsah, S. and Salcito, K. (2012) 'Shale Gas and the Overhyping of its CO2 Reductions.' Think Progress (http://thinkprogress.org/climate/2012/08/07/651821/shale-gas-and-the-fairytale-of-its-co2-reductions/)

Al, T., Butler, K., Cunjak, R. and MacQuarrie, K. (2012) 'Opinion: Potential Impact of Shale Gas Exploitation on Water Resources'. Fredericton: University of New Brunswick. (http://www.unb.ca/initiatives/shalegas/shalegas.pdf)

Alberici, S., Boeve, S. and van Breevoort, P. (2014) 'Subsidies and Costs of EU Energy: An Interim Report.' London: Ecofys. (http://ec.europa.eu/energy/studies/doc/20141013_subsidies_costs_eu_energy.pdf)

Allen, L., Cohen, M.J., Abelson, D. and Miller, B. (2012) 'Fossil Fuels and Water Quality', in P.H. Gleick, L. Allen, J. Christian-Smith, M.I. Cohen, H. Cooley, M. Heberger, J. Morrison, M. Palaniappan and P. Schulte (eds) *The World's Water: Volume 7*. Oakland: Pacific Institute for Studies in Development, Environment and Security.

Allen, D.T., Torres, V.M., Thomas, J., Sullivan, D.W., Harrison, M., Hendler, A., Herndon, S.C., Kolb, C.E., Fraser, M.P., Hill, A.D., Lamb, B.K., Miskimins, J., Sawyer, R.F. and Seinfeld, J.H. (2013) 'Measurements of Methane Emissions at Natural Gas Production Sites in the United States'. *Proceedings of the National Academy of Sciences of the United States of America* 110(44): 17768-17773.

Alley, B., Beebe, A., Rodgers, J. Jr. and Castle, J.W. (2011) 'Chemical and Physical Characterization of Produced Waters from Conventional and Unconventional Fossil Fuel Resources'. *Chemosphere* 85: 74-82.

Alvarez, R.A., Pacala, S.W., Winebrake, J.J., Chameides, W.L. and Hamburg, S.P. (2012) 'Greater Focus Needed on Methane Leakage from Natural Gas Infrastructure'. *Proceedings of the National Academy of Sciences of the United States of America* 109(17): 6435-6440.

API (American Petroleum Institute) (2014) 'Hydraulic Fracturing: Unlocking America's Natural Gas Resources'. Washington, DC: API. (http://www.api.org/oil-and-natural-gas-overview/exploration-and-production/hydraulic-fracturing/hydraulic-fracturing-primer)

Bassi S., Rydge, J., Khor, C.S., Fankhauser, S., Hirst N. and Ward, B. (2013) 'A UK "Dash" for Smart Gas'. Policy Brief. London: Grantham Research Institute on Climate Change and the Environment and Centre for Climate Change Economics and Policy. (http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2014/03/PB-uk-dash-for-smart-gas.pdf)

Bazilian, M., Brandt, A.R., Billman, L., Heath, G., Logan, J., Mann, M., Melaniana, M. and Statwick, P. (2014) 'Ensuring Benefits from North American Shale Gas Development: Towards a Research Agenda'. *Journal of Unconventional Oil and Gas Resources*. In press.

BCOGC (BC Oil & Gas Commission) (2014) 'Investigation of Observed Seismicity in the Montney Trend'. Victoria: BCOGC. (http://www.bcogc.ca/node/12291/download)

Bernton, H. (2014) 'China Rethinking Plans to Develop Coal-to-Gas Plants'. *The Sydney Morning Herald*, 30 December. (http://www.smh.com.au/environment/climate-change/china-rethinking-plans-to-develop-coaltogas-plants-20141229-12fb8c.html)

BJMEMC (Beijing Municipal Environmental Monitoring Centre) (2014) 'Ministry of Environmental Protection and 31 Provinces (Autonomous Regions and Municipalities) to Sign "Letters of Responsibility for Air Pollution Control Targets"'. Beijing: BJMEMC. (http://www.bjmemc.com.cn/g327/s921/t1914.aspx)

Bloomberg (2014) 'Li Says China Will Declare War on Pollution as Smog Spreads'. *Bloomberg News,* 5 March. (http://www.bloomberg.com/news/2014-03-05/china-to-declare-war-on-pollution-as-smog-spreads-across-country.html)

BP (British Petroleum) (2014) 'Statistical Review of World Energy June 2014'. London: BP. (https://www.bp.com/content/dam/bp/pdf/Energy-economics/statistical-review-2014/BP-statistical-review-of-world-energy-2014-full-report.pdf)

Brady, W.J. (2012) 'Hydraulic Fracturing Regulation in the United States: The Laissez-Faire Approach of the Federal Government and Varying State Regulations'. Denver, CO: University of Denver, Sturm College of Law. (http://www.law.du.edu/documents/faculty-highlights/Intersol-2012-HydroFracking.pdf)

Brandt, A.R., Heath, G.A., Kort, E.A., O'Sullivan, F., Petron, G. and Jordaan, S.M. (2014) 'Methane Leaks from North American Natural Gas Systems'. *Science* 343(6172): 733-735.

Brink, S., Singer, L.E., Sengupta, M., Godfrey, H., Lyser, S. and Mignotte, S. (2013) 'Methane Mitigation Opportunities in China'. Woodrow Wilson School of Public & International Affairs Graduate Policy Workshop. Princeton, NJ: Princeton University. (https://www.princeton.edu/~mauzeral/teaching/WWS591e_Methane_Workshop_FinalReport%202013.pdf)

British Embassy Beijing (2014) ‘China Energy Monthly Report’. Beijing: British Embassy. (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/333075/China_Energy_Monthly_June_2014.pdf)

Brittingham, M.C., Maloney, K.O., Farag, A.M., Harper, D.D. and Bowen, Z.H. (2014) ‘Ecological Risks of Shale Oil and Gas Development to Wildlife Aquatic Resources and Their Habitats’. *Environmental Science and Technology* 48(19): 11034-11047.

Broderick, J. and Anderson, K. (2012) ‘Has US Shale Gas Reduced CO2 Emissions? Examining Recent Changes in Emissions from the US Power Sector and Traded Fossil Fuels.’ Norwich: The Tyndall Centre. (http://www.tyndall.ac.uk/sites/default/files/broderick_and_anderson_2012_impact_of_shale_gas_on_us_energy_and_emissions.pdf)

Broderick. J., et al. (2011) ‘Shale gas: an updated assessment of environmental and climate change impacts.’ Manchester: A report commissioned by The Co-operative and undertaken by researchers at the Tyndall Centre for Climate Change Research. (http://www.co-operative.coop/Corporate/Fracking/Shale%20gas%20update%20-%20full%20report.pdf)

Brown, S.P.A., Gabriel, S.A. and Egging, R. (2010) ‘Abundant Shale Gas Resources: Some Implications for Energy Policy’. Background Paper. Washington, DC: Resources for the Future and National Energy Policy Institute. (http://www.rff.org/Documents/Features/NEPI/RFF-BCK-Brownetal-ShaleGas.pdf)

CAAC (Clean Air Alliance of China) (2013) ‘State Council Air Pollution Prevention and Control Action Plan: China Clean Air Updates’. (http://www.cleanairchina.org/file/loadFile/27.html)

Calow, R.C., Howarth, S.E. and Wang, J. (2009) ‘Irrigation Development and Water Rights Reform in China’. *Water Resources Development* 25(2): 227-248.

Carbon Tracker Initiative (2014) ‘Carbon Supply Cost Curves: Evaluating Financial Risk to Coal Capital Expenditures’. London: Carbon Tracker Initiative. (http://www.carbontracker.org/report/carbon-supply-cost-curves-evaluating-financial-risk-to-coal-capital-expenditures/)

Carmody, L. (ed.) (2010) *Water in China: Issues for Responsible Investors*. Singapore: Responsible Research. (http://www.sustainalytics.com/sites/default/files/water_in_china-_issues_for_responsible_investors_feb2010.pdf)

Chen, A. (2013) ‘Tight Gas: China’s Unsung Unconventional Energy Revolution’. *Reuters,* 8 July. (http://www.reuters.com/article/2013/07/08/china-tightgas-idUSL3N0EG2BF20130708)

Chen, A., Hua, J. and Zhu, C. (2014) ‘China Finds Shale Gas Challenging, Halves 2020 Output Target’. *Reuters*, 7 August. (http://www.reuters.com/article/2014/08/07/us-china-shale-target-idUSKBN0G70GS20140807)

Chignell, S. and Gross, R.J.K. (2013) ‘Not Locked In? The Overlooked Impact of New Gas-Fired Generation Investment on Long-Term Decarbonisation in the UK’. *Energy Policy* 52(C): 699-705.

China 2050 Pathways Development Group (2014) ‘China 2050 Pathways’. (http://2050pathway-en.chinaenergyoutlook.org)

China FAQs (2014) ‘Table: What Are China’s National Climate and Energy Targets?’. The Network for Climate and Energy Information. Washington, DC: WRI. (http://www.chinafaqs.org/files/chinainfo/ChinaFAQs_table_China_climate_energy_targets_0.pdf)

China Shale Gas Network (2015) ‘Guo Feng Jiao: 2020 shale gas production is expected to account for about 15% share of domestic natural gas’. 21st Century Business Herald. (http://www.csgcn.com.cn/news/show-59334.html)

China Water Risk (2014) ‘China Tightens Water & Air Emissions Rules for Certain Sectors’. (http://chinawaterrisk.org/notices/china-tightens-water-air-emissions-rules-for-certain-sectors/)

Chongqing Provincial Government (2015) ‘Chongqing shale gas industry development guidance (2015-2020)’. (http://www.cq.gov.cn/publicinfo/web/views/Show!detail.action?sid=3970910).

Chou, E. (2013) ‘Shale Gas in China: Development and Challenges.’ Cambridge, MA: University of Harvard. (http://blogs.law.harvard.edu/ellachou/files/2013/07/Shale-Gas-in-China-Draft.pdf)

Clark, C.E. and Veil, J.A. (2009) ‘Produced Water Management Volumes and Management Practices in the United States’. Prepared for DOE National Energy Technology Laboratory. (http://www.bucknell.edu/script/environmentalcenter/marcellus/default.aspx?articleid=5YUWKAKC65NSDFJORM8CTPDQH)

CLPIC (n.d.) ‘Chongqing Longjing Papermaking Industry Co., Ltd. – About Us’. (http://www.toocle.com/ChinaSuppliers/1067511/Chongqing-Longjing-Papermaking-Industry-Co-,.html)

Committee on Induced Seismicity Potential in Energy Technologies, Committee on Earth Resources, Committee on Geological and Geotechnical Engineering, Committee on Seismology and Geodynamics, Board on Earth Sciences and Resources and Division on Earth and Life Studies (2013) ‘Induced Seismicity Potential in Energy Technologies’. National Academy of Sciences.

CNREC (China National Renewable Energy Centre) (2014) ‘2013: Progress for RE and for CNREC’. Beijing: CNREC. (http://www.cnrec.org.cn/english/publication/2014-03-31-414.html)

Colborn, T., Kwiatkowski, C., Schultz, K. and Bachran, M. (2011) ‘Natural Gas Operations from a Public Health Perspective’. *Human and Ecological Risk Assessment* 17: 1039-1056.

CTI (Carbon Tracker Initiative) and ASrIA (Association for Sustainable and Responsible Investment in Asia) (2014) ‘The Great Coal Cap: China’s Energy Policies and the Financial Implications for Thermal Coal’. London: CTI (http://www.carbontracker.org/report/the-great-coal-cap-chinas-energy-policies-and-the-financial-implications-for-thermal-coal/)

Darrah, T.H., Vengosh, A., Jackson, R.B., Warner, N.R., and Poreda, R.J. (2014) 'Noble Gases Identify the Mechanisms of Fugitive Gas Contamination in Drinking-Water Wells Overlying the Marcellus and Barnett Shales'. *Proceedings of the National Academy of Sciences of the United States of America* 111 (39): 14076-14081.

Ding, Y., Han. W., Chai, Q., Yang, S. and Shen, W. (2013) 'Coal-Based Synthetic Natural Gas (SNG): A Solution to China's Energy Security and CO_2 Reduction?' *Energy Policy* 55: 445-453.

Doczi, J., Calow, R. and d'Alancon, V. (2014) 'Growing More with Less: China's Progress on Agricultural Water Management and Reallocation'. London: Development Progress.

DOE (Department of Energy) (2014a) 'Environmental Impacts of Unconventional Natural Gas Development and Production'. DOE/NETL-2014/1651. Washington, DC: DOE, National Energy Technology Laboratory, Office of Fossil Energy. (http://www.netl.doe.gov/File%20Library/Research/Oil-Gas/publications/NG_Literature_Review3_Post.pdf)

DOE (Department of Energy) (2014b) 'Life Cycle Analysis of Natural Gas Extraction and Power Generation'. DOE/NETL-2014/1646. Washington, DC: DOE, National Energy Technology Laboratory, Office of Fossil Energy. (http://www.netl.doe.gov/File%20Library/Research/Energy%20Analysis/Life%20Cycle%20Analysis/NETL-NG-Power-LCA-29May2014.pdf)

DSIRE (Database of State Incentives for Renewables & Efficiency) (2014) 'Current RPS Data: DSIRE PS Data Spreadsheet'. Raleigh: NC: Database of State Incentives for Renewables & Efficiency. (http://www.dsireusa.org/rpsdata/index.cfm)

DRC (Development Research Centre) (2015) '2020 shale gas production is expected to account for about 15% of the share of domestic natural gas'. Beijing: Development Research Centre of the Chinese State Council. (http://www.csgcn.com.cn/news/show-59334.html)

Eaton, S. and Kostka, G. (2014) 'Authoritarian Environmentalism Undermined? Local Leaders' Time Horizons and Environmental Policy Implementation in China'. *The China Quarterly* 218: 359-380.

Environmental Defense Fund (EDF) (2013) 'Natural Gas: EDF Is Fighting for Tough Rules and Enforcement'. New York: EDF. (www.edf.org/climate/natural-gas)

Environmental Defense Fund (EDF) (2014) 'What Will It Take to Get Sustained Benefits from Natural Gas?' New York: EDF. (http://www.edf.org/methaneleakage)

EIA (Energy Information Administration) (2013a) 'Coal Regains Some Electric Generation Market Share from Natural Gas'. *Today in Energy*, 23 May. Washington, DC: EIA. (http://www.eia.gov/todayinenergy/detail.cfm?id=11391)

EIA (Energy Information Administration) (2013b) 'Electric Power Annual: Table 3.1B'. Washington, DC: EIA. (http://www.eia.gov/electricity/annual/)

EIA (Energy Information Administration) (2013c) 'Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States'. Washington DC: EIA. (http://www.eia.gov/analysis/studies/worldshalegas/pdf/fullreport.pdf)

EIA (Energy Information Administration) (2013d) 'Working Gas in Underground Storage', in 'Natural Gas'. Washington, DC: EIA. (http://www.eia.gov/naturalgas/weekly/#tabs-storage-3)

EIA (Energy Information Administration) (2014a) 'Coal'. Washington, DC: EIA (http://www.eia.gov/coal/data.cfm#production)

EIA (Energy Information Administration) (2014b) 'International Energy Statistics'. Washington, DC: EIA. (http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm#)

EIA (Energy Information Administration) (2014c) 'Short-Term Energy Outlook. Table 9a: US Macroeconomic Indicators and CO2 Emissions'. Washington, DC: EIA. (http://www.eia.gov/forecasts/steo/tables/?tableNumber=5#startcode=2005)

EIA (Energy Information Administration) (2014d) 'How Much Coal, Natural Gas, or Petroleum Is Used to Generate a Kilowatt Hour of Electricity?' Washington, DC: EIA. (http://www.eia.gov/tools/faqs/faq.cfm?id=667&t=8)

EIA (Energy Information Administration) and ARI (Advanced Resources International) (2013) 'World Shale Gas and Shale Oil Resource Assessment'. Washington, DC: EIA and ARI. (http://www.adv-res.com/pdf/A_EIA_ARI_2013%20World%20Shale%20Gas%20and%20Shale%20Oil%20Resource%20Assessment.pdf)

EPA (Environmental Protection Agency) (2006) 'Cost-Effective Directed Inspection and Maintenance Control Opportunities at Five Gas Processing Plants and Upstream Gathering Compressor Stations and Well Sites'. Washington, DC: EPA. (http://www.epa.gov/gasstar/documents/clearstone_II_03_2006.pdf)

EPA (Environmental Protection Agency) (2012) 'Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Reviews'. *EPA Federal Register* 77(159): 49490-49600.

EPA (Environmental Protection Agency) (2014) 'Class II Wells – Oil and Gas-Related Injection Wells'. Washington, DC: EPA. (http://water.epa.gov/type/groundwater/uic/class2/index.cfm)

FAO (Food and Agricultural Organization) Aquastat (2011) 'Country Profile – China'. Rome: FAO. (http://www.fao.org/nr/water/aquastat/countries_regions/CHN/index.stm)

Farah, P.D. and Tremolada, R. (2013) 'A Comparison between Shale Gas in China and Unconventional Fuel Development in the United States: Health, Water and Environmental Risks'. gLAWcal Working Paper and IUSE Working Paper. (http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2341738)

Financial Times (2014) 'Commodities'. The Financial Times. (http://markets.ft.com/research/markets/Tearsheets/Summary?s=US@NG.1:NYM)

FracFocus (2014) 'Chemicals & Public Disclosure', Oklahoma City, OK: Ground Water Protection Council and the Interstate Oil and Gas Compact Commission. (http://fracfocus.org/chemical-use/chemicals-public-disclosure)

Freyman, M. (2014) 'Hydraulic Fracturing & Water Stress: Water Demand by the Numbers'. Boston, MA: Ceres (http://www.ceres.org/resources/reports/hydraulic-fracturing-water-stress-water-demand-by-the-numbers/view)

Fuling District of Chongqing Government (2014) 'Fuling Shale Gas Development and Usage Implementation Plan'. Chongqing: Fuling District of Chongqing Government. (http://www.flagri.gov.cn/jiaoshi/Details.aspx?topicId=544965&ci=3192&psi=3408)

Gao, F. (2012) 'Will There Be a Shale Gas Revolution in China by 2020?' Oxford: Oxford Institute for Energy Studies. (http://www.oxfordenergy.org/2012/04/will-there-be-a-shale-gas-revolution-in-china-by-2020/)

GAO (Government Accountability Office) (2014) 'EPA Program to Protect Underground Sources from Injection of Fluids Associated with Oil and Gas Production Needs Improvement'. Washington, DC: GAO.

Global Commission on the Economy and Climate (2014) 'New Climate Economy Report'. Global Commission on the Economy and Climate (http://newclimateeconomy.report/energy/#section-446-content-459)

Green, F. and Stern, N. (2014) 'An Innovative and Sustainable Growth Path for China: A Critical Decade'. London: Centre for Climate Change Economics and Policy and Grantham Research Institute on Climate Change and the Environment. (http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2014/05/Green-and-Stern-policy-paper-May-20141.pdf)

Grubert, E.A., Beach, F.C. and Webber, M.E. (2012) 'Can Switching Fuels Save Water? A Life Cycle Quantification of Freshwater Consumption for Texas Coal- and Natural Gas-Fired Electricity'. *Environmental Research Letters* 7(4): 045801.

Harvey, S., Gowrishankar, V. and Singer, T. (2012) 'Leaking Profits: The US Oil and Gas Industry Can Reduce Pollution, Conserve Resources, and Make Money by Preventing Methane Waste'. New York: Natural Resources Defense Council. (http://www.nrdc.org/energy/files/Leaking-Profits-Report.pdf)

He, Y. (2014) 'A Brief Analysis of Shale Gas Industry Policies'. *Mondaq*, 23 May. (http://www.mondaq.com/x/316130/Oil+Gas+Electricity/A+Brief+Analysis+Of+Shale+Gas+Industry+Policies)

Hilton, I. and Geall, S. (2014) 'Culture of Secrecy behind China's Pollution Crisis'. *Chinadialogue*, 5 August. (https://www.chinadialogue.net/article/show/single/en/6962-Culture-of-secrecy-behind-China-s-pollution-crisis)

Hoffman, A., Olsson, G. and Lindström, A. (2014) 'Shale Gas and Hydraulic Fracturing: Framing the Water Issue'. Report 34. Stockholm: SIWI. (http://www.siwi.org/wp-content/uploads/2014/08/2014_Fracking_Report_web.pdf)

Hornby, L. (2015) 'China's Cnooc shelves shale project'. *Financial Times,* 27 March. (http://www.ft.com/cms/s/0/fa536e1c-d47b-11e4-8be8-00144feab7de.html?siteedition=intl#axzz3Vpo1EWTR)

Horner, R. and Clark, C. (2012) 'The Evolving Regulatory Landscape of Shale Gas Development'. Western Energy Policy Research Conference, Boise ID, 30-31 August. (http://epi.boisestate.edu/media/12971/robert%20horner%20the%20evolving%20regulatory%20landscape%20of%20shale%20gas%20development.pdf)

Howarth, R.W, Santoro, R. and Ingraffea, A. (2011) 'Methane and the Greenhouse-Gas Footprint of Natural Gas from Shale Formations.' *Climatic Change* 106(4): 679-690.

Hu, F. (2014) 'Prioritising EIA Reform in China'. Hong Kong: China Water Risk. (http://chinawaterrisk.org/resources/analysis-reviews/prioritising-eia-reform-in-china/)

Hua, J. and Chen, A. (2014) 'Sinopec's Fuling Verified as China's First Large Shale Gas Play'. *Reuters,* 17 July. (http://in.reuters.com/article/2014/07/17/china-sinopec-shalegas-idINL4N0PS2BX20140717)

ICF International (2014) 'Economic Analysis of Methane Emission Reduction Opportunities in the US Onshore Oil and Natural Gas Industries'. Fairfax, VA: ICF International (http://www.edf.org/sites/default/files/methane_cost_curve_report.pdf)

IEA (International Energy Agency) (2011) *World Energy Outlook 2011. Special Report: Are We Entering a Golden Age of Gas?* Geneva: IEA. (http://www.worldenergyoutlook.org/goldenageofgas/)

IPCC (Intergovernmental Panel on Climate Change) (2007) 'Direct Global Warming Potentials', in IPCC *Fourth Assessment Report: Climate Change 2007.* Cambridge: Cambridge University Press. (http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html)

IPCC (2014) 'Climate Change 2014: Synthesis report to Assessment Report 5'. Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press. (http://www. ipcc.ch/report/ar5/syr/)

IPE (Institute of Public and Environmental Affairs) and NRDC (Natural Resources Defense Council) (2014) 'Pollution Information Transparency Index (PITI): 2013-2014 Annual Assessment of Environmental Transparency in 120 Chinese Cities'. Beijing: IPE and NRDC. (http://www.ipe.org.cn/en/about/notice_de.aspx?id=11598&WebShieldSessionVerify=fgWbtVy7ldlPr1YVgPTN)

Jackson, R.B. (2014) 'The Integrity of Oil and Gas Wells'. *Proceedings of the National Academy of Sciences of the United States of America* 111: 10902-10903.

Jackson, R.B., Down, A., Phillips, N.G., Ackley, R.C., Cook, C.W., Plata, D.L. and Zhao, K. (2014) 'Natural Gas Pipeline Leaks across Washington, D.C.' *Environmental Science & Technology* 48: 2051-2058.

Jacoby, H.D., O'Sullivan, F.M. and Paltsev, S. (2012) 'The Influence of Shale Gas on US Energy and Environmental Policy'. *Economics of Energy and Environmental Policy* 1(1): 37-51.

Jenner, S. and Lamadrid, A.J. (2013) 'Shale Gas Vs. Coal: Policy Implications from Environmental Impact Comparisons of Shale Gas, Conventional Gas, and Coal on Air, Water, and Land in the United States'. *Energy Policy* 53: 442-453.

Jiang, M., Hendrickson, C.T. and VanBriesen, J.M. (2014) 'Life Cycle Water Consumption and Wastewater Generation Impacts of a Marcellus Shale Gas Well'. *Environmental Science & Technology* 48(3): 1911-1920.

Joffe, D. (2013) 'A Role for Shale Gas in a Low-Carbon Economy? Further Explanations.' London: UK Committee on Climate Change. (http://www.theccc.org.uk/wp-content/uploads/2013/09/Shale-gas-blog-final.pdf)

Karhl, F. and Wang, X. (2014) 'Integrating Renewables into Power Systems in China: A Technical Primer – Power Systems Operations'. Beijing, China: Regulatory Assistance Project. (http://www.raponline.org/document/download/id/7459)

Kai, M. (2013) 'Committing to the Development of an Ecological Civilization'. *Qiushi Journal, Organ of the Central Committee of the Communist Party of China* 2013(4): 5-20.

Kaiman, J. (2014) 'China Says More than Half of its Groundwater Is Polluted'. *The Guardian*, 23 April. (http://www.theguardian.com/environment/2014/apr/23/china-half-groundwater-polluted)

Karhl, F. and Wang, X. (2014) 'Integrating Renewables into Power Systems in China: A Technical Primer – Power Systems Operations'. Beijing, China: Regulatory Assistance Project. (http://www.raponline.org/document/download/id/7459)

Kosnik, R.L. (2007) 'The Oil and Gas Industry's Exclusions and Exemptions to Major Environmental Statutes'. Washington, DC: Earthworks and Oil and Gas Accountability Project. (www.shalegas.energy.gov/resources/060211_earthworks_petroleumexemptions.pdf)

Larson, C. (2013) 'China Wants to Cut Down on Coal – And That's Bad for Global Warming'. *Bloomberg Businessweek*, 30 September. (http://www.businessweek.com/articles/2013-09-30/chinas-synthetic-natural-gas-plants-could-accelerate-climate-change)

Lee, A., Zinamen, O., Logan, J., Bazilian, M., Arent, D., and Newmark, R., (2012) 'Interactions, Complementarities and Tensions at the Nexus of Natural Gas and Renewable Energy'. *The Electricity Journal* 25(10): 38-48.

Levi, M. (2013) 'Climate Consequences of Natural Gas as a Bridge Fuel'. *Climatic Change* 118(3-4): 609-623.

Liangchun, D. (2014) 'China Needs to Scale up Wind and Solar in 13th Five Year Plan'. *Chinadialogue*, 25 September. (https://www.chinadialogue.net/blog/7349-China-needs-to-scale-up-wind-and-solar-in-13th-Five-Year-Plan/en)

Ling, S.Y. (2012) 'China Mulls Tripling Coalbed Methane Production Subsidy: Report'. *Platts*, 16 November. (http://www.platts.com/latest-news/natural-gas/singapore/china-mulls-tripling-coalbed-methane-production-7257091)

Litovitz, A., Curtright, A., Abramzon, S., Burger, N., and Samaras, C. (2013) 'Estimation of Regional Air-Quality Damages from Marcellus Shale Natural Gas Extraction in Pennsylvania'. *Environmental Research Letters* 8(1): 014017.

Logan, J., Lopez, A., Mai, T., Davidson, C., Bazilian, M. and Arent, D. (2013) 'Natural Gas Scenarios in the US Power Sector'. *Energy Economics* 40(0): 183-195.

Lu, X., Salovaara, J. and McElroy, M.B. (2012) 'Implications of the Recent Reductions in Natural Gas Prices for Emissions of CO_2 from the US Power Sector.' *Environmental Science and Technology* 46: 3014-3021.

Luo, T., Otto, B. and Maddocks, A. (2013) 'Majority of China's Proposed Coal-Fired Power Plants Located in Water-Stressed Regions'. Washington, DC: WRI. (http://www.wri.org/blog/2013/08/majority-china%E2%80%99s-proposed-coal-fired-power-plants-located-water-stressed-regions)

MacKay, D.J.C. and Stone, T.J. (2013) 'Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use'. London: Department of Energy and Climate Change. (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/237330/MacKay_Stone_shale_study_report_09092013.pdf)

Marsters, P.V. (2012) 'A Revolution on the Horizon: The Potential of Shale Gas Development in China and Its Impact on Water Resources'. *China Environment Series* 12: 35-47.

Martina, M., Hui, L., Stanway, D. and Reklev, S. (2014) 'China to "Declare War" on Pollution, Premier Says'. *Reuters*, 4 March. (http://www.reuters.com/article/2014/03/05/us-china-parliament-pollution-idUSBREA2405W20140305)

McCabe, D. et al. (2015) 'Waste Not: Common sense ways to reduce methane pollution from the oil and natural gas industry'. Clean Air Task Force/ National Resources Defence Council/ Sierra Club (http://www.catf.us/resources/publications/files/WasteNot.pdf)

McFeeley, M. (2013) 'Three Reasons Why the Obama Administration Shouldn't Use FracFocus.org in Its New Fracking Disclosure Rule'. *NRDC Switchboard*. New York: NDRC. (http://switchboard.nrdc.org/blogs/mmcfeeley/three_reasons_why_the_obama_ad.html)

McFeeley, M. (2014) 'Falling through the Cracks: Public Information and the Patchwork of Hydraulic Fracturing Disclosure Laws'. *Vermont Law Review* 38(4): 849-941.

McJeon, H., Edmonds, J, Bauer, N., Clarke, L., Fisher, B., Flannery, B.P., Hilaire, J., Krey, V., Marangoni, G., Mi, R., Riahi, K., Rogner, H. and Tavoni, M. (2014) 'Limited Impact on Decadal-Scale Climate Change from Increased Use of Natural Gas'. *Nature* 514: 482-485.

Meldrum, J., Nettles-Anderson, S., Heath, G. and Macknick, J. (2013) 'Life Cycle Water Use for Electricity Generation: A Review and Harmonization of Literature Estimates'. *Environmental Research Letters* 8: 015031.

MEP (Ministry of Environmental Protection) (2003) 'Report on the State of the Environment in China 2003 – the Freshwater Environment'. Beijing: MEP.

MEP (Ministry of Environmental Protection) (2012) 'MEP Releases 2012 Report on the State of the Environment in China: Overall Environmental Quality across China Maintained Stable but the Situation Remained Severe'. Beijing: MEP. (http://english.mep.gov.cn/News_service/news_release/201306/t20130607_253508.htm)

MEP (Ministry of Environmental Protection) (2014a) 'Ministry of Environmental Protection and the Ministry of Land and Soil Pollution Nationwide Survey Released Bulletin'. Beijing: MEP. (http://www.mep.gov.cn/gkml/hbb/qt/201404/t20140417_270670.htm)

MEP (Ministry of Environmental Protection) (2014b) 'Opinions on Strengthening the Management of Environment Impact Assessment Agencies'. Beijing: MEP.

MEP (Ministry of Environmental Protection) (2014c) 'Guidance on Promoting Public Participation in Environmental Protection'. Beijing: MEP.

Mordick, B. (2014) 'Leaky Oil and Gas Wells Threaten the Environment and Public Health and Safety'. New York: NRDC. (http://switchboard.nrdc.org/blogs/bmordick/leaky_oil_and_gas_wells_threat.html)

Myllyvirta, L. (2015) 'China's Coal Consumption Fell in 2014'. The Energy Collective. (http://theenergycollective.com/lauri-myllyvirta/2187741/it-s-official-china-s-coal-consumption-fell-2014)

NBS (National Bureau of Statistics) (2013) 'Annual Data'. Beijing: NBS. (http://www.stats.gov.cn/english/statisticaldata/AnnualData/)

NDPHL (2007) '2007/7 Annual Report'. Chongqing: NDPHL. (http://www.ndpaper.com/eng/ir/reports/ar19688-e109.pdf)

NDRC (National Development and Reform Commission of China) (2010) 'Letter from Director-General, Department of Climate Change to Executive Secretary, UNFCCC Secretariat stating China's mitigation actions under the Copenhagen Accord'. 28 January 2010. (http://unfccc.int/files/meetings/cop_15/copenhagen_accord/application/pdf/chinacphaccord_app2.pdf)

NRDC (Natural Resources Defense Council) (2012) 'Hydraulic Fracturing Can Potentially Contaminate Drinking Water Sources'. *Water Facts*. New York: NRDC. (http://www.nrdc.org/water/files/fracking-drinking-water-fs.pdf)

NRDC (Natural Resources Defense Council) (2014) '"The True Cost of Coal in 2012" Report Released'. Policy Research Project. New York: NRDC and China Coal Consumption Cap Plan. (http://www.nrdc.cn/coalcap/index.php/English/project_content/id/508)

NEA (National Energy Administration) (2014) 'NEA Energy Work Plan for 2014'. Beijing: NEA. (http://zfxxgk.nea.gov.cn/auto82/201401/t20140124_1756.htm)

NETL (National Energy Technology Laboratory) (2013) 'Modern Shale Gas Development in the United States: An Update'. Washington, DC: Strategic Center for Natural Gas and Oil, NETL. (http://www.netl.doe.gov/File%20Library/Research/Oil-Gas/shale-gas-primer-update-2013.pdf)

OECD (Organisation for Economic Co-operation and Development) (2004) 'Emission Scenario Document on Water Treatment chemicals'. Emission Scenario Documents 4. Paris: OECD. (http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2004)9&doclanguage=en)

OECD (Organisation for Economic Co-operation and Development) (2006) 'Environmental Compliance and Enforcement in China: An Assessment of Current Practices and Ways Forward'. Paris: OECD. (http://www.oecd.org/env/outreach/37867511.pdf)

O'Sullivan, F. and Paltsev, S. (2012) 'Shale Gas Production: Potential Versus Actual Greenhouse Gas Emissions'. *Environmental Research Letters* 7(4): 1-6.

Patton, J. and Guo, A. (2014) 'Russia, China Add to $400 Billion Gas Deal With Accord'. *Bloomberg*, 10 November. (http://www.bloomberg.com/news/2014-11-10/russia-china-add-to-400-billion-gas-deal-with-accord.html)

People's Daily (2014) '2014-2015 Action Plan on Energy Saving, Emissions Reduction, and Low-Carbon'. *People's Daily*, 26 May (http://politics.people.com.cn/n/2014/0526/c1001-25065061.html)

Perry, C. (2013) 'ABCDE+F: a framework for thinking about water resources management.' *Water International*, 38:1, 95-107.

PRC (People's Republic of China) (2011) 'Outline of the 12th Five Year Plan'. Beijing: PRC (http://ec.europa.eu/regional_policy/international/pdf/china_draft_12th_5yearplan17032011.pdf)

PRC (People's Republic of China) (2013a) 'Air Pollution Prevention and Action Plan'. Beijing: PRC. (http://www.gov.cn/zwgk/2013-09/12/content_2486773.htm)

PRC (People's Republic of China) (2013b) 'Shale gas development guidance (2011–15)'. (http://www.coalchina.org.cn/page/zt/130130/125gh/15.pdf)

PRC (People's Republic of China) (2014) *Energy Development Strategy Action Plan (2014-2020)*. Beijing: PRC. (http://www.gov.cn/zhengce/content/2014-11/19/content_9222.htm or http://news.xinhuanet.com/english/china/2014-11/19/c_133801014.htm)

ProPublica (2012) 'Injection Wells: The Poison Beneath Us'. New York: ProPublica. (http://www.propublica.org/article/injection-wells-the-poison-beneath-us)

Rahm, B.G. and Riha, S.J. (2014) 'Evolving Shale Gas Management: Water Resource Risks, Impacts and Lessons Learned'. *Environmental Science: Processes & Impacts* 16: 1400-1412.

Reig, P., Luo, T. and Proctor, J.N. (2014) *Global Shale Gas Development: Water Availability and Business Risks*. Washington, DC: WRI. (http://www.wri.org/sites/default/files/wri14_report_shalegas.pdf)

Reuters (2014) 'China's Sinopec to Push on with $10 Bln Coal-to-Gas Plan'. *Reuters*, 4 September. (http://in.reuters.com/article/2014/09/04/sinopec-coal-gas-idINL3N0QZ37J20140904)

Reuters (2013) 'Press Digest – China – Aug 27'. Reuters, 26 August. (http://www.reuters.com/article/2013/08/27/press-digest-china-idUSL4N0GS0EP20130827)

Rich, A., Grover, J.P., Sattler, M.L. (2013) 'An Exploratory Study of Air Emissions Associated with Shale Gas Development and Production in the Barnett Shale'. *Journal of the Air & Waste Management Association* 64(1): 61-72.

Russell, C. (2014) 'China's Coal Proposals Leave Some Hope for Exporters: Russell'. Reuters, 11 September. (http://www.reuters.com/article/2014/09/11/us-column-russell-coal-asia-idUSKBN0H60Y720140911)

Sandalow, D., Wu, J., Yang, Q., Hove, A., and Lin, J. (2014) 'Meeting China's Shale Gas Goals'. Working Draft for Public Release. New York: School of International and Public Affairs and Columbia University's Center on Global Energy Policy. (http://energypolicy.columbia.edu/research/shale-gas-development-china)

Sanderson, P. (2014) 'New Lee & Man Paper Machine Begins Production in China'. *Resource Efficient Business*, 5 August. (http://www.rebnews.com/news/manufacturing/new_lee_man_paper_machine_begins_production_china.html)

Sathaye, J., Lucon, O. and Rahman, A. (2011) 'Renewable Energy in the Context of Sustainable Development', in O. Edenhofer, R. Pichs-Madruga, Y, Sokona, T. Zwickel, C. von Stechow, K. Seyboth, P. Eickemeier, P. Matschoss, S. Kadner, G. Hansen and S. Schlömer (eds) *Renewable Energy Sources and Climate Change Mitigation*. IPCC Special Report. Cambridge: Cambridge University Press.

Schmale, J., Shindell, D., von Schneidemesser, E., Chabay, I. and Lawrence, M. (2014) 'Air Pollution: Clean up Our Skies'. *Nature News* 515: 335-337.

Schrag, D.P. (2012) 'Is Shale Gas Good for Climate Change?' *American Academy of Arts & Sciences* 142(2): 72-80.

Shanghai Daily (2015) 'Chinese new reform moves for coal sector'. (http://coal.steelguru.com/china/19594/chinese_new_reform_moves_for_coal_sector)

Shell (2014) 'Understanding Tight and Shale Gas'. London: Shell. (http://www.shell.us/aboutshell/shell-businesses/onshore/shale-tight.html)

Shonkoff, S.B.C., Hays, J. and Finkel, M.L. (2014) 'Environmental Public Health Dimensions of Shale and Tight Gas Development'. *Environmental Health Perspectives* 122(8): 787-795.

Sovacool, B.K. (2014) 'Cornucopia or Curse? Reviewing the Costs and Benefits of Shale Gas Hydraulic Fracturing (Fracking)'.*Renewable and Sustainable Energy Reviews* 37: 249-264.

SPE (Society of Petroleum Engineers International) (1997) 'Petroleum Reserves Definitions.' London: SPE. (http://www.spe.org/industry/docs/Petroleum_Reserves_Definitions_1997.pdf)

Stanway, D. (2013) 'To Tackle Pollution, China to Drop Pursuit of Growth at all Costs'. *Reuters*, 18 November. (http://www.reuters.com/article/2013/11/18/us-china-reform-environment-idUSBRE9AH07M20131118)

Stanway, D. and Hardy, W. (2014) 'China's Coal Industry Says Times Are Hard, Outlook Worse.' *Reuters,* 24 July. (http://www.reuters.com/article/2014/07/24/us-china-coal-idUSKBN0FT1GG20140724)

Stark, M. et al. (2014) 'Achieving high performance in unconventional operations Integrated planning, services, logistics and materials management'. Accenture. (http://www.accenture.com/SiteCollectionDocuments/PDF/Accenture-High-Performance-Unconventional-Operations.pdf)

Taylor, L. and Branigan, T. (2014) 'US and China Strike Deal on Carbon Cuts in Push for Global Climate Change Cact'. *The Guardian,* 12 November. (http://www.theguardian.com/environment/2014/nov/12/china-and-us-make-carbon-pledge)

The Economist (2015) 'In a bind: Will falling oil prices curb America's shale boom?' *The Economist,* 6 December. (http://www.economist.com/news/finance-and-economics/21635505-will-falling-oil-prices-curb-americas-shale-boom-bind)

Trambath, A., Luke, M., Shellenberger, M. and Nordhaus, T. (2013) 'Coal Killer: How Natural Gas Fuels the Clean Energy Revolution'. Oakland: Breakthrough Institute. (http://thebreakthrough.org/images/main_image/Breakthrough_Institute_Coal_Killer.pdf)

Tse, P.K. (2013) 'The Mineral Industry of China'. United States Geological Survey 2012 Minerals Yearbook: China. (http://minerals.usgs.gov/minerals/pubs/country/2012/myb3-2012-ch.pdf)

UK Government (2014) 'Electricity Market Reform: Capacity Market'. London: Department of Energy and Climate Change. (https://www.gov.uk/government/collections/electricity-market-reform-capacity-market)

UN (2012) 'Green Growth'. New York: UN Sustainable Development Knowledge Platform. (http://sustainabledevelopment.un.org/index.php?menu=1447)

UNEP (UN Environment Programme) (2000) *Mining and Sustainable Development II: Challenges and Perspectives.* Vol. 23. Paris: UNEP, Division of Technology, Industry and Economics. (http://www.uneptie.org/media/review/vol23si/unep23.pdf)

UNFCCC (UN Framework Convention on Climate Change) (2010) 'Report of the Conference of the Parties on Its Fifteenth Session, Held in Copenhagen from 7 to 19 December 2009. Addendum. Part Two: Action taken by the Conference of the Parties at Its Fifteenth Session'. UN Doc FCCC/CP/2009/11/Add.1. (http://unfccc.int/resource/docs/2009/cop15/eng/11a01.pdf)

UNFCCC (2009) 'The Copenhagen Accord: Outcome of the work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention'. United Nations Framework Convention on Climate Change: Decision 2/CP.15.

US House of Representatives (2011) 'Chemicals Used in Hydraulic Fracturing'. Washington, DC: US House of Representatives Committee on Energy and Commerce Minority Staff. (http://democrats.energycommerce.house.gov/sites/default/files/documents/Hydraulic-Fracturing-Chemicals-2011-4-18.pdf)

Van Hende, K.B.H., De Silva, N., Maurin, C. and Xiao, P. (2014) 'Mapping out China's Shale Gas Future: Challenges Towards Development'. *Oil, Gas & Energy Law* 3 (Special Issue in Unconventional Oil and Gas).

Vidic, R.D., Brantley, S.L., Vandenbossche, J.M., Yoxtheimer, D. and Abad, J.D. (2013) 'Impact of Shale Gas Development on Regional Water Quality'. *Science* 340: 1235009.

Wang, A.L. (2013) 'The Search for Sustainable Legitimacy: Environmental Law and Bureaucracy in China'. *Harvard Environmental Law Review* 37: 365-440.

Warner, N.R., Darrah, T.H., Jackson, R.B., Millot, R., Kloppman, W. and Vengosh, A. (2014) 'New Tracers to Identify Hydraulic Fracturing Fluids and Accidental Releases from Oil and Gas Operations'. *Environmental Science and Technology* 48(21): 12552-12560.

Williams, L. (2014) 'China's Climate Change Policies: Actors and Drivers'. Sydney: Lowy Institute for International Policy. (http://www.lowyinstitute.org/publications/chinas-climate-change-policies-actors-and-drivers)

Wolak, F. (2012) 'Careful What You Wish For: The Shale Gas Revolution and Natural Gas Exports'. Policy Brief. Stanford, CA: Stanford Institute for Economic Policy Research. (http://siepr.stanford.edu/?q=/system/files/shared/pubs/papers/briefs/PolicyBrief11_2012.pdf)

World Bank (2014) 'World Data Bank'. (http://data.worldbank.org/)

Xie, J., Liebenthal, A., Warford, J.J., Dixon, J.A., Wang, M., Gao, S., Wang, S., Jiang, Y. and Ma, Z. (2009) 'Addressing China's Water Scarcity: Recommendations for Selected Water Resource Management Issues'. Washington, DC: World Bank.

Xin, L. (2014) 'China's Coal-to-Gas Output to Disappoint Next Year.' *Interfax Global Energy*, 22 September. (http://interfaxenergy.com/gasdaily/article/13654/chinas-coal-to-gas-output-to-disappoint-next-year)

Xinhua (2014) 'Xi Jinping: Actively Promote Energy Production and Consumption Revolution'. *Xinhua*, 13 June. (http://news.163.com/14/0613/18/9UL0G7QB0001124J.html)

Yang, C.-J.and Jackson, R.B. (2013) 'China's Synthetic Natural Gas Revolution'. *Nature Climate Change* 3: 852-854.

Yang H., Flower, R.J. and Thompson, J. R. (2013) 'Shale-Gas Plans Threaten China's Water Resources'. *Science* 340: 340(6138):1288.

Yingchun, G. (2013) 'China Will Notably Cut CO2 Emissions by 2020'. *China.org.cn*, 21 November. (http://www.china.org.cn/environment/warsaw_climate_talks/2013-11/21/content_30663021.htm)

Zammerilli, A., Murray, R.C., Davis, T. and Littlefield, J. (2014) *Environmental Impacts of Unconventional Natural Gas Development and Production.* Pittsburgh, PA: DOE, National Energy Technology Laboratory, Office of Fossil Energy. (http://www.netl.doe.gov/File%20Library/Research/Oil-Gas/publications/NG_Literature_Review3_Post.pdf)

Annex A: Fracking water resource use assumptions and calculations

The direct water withdrawal requirements to drill and frack shale gas vary significantly between operations. They depend on the depth of the well to be drilled, the length of the horizontal well bore, the number of frack stages, the drilling and fracking equipment used, the rock type and the other constituents of the fracking fluid, among others (Gao, 2012). Because of these numerous factors, it is difficult to assign a specific range to use in attempting to assess the scale of water requirements to develop China's fracking industry. However, experience in the US suggests a typical shale gas well there probably requires somewhere in the region of *3-8 million* US gallons of water to frack (see for example, DOE, 2014a).[70]

China's shale gas resources are typically geologically deeper than those in the US [71] and, as supported by the limited Chinese data available (Yang, Flowers and Thompson, 2013), we might predict its wells to require a larger amount of water to frack (NETL, 2013). However, since the shale gas industry is still in its nascent stages in the country, only limited water-use data per fracking job are available. As the technology matures and innovation occurs it is likely that such water requirements will be similar in China to current usage in the US. Thus, to estimate China's likely future water usage, we rely on the US data (DOE, 2014a), along with the generous assumption that other fracking variables besides drill depth will remain relatively constant between the US and Chinese shale gas industries.

For the purpose of our calculations below, we assume the typical Chinese shale gas well will require about 5 million US gallons (about 19,000 m^3) of water to drill and frack. This is slightly more generous than the figure of 4 million US gallons used in reports by Gao (2012) and the Wilson Center (Marsters, 2012), which is based on the reported average for fracking activities in the Barnett Shale basin of the US. We also provide a brief sensitivity study that shows variance of water use per well has very little impact on our conclusions.

The drilling and fracking process requires clean water, but reuse and recycling of water from previous fracking activities is also possible. In the US,[72] rates of recycling vary widely between different shale basins, owing to the amount of water produced from each well and the different levels of pollution in the produced water from these areas. A review by Zammerilli et al. (2014) highlights companies in the Barnett and Fayetteville Shale Basins that meet about 6% of their direct water withdrawal needs for drilling and fracking from recycling, while companies in the Haynesville Basin are unable to recycle any because of worse quality of the wastewater. Companies in the Marcellus Basin, by contrast, are able to recycle at least 15% of their flow-back water, because of better water quality (Abdalla and Drohan, 2010).

For China, Gao (2012) moderates his estimate of water use by assuming 25% of all fracking water will be recycled (i.e. a single fracking job will withdraw only 3 million US gallons of freshwater and recycle an additional 1 million US gallons from previous jobs). In attempt to be conservative, we ignore this possibility in our estimate and calculations below, assuming the nascent Chinese shale gas industry will not undertake water recycling in its early years.

---

[70] Similarly, a full lifecycle analysis of the direct and indirect water consumption for the shale gas extraction process in the US estimates a requirement of about 4.3 million US gallons (Jiang et al., 2014). The authors estimate indirect uses account for about 30% of this total, so their equivalent estimate for direct withdrawals equates to about 3 million US gallons.

[71] For example, the Bakken Shale in the US runs from 3,000 to 1,200 ft while the depth of five of the six formations in the Sichuan and Yangtze Platform basins are approximately 10,000-16,000 ft (measured depth (MD) below the surface, although true vertical depth (TVD) of wells will vary depending on rock formations).

[72] We reason that the combination of the potential bias in reporting to FracFocus mentioned above, the likely increased depth of Chinese shale resources and the potential for increased length of the lateral portion of the well (as demonstrated by Sinopec's 21-stage fracture) suggest Chinese requirements may be higher than those in the US.

In terms of well production, we estimate that one fracked well will produce 50 million cubic metres of shale gas in its lifetime (Mackay and Stone, 2013)[73].Since China expresses its shale gas targets in terms of production, we then need to account for the exponential decline in well production. This is more difficult because the production profile from shale gas wells is highly non-linear. Instead, we simplify this decay by assuming an average well will produce 50% of its lifetime production (i.e. 25 million cubic metres) within the first three years and will do so in a consistently spaced manner (i.e. producing ~8 million cubic metres per year). We then assume wells cease contributing to the production targets after these three years of production, to simplify the calculations.[74]

Using these projections and data, we can estimate the number of wells that will need to be drilled and the implications of this for water use at different scales. The Chinese government set its 2020 production target of 30 bcm from a negligible production rate in early 2014. So we first assume shale gas extraction began in January 2014 and will run until December 2020. Using our previous assumption on the decline in gas production, only those wells drilled between 2018 and 2020 will contribute to the yearly production target in 2020, although wells drilled in earlier years are still important from a water use perspective. Satisfying the 2020 target results in a need to drill an average of 1,200 wells per year – about 8,400 wells in total. At 19,000 cubic metres of water needed to hydraulically fracture each well, such an endeavour will require about 160 million cubic metres of water to frack – about 23 million cubic metres per year if China evenly spaces out its production. If we make a conservative assumption that all of this production will occur in Chongqing, then this equates to only 0.05% of its total yearly water resources, 0.3% of its total yearly water withdrawals and 0.6% of its total yearly industrial water withdrawals. In the extremely unlikely scenario where all 8,400 wells were drilled in one year, this would equate to 0.3% of total yearly water resources, 1.9% of total yearly water withdrawals and 4.1% of total yearly industrial water withdrawals in Chongqing.

We can run similar calculations specifically for the Fuling field production target for Chongqing of 10 bcm by 2017. Here, we assume an extraction period from January 2014 until December 2017, with wells drilled between 2015 and 2017 contributing to the production target. This results in a need to drill about 400 wells per year – about 1,600 wells in total. These wells will require about 30 million cubic metres of water to frack – about 7.5 million cubic metres per year with evenly spaced production. This equates to only 0.02% of Chongqing's total yearly water resources, 0.09% of its total yearly water withdrawals and 0.2% of its total yearly industrial water withdrawals. Even in the unlikely scenario where all 1,600 wells were drilled in one year (i.e. 30 million cubic metres of water use), this would still equate to only 0.06% of total yearly water resources, 0.4% of total yearly water withdrawals and 0.8% of total yearly industrial water withdrawals for Chongqing.

Data on the production of tight gas are less precise and less widely available for China – both in terms of water requirements per well and in terms of the location and scale of development in coming years. By conservatively assuming tight gas production requires the same water requirements as shale gas production, we are able to at least investigate whether the impact of the wider fracking industry is likely to change our conclusions for shale development alone. Here, combining the 2020 targets for shale and tight gas (30 and 80 bcm, respectively), we find the water requirements are still relatively small when assessed at the regional or national scale. For example, if we considered all 110 bcm of national production to occur in Chongqing, this would still only require 2.2% of the current industrial water uses in the region using the same calculation as before.

The accuracy of these numbers is relatively unimportant given the uncertainty associated with the assumptions we have made in arriving at them. The importance in these findings lies in the fact that they show that even very aggressive fracking is unlikely to be constrained by water requirements when considered at a regional or national level.

---

[73] This is drawn from a comparison of the 'low' estimate for what constitutes an economically viable well in the UK (Mackay and Stone, 2013). This correlates with mid-way between a Tier 3 and Tier 4 prospect for the US (http://www.ogj.com/articles/print/volume-112/issue-1/drilling-production/study-develops-fayetteville-shale-reserves.html). While we note this is higher than historic US gas production, we justify this by the fact that Chinese wells are likely to be substantially more costly to drill and therefore will likely require the expectation of a larger recovery to justify their investment.

[74] Although we acknowledge this approach is a significant simplification of the likely expansion of well drilling, we justify the simplification in two ways. First, over the period we are interested in, this method provides similar results for the number of required wells. Second, the number of uncertainties surrounding the potential development of the Chinese industry suggests any detailed hypothetical analysis is unwarranted.

ODI is the UK's leading independent think tank on international development and humanitarian issues.

ISSN: 2052-7209

All ODI Reports are available from www.odi.org

Cover photo: Shell: Checking gas detectors at Changbei, China.

Overseas Development Institute
203 Blackfriars Road
London SE1 8NJ
Tel +44 (0)20 7922 0300
Fax +44 (0)20 7922 0399

www.odi.org

from the British people

This material has been funded by UK aid from the UK Government, however the views expressed do not necessarily reflect the UK Government's official policies.