THEODOR COJOIANU

MENGHONS PROJECT REPORT HSP 2427

Shale Gas and Hydraulic Fracturing: Risk and Opportunity Analysis for Oil and Gas Companies, Investors and the Future Energy Sector – Lessons from the US

14th January 2014

THE UNIVERSITY *of* EDINBURGH

Shale Gas and Hydraulic Fracturing:

Risk and Opportunity Analysis for

Oil and Gas Companies, Investors and

The Future Energy Sector-Lessons from the US

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MEng Project Mission Statement

Shale Gas and Hydraulic Fracturing:

Risk and Opportunity Analysis for Oil and Gas

Companies, Investors and the Future Energy Sector -

Lessons from the US

Student: Theodor Cojoianu

Supervisor: Dr. Peter Ewen

Project Background:

The project will explain how shale gas is now accessible for extraction due to technological innovations in horizontal drilling and hydraulic fracturing. The transformative effect of shale gas on the US Energy sector and the consequences worldwide will be described and the debate placed in the context of the transition to a low carbon economy, industry best practices, hydraulic fracturing technology risks, water stress, biodiversity and land use, and community impact. In the light of the US Energy Information Administration (EIA) study of the "137 shale formations in 41 Countries Outside the United States" [1]there is a real potential for other countries to pursue shale gas exploration and production as part of their quest for energy security and independence.

In this respect, one important goal of the project will be to identify the risks associated with shale gas exploration and production as well as the deployment of hydraulic fracturing technology. The thesis will also focus on finding the risk exposure and opportunities of integrated Oil and Gas companies involved in shale gas production in the US, as well as exploring which are the companies best positioned to benefit from the shale gas industry in other countries given their experience in the US context.

Project Aims:

- To provide a literature review of all the academic literature on risks and opportunities of hydraulic fracturing within the shale gas context. The literature review process will track the themes of reviewed publications in order to identify under-researched areas and propose further questions for academic research.
- To assess the risks and opportunities for integrated Oil and Gas companies involved in shale gas extraction and hydraulic fracturing in the US. The assessment will include carbon exposure, water stress, community impact, land and natural resource use as well as company management approaches to mitigating shale development impacts.
- To identify the leaders and laggards in industry best practices by relative benchmarking of Oil and Gas companies. The relative benchmarking exercise will be conducted in alignment with the MSCI ESG Research Intangible Value Assessment Methodology and Company Scores.
- To provide a top level comparison between US and other countries which are considering whether to pursue the dash for gas as a road for energy security and independence.
- To identify the companies best positioned to benefit from shale gas developments in other countries.

Resources Required:

- Microsoft Office Suite
- Matlab- Tool for Optimizing Portfolios of Companies
- MSCI ESG Research Internal Databases and Research Tools
- End Note X5 – Software for managing the references and bibliographies for the literature review.

The supervisor and student are satisfied that this project is suitable for performance and assessment in accordance with the guidelines of the course documentation.

Signed:

Theodor Cojoianu…………………………….

Dr. Peter Ewen……………………………….

Declaration of Originality

I declare that this thesis is my own work except where stated.

…………………………………………………………………..

Theodor Cojoianu, The University of Edinburgh

Abstract

The present Masters (MEng) thesis aims to analyse both qualitatively and quantitatively, the risks and opportunities arising from shale gas development in the US. The thesis draws upon multiple studies in order to identify the most prominent shale development impacts and most pressing risks. Through the literature review and Scopus database analysis, the thesis illustrates both the exponential rise in shale gas related research in the past few years and the fact that academic research has yet to catch up with the numerous challenges this industry poses.

Next, risks are quantified at the company level, regional level and US wide level. A case study on shale gas development in Pennsylvania (PA) is illustrated through production, wastewater and shale operator violations statistics. The study further shows that the number of unconventional well permits has surpassed those awarded for conventional oil and gas development and in addition, shale gas production volumes are 7 times higher than conventional gas production volumes. On the other hand, the cumulative unconventional wastewater volumes in PA have been 6 times larger than wastewater coming from conventional oil and gas activities. On average, the wastewater per gas produced ratio in unconventional wells is lower than conventional ones.

Shale gas production and water risk statistics are extrapolated at the US wide level based on industry datasets and the case study built on Pennsylvania. Shale gas operator risks are quantified using production, wastewater and violations metrics, together with company ESG scores. Last but not least, the thesis presents an outlook of shale gas development around the world together with different global shale gas estimation approaches.

1 MEng Thesis Project Background

1.1 Introduction

This MEng Placement project is being undertaken within the London office of MSCI ESG Research, an integrated business unit of MSCI (formerly known as Morgan Stanley Capital International), during the employment period 17th June 2013 – 20th December 2013. The present submission represents the MEng thesis deliverable in accordance with the University of Edinburgh guidelines[2].

I am currently working as an Energy and Business Performance Analyst within MSCI ESG Research, focusing on researching the risk exposure of shale gas operators in the United States both qualitatively and quantitatively. Part of my 6 month placement I have participated in shale gas and energy finance conferences, I have participated in analyst calls with an MSCI client and presented the initial findings of the present research and participated in several other MSCI projects which are presented in more detail in the Statement of Achievement.

1.2 Indication of Research Impacts

Initial findings of the thesis were discussed at the Shale Gas Impacts Conference in October 2013, organised by SGH Martineau, a law firm specialised in UK energy and electricity markets among several other areas. Input regarding the thesis was gathered from energy and environmental experts from SGH Martineau and JP Morgan Asset Management.

As a result of the conference, contacts have been established with the Environmental and Social Risk Division of JP Morgan, with whom an initial exchange of findings has been shared during a conference call. The lending arm of JP Morgan, who is a major investor in US shale gas, is directly interested in shale gas operator company risk, for both listed and unlisted companies.

I participated directly in MSCI ESG Research's RFP for the Hydraulic Fracturing Research Disclosure, which aimed to assess the disclosure practices of c. 50 global shale operators. The research was awarded to a different company, who presented the findings in late November. The outputs of the research are accounted for in the thesis, having participated in the presentation webinar[3, 4].

The thesis tackles among other topics, the quantification of risk for shale gas operators resulting from shale development operations. The topic was approached conceptually by just several studies[3, 5, 6], and out of the publically available studies, MSCI ESG Research makes an attempt to quantify company risk[5]. In this respect, the thesis is one of the first studies to explore company risk management approaches and performance related to shale gas development.

The present research is of direct interest to shale gas operators,oil and gas government and state departments in the US and worldwide, energy consultants, energy and carbon finance professionals, policy makers, economists, lending arms of banks and investors, communities leasing land for shale gas production, academics and last but not least, it is of direct interest to decision makers considering shale gas development risks and opportunities.

1.3 QuantumGIS Analysis Tool

Most datasets leveraged for the thesis contained information regarding the geo-location of conventional and unconventional wells (in Pennsylvania and US wide) and wastewater and disposal facilities (Pennsylvania only) used in by the shale gas industry. For the thesis purposes, the Quantum GIS software (version 1.8 Lisboa) was leveraged to improve the robustness of the datasets, perform data quality checks, analyse special datasets and provide high resolution data visualisations.

QuantumGIS or QGIS is an open source Geographic Information System (GIS) which is used to create, visualise and analyse geospacial information. The required training and tutorials in order to use the software at its full capabilities were undertaken during the placement at MSCI ESG Research[7].

1.4 MEng Thesis Outlook

Chapter 2 sets out by presenting the historical number of publications and uptake in research related to shale gas development and hydraulic fracturing risks. Next, the findings resulting from comprehensive literature review are presented. The findings enhance the insights presented in the Phase I submission, and focus on economic impacts of shale gas, water usage, wastewater and water contamination risks, air and carbon emissions and finally litigation and reputational risks of shale gas operators.

Chapter 3 represents a compelling case study on shale gas development in Pennsylvania from a production, wastewater management and company violations perspective. Shale gas production, waste and violations datasets, records and reports from the Pennsylvania Department of Environmental Protection (PA DEP) are analysed extensively to provide both a top level overview of shale gas in Pennsylvania and a disaggregate shale gas operator risk and opportunity perspective. Several metrics for analysing company shale risk exposure are established based on the datasets and an initial company benchmarking discussion takes place.

In **Chapter 4**, the focus shifts entirely on quantifying shale gas operator risk based on the performance metrics described in Chapter 3 and company environmental, social and governance (ESG) scores provided by MSCI ESG Research. A risk methodology is proposed, based on the Intangible Value Assessment methodology used by the energy team within MSCI ESG Research. Finally, the companies which have benefited mostly from shale gas development while having minimal environmental impacts are indentified together with industry laggards.

Chapter 5 is an extension of Chapter 3 at an US wide level. Datasets from the FracFocus National Chemical Registry, together with Pennsylvania datasets are merged in order to provide a US country case study on shale gas development. MSCI ESG Research company scores are further leveraged to provide an assessment of the environmental and social risk performance of US shale gas operators, and to identify the best and worst performing operators across the country.

Finally, **Chapter 6** provides a literature review of the different studies estimating shale reserves at a global level. Based on the literature review, the most robust global estimations are chosen to support the discussion regarding the state of shale gas development across the globe.

2 Literature Review and Shale Gas Research Trends

2.1 Introduction

The aim of this chapter is to both provide a comprehensive literature review related to shale gas development risks and to illustrate general trends in shale development and hydraulic fracturing related research. The Scopus Database [8]has been leveraged in order to download approximately 12,000 + titles abstracts and citation statistics of publications that have as central or partial themes: hydraulic fracturing and shale gas.

The database has been the enabler for effectively determining how the research output on shale gas evolved across the years and for further enhancement of the academic literature review on shale gas development risks which has been presented in the Phase I research piece[9].

2.2 Shale Gas and Hydraulic Fracturing Research Trends

Scopus is the world largest database of citations and abstracts of peer-reviewed literature which provides a very comprehensive overview of the research output around the world in the fields of science, technology and social sciences among others[8].Since shale gas development has gained worldwide interest and since it requires an interdisciplinary approach to unveiling both its merits and risks[10], Scopus represents one of the best sources to leverage for both our literature review and the identification of research gaps in the field. The database contains more than 50 million records; from 20,000 peer-reviewed journals and 5000+ publishers.

In order to put together the abstracts and citation data of our topic of interest, a query has been designed to capture the majority of publications linked to shale gas development and hydraulic fracturing. The query contained all the publications written in English which contained or referred to the terms: “hydraulic fracturing”, “fracking”, “fracing”,“fraccing”or“shale gas”. The query contains the different spellings for the hydraulic fracturing procedure as they have appeared in different academic publications or the media[11].The search for studies has then been limited to the following subject areas: Energy, Engineering, Environmental Science, Business Management and Accounting, Social Sciences, Multidisciplinary and Economics, Econometrics and Finance (8,213 publications in total as outputted by Scopus).A further constraint in our query was to look for publications in the following categories: conference papers, articles, business articles, reviews and conference reviews, letters, books, reports and abstract reports and book chapters. Hence, Scopus outputs 7,374 publications and their abstracts, citation data and index keywords. The query has been made as of 18/10/2013 and hence, not all studies published in 2013 are included.

The insight drawn from analysing the collection of studies is that the number of hydraulic fracturing and shale gas related studies has risen exponentially in the past 10 years (Figure 1).The regulators, academia and state and US federal law have yet to catch up with the implications of the scale at which shale gas is developed[12].

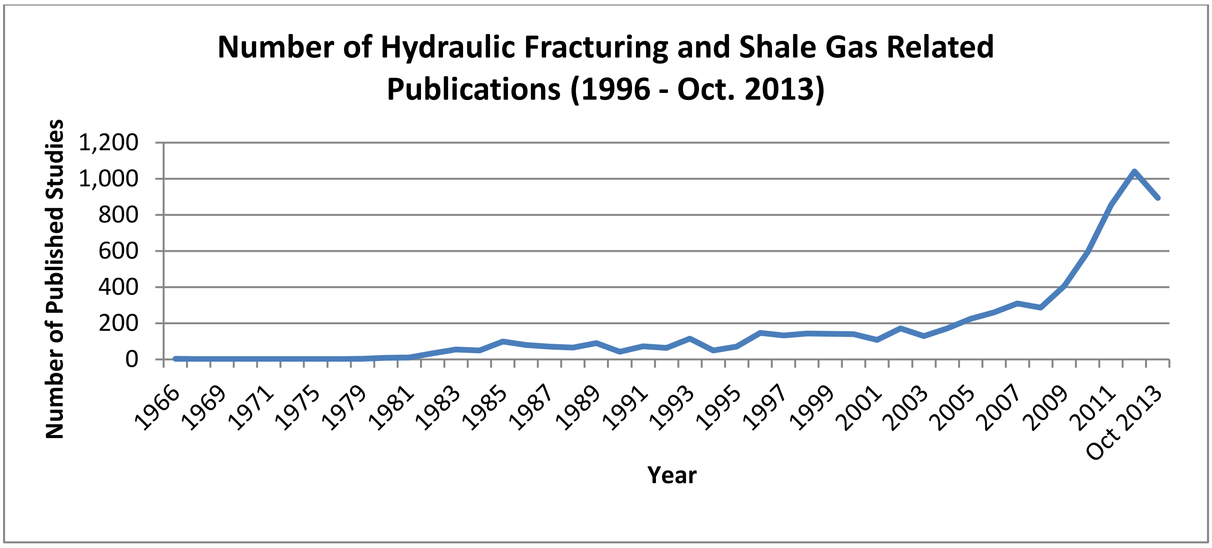

Figure 1: Scopus Analysis on Total Number of Hydraulic Fracturing and Shale Gas related publications (1996 - Oct 2013). Dataset: Scopus 2013

In order to put the timeline above into context, a closer look at the evolution of the hydraulic fracturing technology is necessary (Figure 2, [9]).

Hydraulic Fracturing Technological Milestones [2]	
Early 1900s	Natural gas extracted from shale wells. Vertical wells fractured with foam.
1983	First gas well drilled in Barnett Shale in Texas
1980-1990s	Cross-linked gel fracturing fluids developed and used in vertical wells
1991	First horizontal well drilled in Barnett Shale
1991	Orientation of induced fractures identified
1996	Slickwater fracturing fluids introduced
1996	Microseismic post-fracturing mapping developed
1998	Slickwater refracturing of originally gel-fractured wells
2002	Multi-stage slickwater fracturing of horizontal wells
2003	First hydraulic fracturing of Marcellus Shale[3]
2005	Increased emphasis on improving the recovery factor
2007	Use of multi-well pads and cluster drilling

Figure 2: Hydraulic Fracturing Technological Milestones (1900 - 2007). Source: Department of Environmental Conservation (Generic Environmental Impact Supplement), New York State.

It can be hence observed that hydraulic fracturing has been used in its incipient form since the 1900s in conventional vertical oil wells on very small distances. It wasn't until 1991 that the first horizontal well was drilled, or until 1996 that **slickwater fracturing** was introduced. According to Professor

Anthony Ingraffea from Cornell University, shale oil and gas development poses significantly higher risks than conventional oil and gas development due to the fact that it requires several technologies recently combined (after 2007) to make unconventional gas economically recoverable[11].

These technologies are: directional drilling, the usage of high fracturing fluid volumes and the use of multi-well pads and cluster drilling. It wasn't then until after 2007 when shale gas development has emerged in the form that we know it today and for which the full range of risks associated with it are yet to be understood[13]. The uptake in research on this topic is highlighted in Figure 1, where the period 2007-2008 is a trigger for an exponential increase in research undertaken in the area.

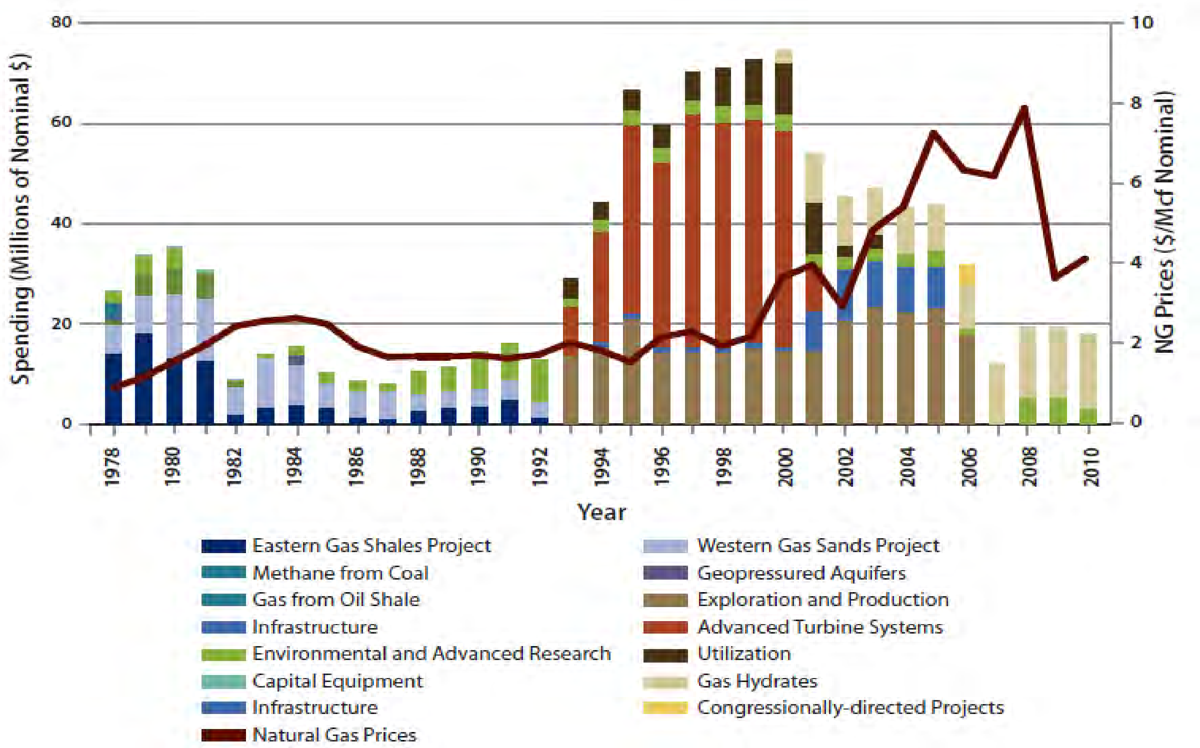

Figure 3: US Department of Energy Natural Gas Funding History. Source: Department of Energy Office of Fossil Energy. MIT 2011.

Figure 3 illustrates the historical US Department of Energy funding of natural gas R&D projects. It is evident that although the US energy market has been revolutionised by increasing shale gas production, state funding for natural gas decreased year on year[10], with total expenditure over the period 1978 – 2010 totalling approx. USD 1billion. The low funding levels from the DOE was however compensated by public-private partnerships which supported natural gas R&D[10]. One such example is the establishment of the Royalty Trust Fund (RTF) through the Energy Policy Act of 2005 [12]. The RTF supports a USD 500 million research program on ultra-deepwater and unconventional gas for a 10 year period[10]. However, given the different funding programs across the public and private sectors at the federal level and across different states, the state of natural gas funding in the

US is challenging to assess given that the highest US energy policy reinforcement institution, the US DOE, has brought natural gas funding to historical lows in the last decade.

2.3 Shale Gas and Hydraulic Fracturing Literature Review

Based on the index keywords and abstracts from the compiled Scopus database, publications referring to shale gas development impacts and hydraulic fracturing risks are shortlisted to form the core of the comprehensive literature review presented below. In addition, a compilation of c. 40 studies made by the FracTracker Alliance[14] is included in the consultation process, together with multiple industry reports, MSCI ESG Research industry and company reports. The literature review is concentrated in 4 major themes: shale development economic impacts, water usage and wastewater management and chemical risks, air emissions risks, litigation and reputational risks. A further literature review is presented for the global estimations of shale gas resources in Chapter 6. A comprehensive review of the stages of shale gas development (from drilling to well completion) was presented in Phase I[9], and hence it will not be dwelled directly upon it in this chapter.

2.3.1 Shale Development Economic Impacts

According to the EIA[15],the US has produced a total cumulative 19.8 trillion cubic feet of gas out of shale formations during the period 2007 – 2011. Texas is a leading state in total shale gas production with 9.39 trillion cubic feet of gas in the same period, followed by Louisiana (3.6 tcf), Arkansas (2.6 tcf) and Pennsylvania (1.5 tcf). The position of the states, their associated shale plays and basins as well as cumulative shale gas production can be observed in Figure 4.The map has been prepared using Quantum GIS and geographical and production datasets from the Energy Information Administration (EIA).

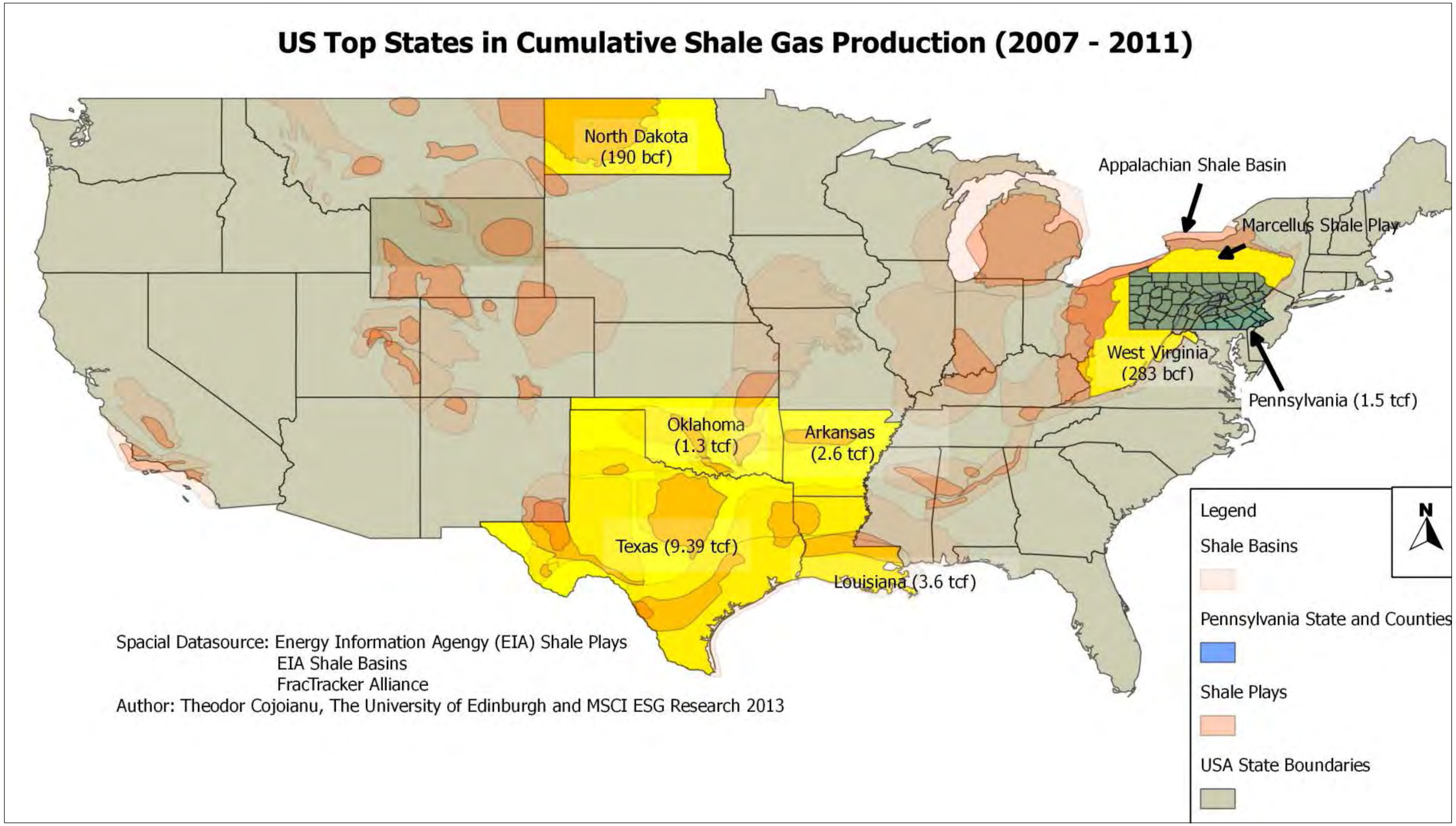

Figure 4: US Top 7 States in Shale Gas Cumulative Production. Source: Theodor Cojoianu, EIA, Quantum GIS.

The scale which shale gas development has reached in the US has impacted heavily the US outlook on energy independence, energy prices, economic growth and long term job creation [16-22]. Energy independence has been high on the US government agenda ever since the Middle East oil embargo on the US [22, 23]. According to EIA projections [24], the US has very high chances of becoming a net exporter of natural gas on the basis of shale gas development growth (113% growth from 2011 to 2040).

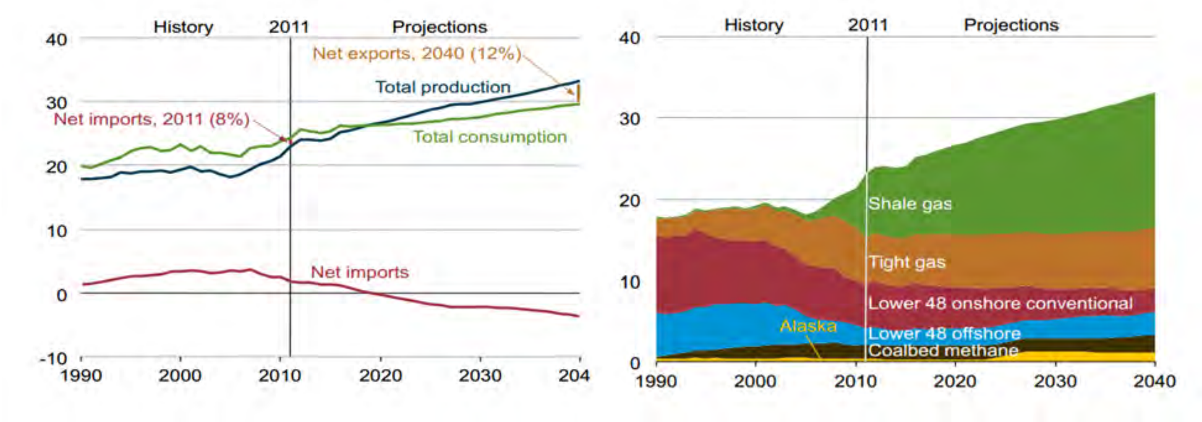

Figure 5: Total US Natural Gas Production and Consumption in trillion cubic feet (tcf), 1990 - 2040 (left) and Breakdown of Produced Natural Gas (tcf) by type 1990 - 2040 (right). Source: EIA Annual Energy Outlook

Shale gas development has so far made a big difference to US natural gas prices and with respect to the correlation between oil and gas pricing[25, 26], it had a decoupling effect between the US natural gas price and the price of oil[22]. At the moment, given limited LNG (Liquefied Natural Gas) terminals in the US, the impact on global energy prices has been minimal. However, given new investment in US LNG terminals, by 2016 the US is expected to become an LNG net exporter[27].

According to Wang et al.[22], the birth of this new industry had deep impacts on economic growth and job creation[28, 29]. Lower gas prices translate into lower costs for industries which are reliant on gas for production of different materials or chemicals. Shale gas lowered the price of Natural Gas Liquids (NGL) which are the raw materials for ethylene which is a core product of the chemical industry. In this respect, the US chemical industry grew significantly as a response to the lowering costs of their business models.

In contrast with the many benefits that shale gas brought to the US, there are numerous risks and negative impacts which have to be addressed sooner rather than later. These risks are explored in the following sections.

2.3.2 Water Usage and Withdrawal and Wastewater Management Risks

Shale oil and gas development became recently economically feasible through the use of hydraulic fracturing and other technology improvements[11, 30]. The majority of opposition to shale gas development is mainly related to water related risks [31-38].

Water is employed in several stages of unconventional oil and gas development, however it is the drilling stage and the hydraulic fracturing stage that are the most water intensive processes[36, 39], with between 1 and 9 million gallons per well[40]. This poses a great stress on the regions which are water scarce and where several water intensive industries might compete for water resources[41].

Furthermore, wastewater management is a general issue, given the fact that between 10% and 300% of the injected water, hydraulic fracturing volume and dissolved solids return to the surface over the lifetime of the well[36]. This poses significant challenges for regions where wastewater infrastructure could not adapt to the new volumes required to be treated from unconventional gas development, but even more, to the high concentration of chemicals, TDS (total dissolved solids) and NORMs (Naturally Occurring Radioactive Materials) contained in unconventional wastewater[35].

Mismanagement of wastewater can result in significant impact for the environment, particularly marine environments. Groundwater contamination from fracturing fluid migration has been given a very low probability of occurring [34, 40] although much of the debate has been centred on fracturing fluid migration. However, water contamination is most likely to occur from spills of unconventional wastewater into marine environments or from inadequate waste water treatment [35, 42]. Another water contaminant is methane. This results from improper well casing and methane migration, which has been confirmed many times in the inspection reports of shale wells, as reported by the Pennsylvania Department of Environmental Protection (PA DEP)[43].

2.3.3 Carbon and Air Emissions Risks

Shale gas is viewed as the transition fuel towards a low carbon economy given the lower emissions compared to coal at the burner tip[44]. However, a study from Cornell University [45](Figure 6) suggests that lifecycle emissions estimations of shale gas are likely to exceed emissions of coal. This results from the study’s claim that leaked, lost or vented emissions are 8% and that methane is more potent (50 to 70 times) than carbon on a 20 year timeframe[46, 47]. The findings of the Cornell study was contested by other 4 studies [48-51] which consider a larger timeframe for methane climate impact and assume significantly smaller leaked emissions percentages.

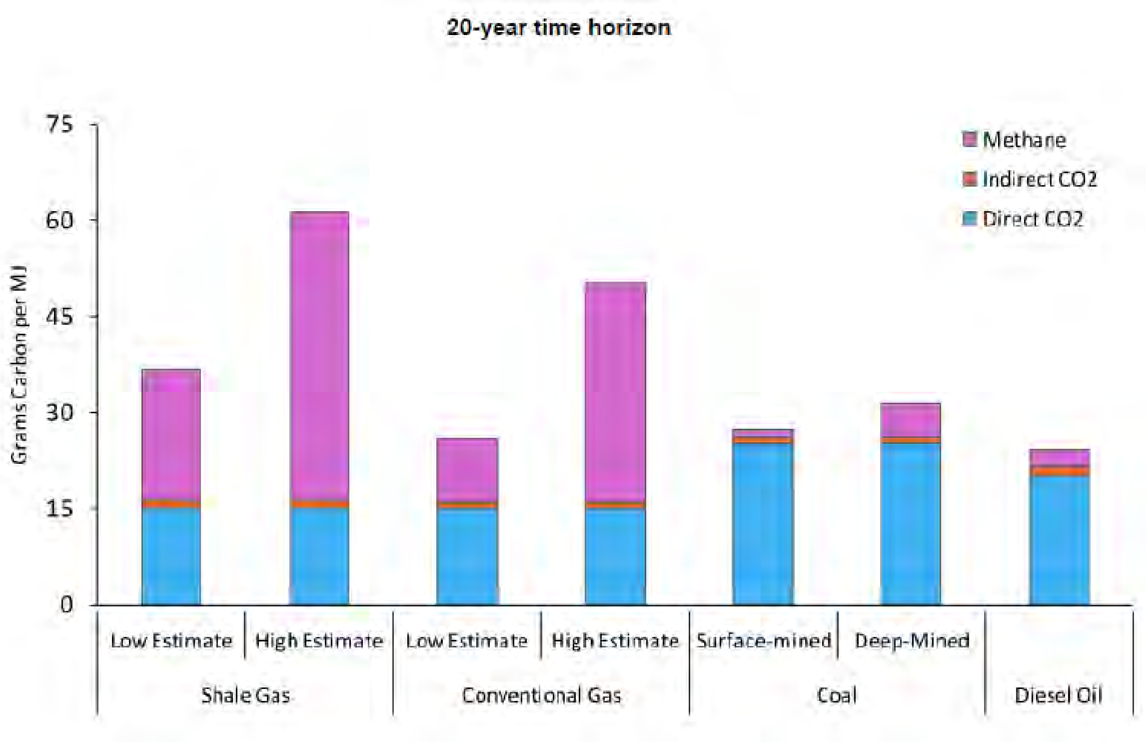

Figure 6: Source: Howarth, Robert, Renee Santoro, and Anthony Ingraffea. 'Methane and the Greenhouse-gas Footprint of Natural Gas from Shale Formations'. Climatic Change 106, no. 4 (2011): 679–690.

A recent study by PWC[52] shows that at the present carbon emission rates, this century's global carbon budget left to avoid the dangerous effects of climate change will be spent by 2034[53]. In this context, Santoro et al. is right to consider the shortest (20 year) period of methane effects given the urgency needed to tackle world climate change.

In the face of more stringent carbon and emissions regulation across the world, oil and gas companies are likely to not be able to develop all the fossil fuel reserves they currently hold on their books, if the global carbon budget to avoid the worst impact of climate change is to be implemented at a global scale[54].

2.3.4 Company Litigation and Reputational Risks

The number of lawsuits related to shale gas development is increasing year on year[55] and are mainly related to royalty disputes, breach of contract, land and lease rights and environmental management[56](Figure 8).

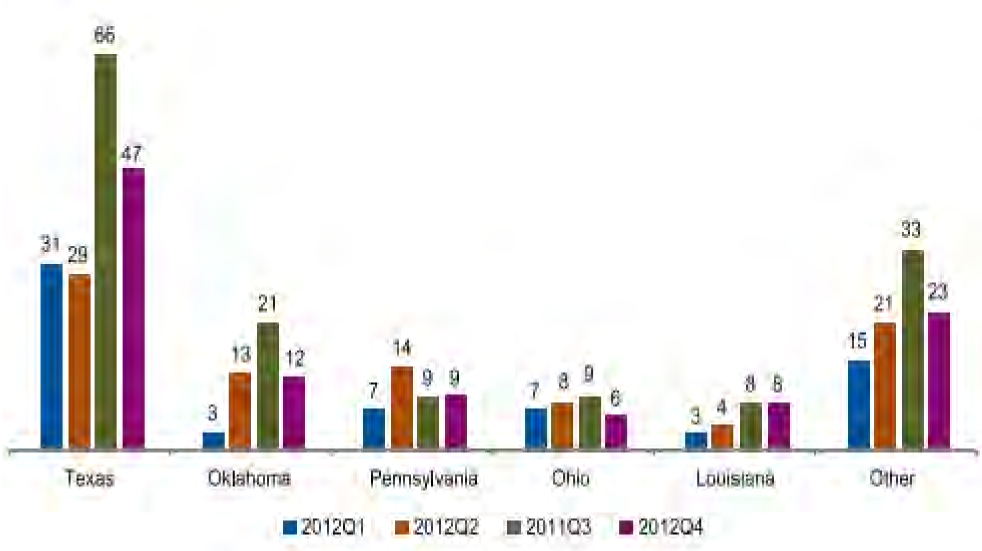

Figure 7: Shale Development Litigation Cases filled in different US States. Source: Navigant Consulting 2013

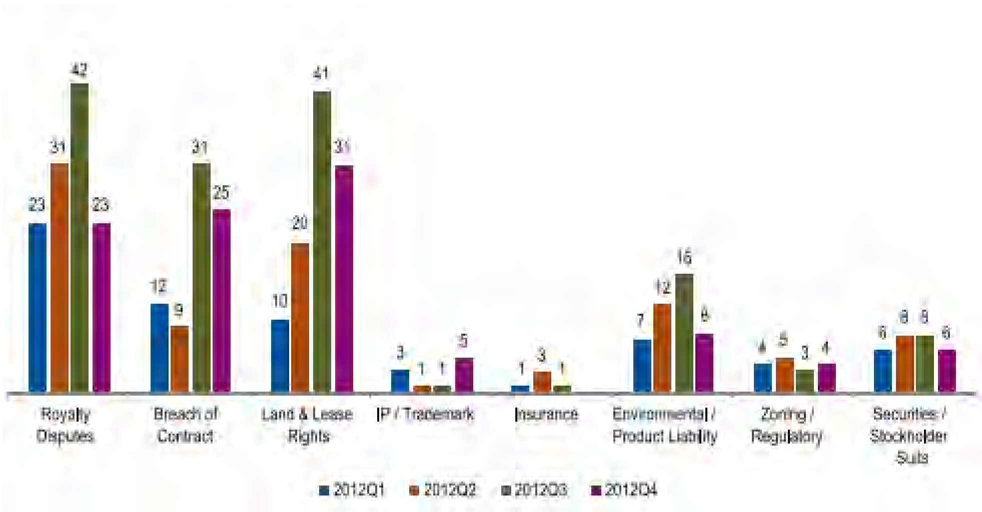

Figure 8: Shale Development Litigation Cases filled by Theme. Source: Navigant Consulting 2013

Not surprisingly, the states with the highest number of litigation cases are the states with the top shale gas production in the US (Figure 4). However, given the lack of federal government and state wide policy, regulation and law reinforcement capabilities for the scale of shale development, many company violations remain unnoticed[57].

2.4 Conclusions

This chapter summarised the research trends and funding challenges in shale development research and provided a comprehensive literature review on the economic impact of shale gas as well as the risks which are likely to materialise for companies, communities and the industry in the near future.

Shale gas had many benefits for the US economy and US's goal towards energy independence and long term job creation. However, this is not achieved without major environmental and societal impacts.

Further to the literature review, shale gas production, water usage and wastewater management together with an assessment of shale gas operator violations are reviewed in the context of Pennsylvania. Based on this case study, an extrapolation will be made to the state of hydraulic fracturing and shale gas at US wide level. The dataset details, methodologies and findings are presented in the next chapters.

Only few studies have so far explored what the consequences for shale gas operators for improper environmental, social and company risk management practices[3, 5, 6].Only the study of Samuel Block, Dana Sasarean and Linda Eling-Lee from MSCI ESG Research have provide an initial framework exploring shale gas operator embedded risk [5]. The thesis aims to build upon MSCI's initial study and provide both a regional and US wide company risk quantification for shale gas operators.

3 Pennsylvania Unconventional Gas Development Case Study

3.1 Introduction and Chapter Outlook

The present chapter focuses on providing a comprehensive case study of shale gas development in Pennsylvania from a production, wastewater management and company violations perspective. The most robust datasets have been used for this exercise and further enhanced through the use of Quantum GIS.

First the Pennsylvania state wide shale gas development statistics are presented. Afterwards, a benchmarking exercise will be carried out between the operating companies in Pennsylvania. This will be done from both a gas production opportunity perspective as well as an environmental risk perspective for the period 2004 – June 2013. In this way, the added value of this chapter consists in updating the academic paper of Lutz et. al[35],who analysed shale gas wastewater management in Pennsylvania till 2011, by considering extra data from 2012 and the first half of 2013. Secondly production data and violations datasets are further leveraged which will indicate the extent of the rewards as well as the litigation and regulation risks arising from shale gas development.

From this analysis several lessons will emerge from Pennsylvania shale gas development, which will be put into context when looking at the US wide case study and when providing an outlook of shale gas in other countries.

3.2 Pennsylvania Shale Development Datasets

The datasets that have been leveraged for building a case study on Pennsylvania unconventional oil and gas production, wastewater and violations were downloaded from the Pennsylvania DEP website[58]which is managed by the Bureau of Oil and Gas Management.

Lutz et al. and Clark[34] acknowledge that these are the most robust datasets that are available to the public and academic community for analysis. These are currently used in EPA's enquiry into hydraulic fracturing impacts[40] which aims to inform state and federal policy and regulation. The data comprised in the datasets is self reported according to the Pennsylvania DEP law and guidance and hence, the datasets are still considered to be incomplete to a certain degree, but the best available across the US[35]. The Oil and Gas Act in Pennsylvania does require all companies to report timely and accurately on their gas production and wastewater practices, however the DEP disclaims any liability for errors or omissions in the datasets.

3.3 Pennsylvania Conventional and Unconventional Production

3.3.1 Production Dataset Introduction

According to Pennsylvania's Oil and Gas Act, unconventional well operators are required to produce and submit production reports biannually. The 15th of August is the date when reports are submitted for the first half of the current year (1st of January – 30th of June) and the 15th of February is the date of submission of the statistics of the second half of the previous year (1st of July – 31st of December). All the other operators have to submit production reports once per year on the 15th of February. Hence the available production data for Pennsylvania ranges from 1st of January 2000 to 30th of June 2013, with the year 2013 containing data only on unconventional oil and gas wells.

First, the production data across all the available years is aggregated (2000 up to the first half of 2013).During the data aggregation process, several corrections have been carried out. The data management system for unconventional oil and gas wells reporting has changed for Pennsylvania in 2010. This has resulted in having the unconventional wells data for the first half of 2010 containing some duplicate values from the second half of 2009. This has been confirmed by a private communication between R. Deitz (Pennsylvania DEP) and Brian Lutz (December 19, 2011)[35].Lutz confirms that according to the same private communication, no duplicates are found in the wastewater dataset which will be explored later.

The following correction is applied to the dataset containing unconventional wells with aggregated data for both the second half of 2009 and first half of 2010: if the production days reported are less than 183, the production data is allocated to the 2010 dataset; if the production days number is higher than 183, the gas production amount is divided by the production days to obtain a daily figure, is then multiplied by 183. This is then allocated to the 2010 dataset. The remaining production amount remains unallocated since it is considered that the amount is already accounted for in the 2009 dataset. This approach is similar to that of Lutz; however it differs in the fact that the remaining production amount is not aggregated to the 2009 dataset which is considered robust.

3.3.2 Pennsylvania Oil and Gas Production Statistics

For this part of the dataset analysis, the Pennsylvania DEP Production data (1st January 2000 – 30th June 2013) and the Pennsylvania Oil and Gas Well Permits database are explored (1st January 2000 – 6th November 2013).

As illustrated in Figure 9, the number of new unconventional well permits in Pennsylvania has risen exponentially since 2004 to surpass the number of new conventional well permits in 2010. In 2013 alone (1 January – 6 November), there were 2368 unconventional well permits issued as opposed to 1371 conventional well permits. According to the DEP Permit for Review Process and Permit

Decision Guarantee Policy it takes between 30 to 40 days for a company to have its drilling permit approved[59].

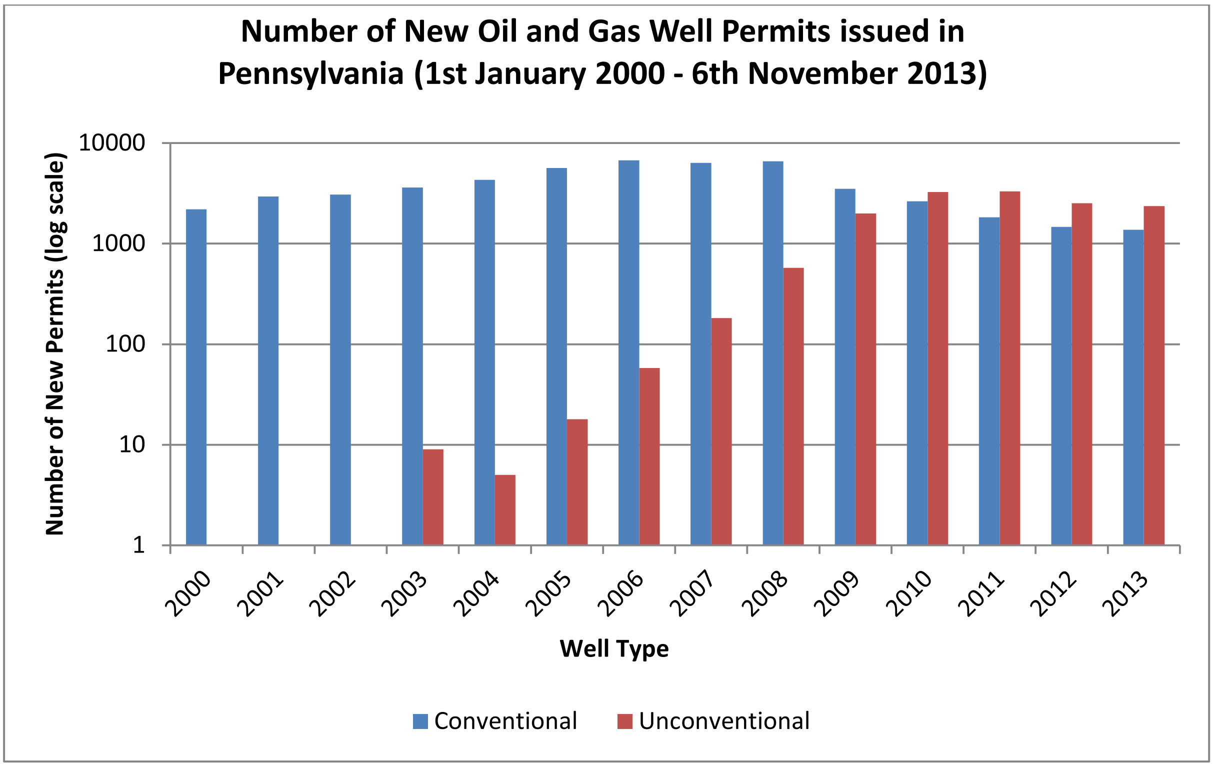

Figure 9: Number of New Permits Issued in PA (2000 - Nov 2013). Dataset: PA Department of Environmental Protection.

Furthermore, Figure 10 illustrates the resource type extracted of new wells in Pennsylvania for both conventional and unconventional well types. Unconventional well permits have been awarded for gas wells in proportion of 99% from 2008 onwards and in proportion of 95% in 2007. Figure 10 confirms the fact that the shale gas revolution in Pennsylvania has shifted the majority of new gas development from conventional wells to unconventional wells in just 4 years (2007 – 2010).

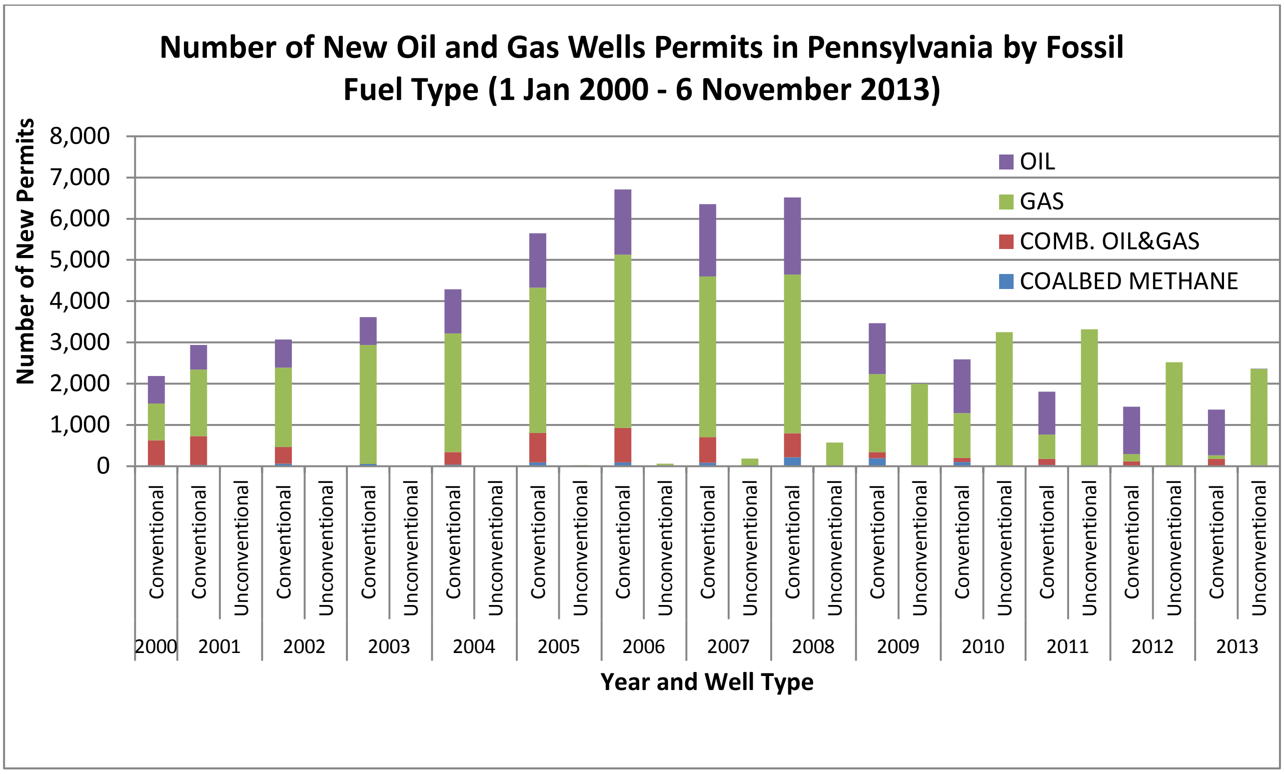

Figure 10: Number of New Well Permits in Pennsylvania by Fuel Type (2000 - Nov 2013). Dataset: PA Department of Environmental Protection

Although there are still more active conventional gas wells in Pennsylvania than unconventional wells, the total gas production volume coming out of unconventional gas wells was 9 times higher than the one from conventional wells, reaching 1.93 trillion cubic feet in 2012 and 1.4 trillion cubic feet in the first half of 2013(Figure 11).

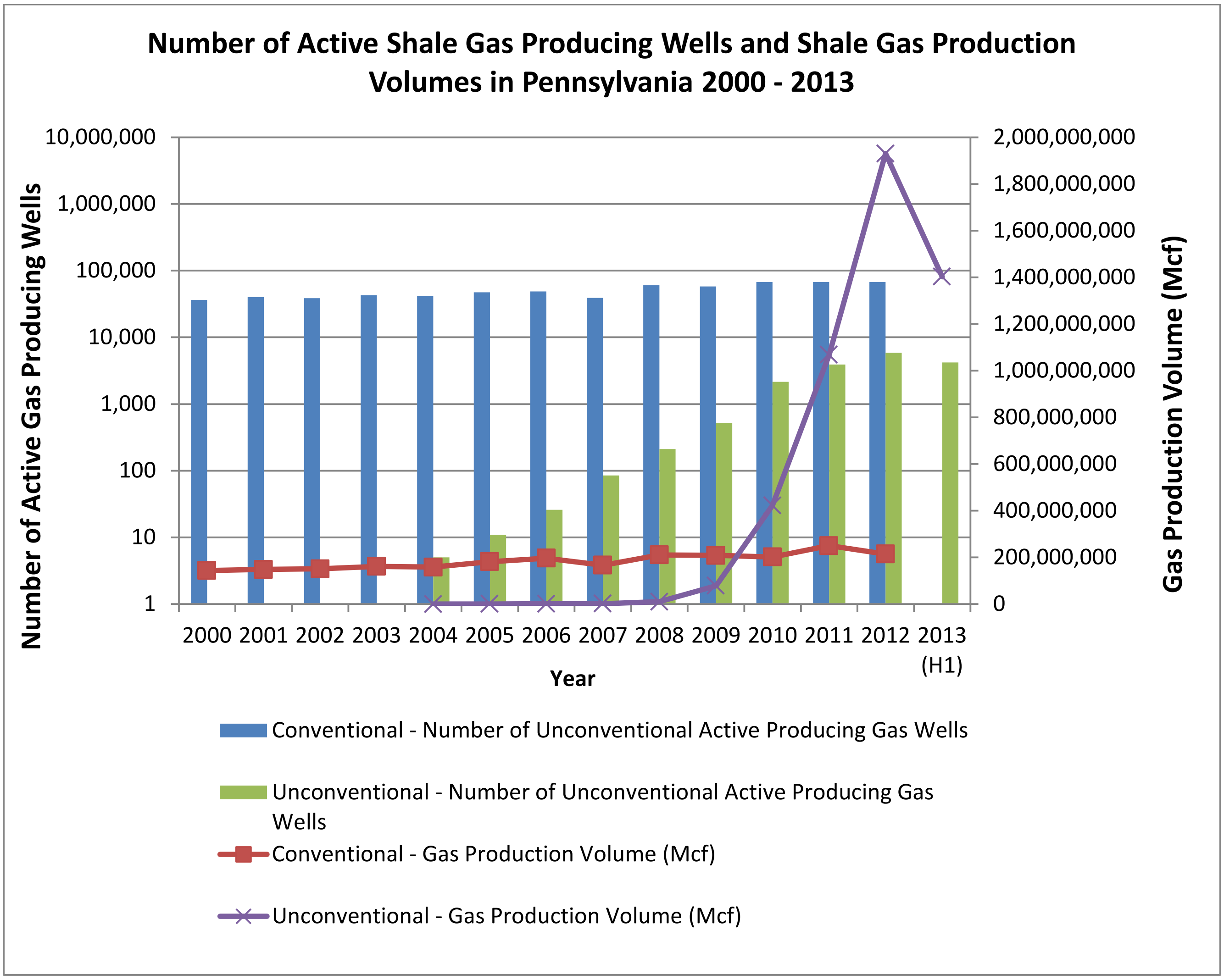

Figure 11: Number of Active Shale Gas Producing Wells and Shale Gas Production Volumes in Pennsylvania (2000 -2013). Dataset: PA DEP

Cumulatively, there were 4.9 trillion cubic feet of gas reported as being produced from unconventional gas wells in Pennsylvania in the period 2004 – H1 2013. In 2011, the EIA statistics put Pennsylvania in 4th place after Arkansas in cumulative shale gas production (Figure 4). The EIA have not revised their statistics since and hence, the present study represents an update to Pennsylvania's shale gas production evolution since 2011.

3.3.3 Pennsylvania Shale Gas Operators Statistics:

There are 94 companies that have been involved historically in shale gas production and exploration in Pennsylvania in 2004 – H1 2013. Out of these 94 companies, 54 were producing gas in the first half of 2013: from as little as 93 Mcf across 3 active wells (Penn Virginia Oil and Gas Corporation) to 304bcf across 534 active wells (Chesapeake Appalachia LLC). Figure 12 illustrates the top 11 companies which have produced the highest amount of shale gas per owned well in Pennsylvania in the first half of 2013. Appendices A.1 and A.2 present the full statistics for all the companies both from a cumulative shale gas production perspective (2004 – 2013) and an average gas production per well in 2013 angle.

Alpha Shale Resources, Citrus Energy Corporation and Rice Drilling B LLC have very few active wells in the first half of 2013; however the wells have been sweet spots for gas production which puts them in the top 3 companies with average shale gas production per owned well in H1 2013. These types of companies tend to be small companies around 100% invested in shale gas development.

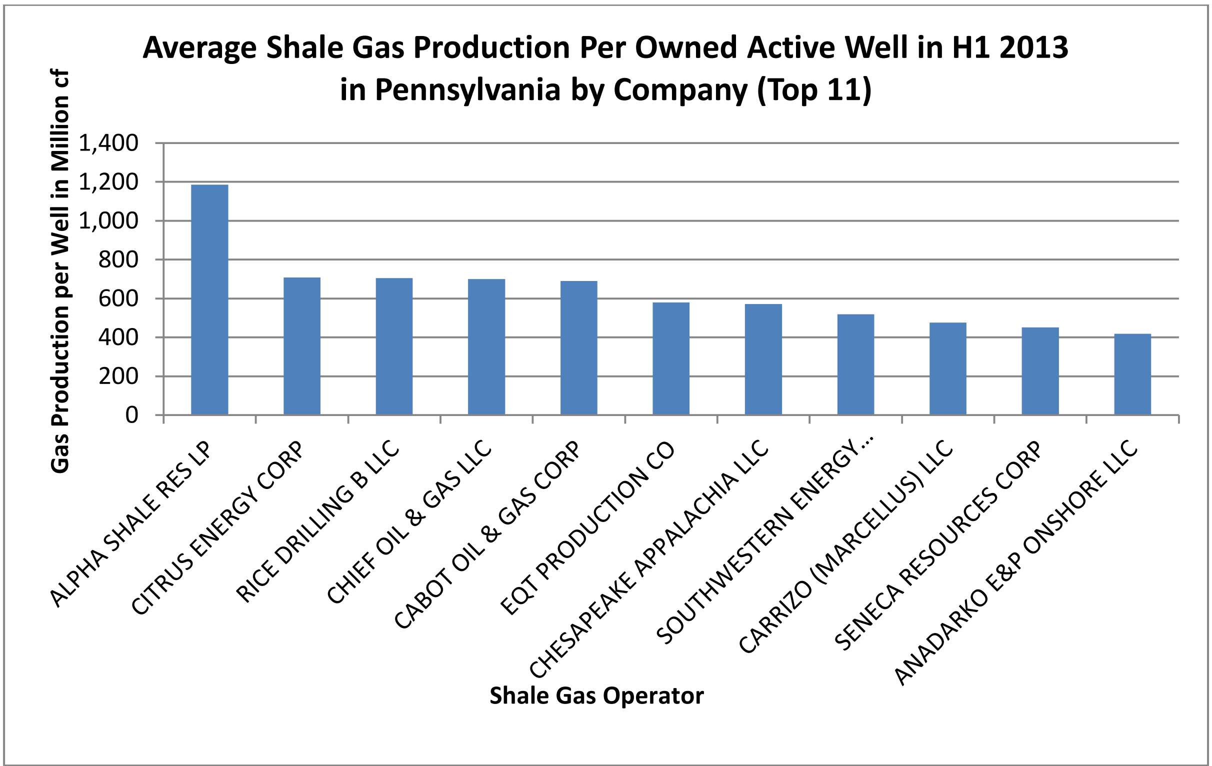

Figure 12: Average Shale Gas Production per Active Well in H1 2013 in Pennsylvania. Top 11 Companies. Dataset: PA DEP

By taking a step back and looking at the cumulative gas production by company in the period 2004 - 2013, we can identify the real winners in the shale gas revolution in Pennsylvania. Figure 13 shows how companies like Chesapeake Appalachia, part of Chesapeake Energy Corporation, Cabot Oil and Gas Corporation or Talisman Energy have collectively produced over 2.17 trillion cubic feet of shale gas in Pennsylvania only, which at September 2013's average industrial gas price of $4.39 / 1000 cubic feet would be valued at approximately $9.52 billion (assuming this is dry gas which requires no further processing)[60].

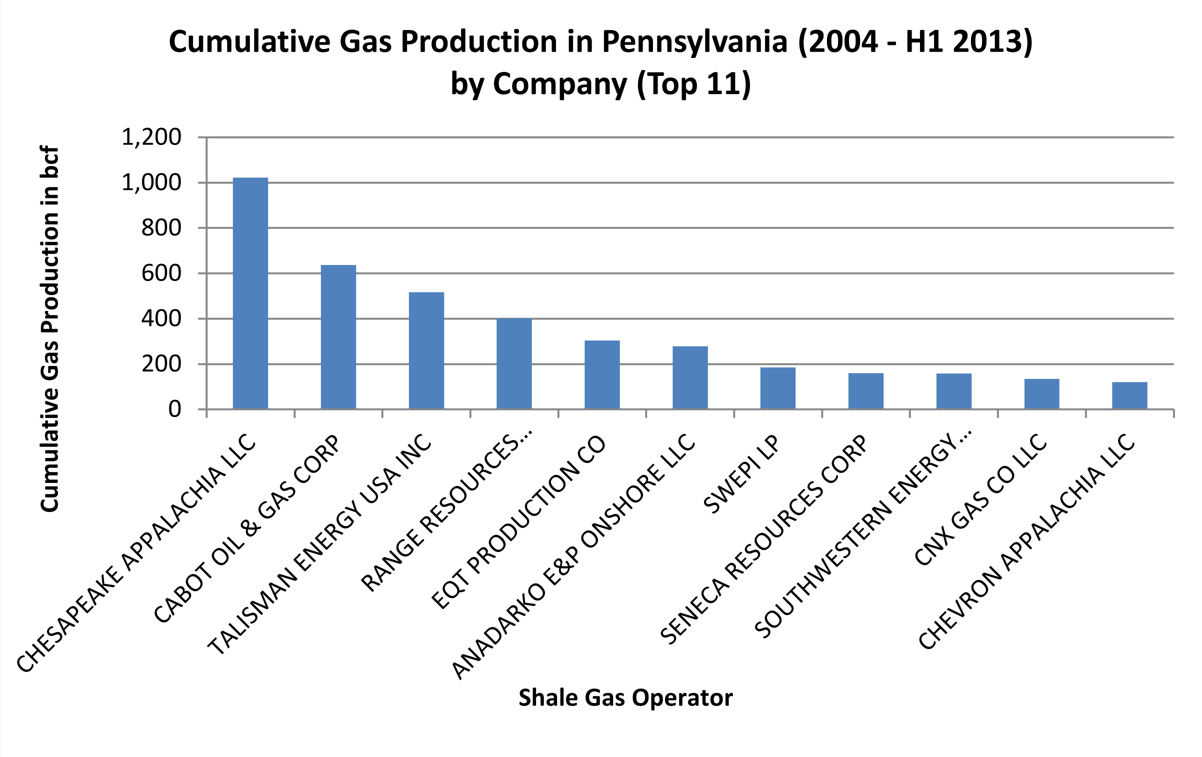

Figure 13: Cumulative Shale Gas Production in Pennsylvania by Operator (2004 - H1 2013).

Block et al.[5]states that companies who have greater shale gas production are more likely to have a high risk exposure to environmental and social risks but not necessarily valuation risks. Less diversified companies who have 90% or higher assets in shale gas and oil development like Chesapeake Energy Corporation, Encana, Range Resources or Southwestern Energy face the highest risk exposure to shale gas and hydraulic fracturing. Multinational integrated oil and gas companies like BP, Shell, ConocoPhillips or Chevron are better able to weather any potential losses or risk in shale gas development by pursuing other businesses they are invested in. Please see Appendix A.2 with the cumulative shale gas statistics for all companies.

3.3.4 Quantum GIS Mapping of Pennsylvania Production

Using the Quantum GIS software, the geographical areas which historically have been most suitable for shale gas extraction in Pennsylvania are mapped. First, the cumulative shale gas production has been aggregated for every county in Pennsylvania. Secondly, this has been mapped on 7 shale gas cumulative production volume intervals as detailed in Figure 14.

Bradford and Susquehanna counties have historically produced most shale gas in Pennsylvania across the studied period 2004 – H1 2013(Bradford – 1.25 tcf; Susquehanna – 1.04 tcf). In Bradford, there were 10 companies that had operating licenses. Out of the 10 companies, the top 3 shale gas producers are: Chesapeake Appalachia with 683 bcf, Talisman Energy with 377 bcf and Southwestern Energy Production with 124 bcf. As the map illustrates, it is the companies that leased land in the North East of Pennsylvania and South West that benefited most from shale gas extraction.

Alpha Shale Resources, one of the small participants in shale gas which was highlighted previously has all of its 10 wells in Green County in South West. Citrus Energy gets all its production from Wyoming in North East, while Rice Drilling B has operations in both Green County and Washington County. These are all examples of companies set up specifically to benefit from the shale gas revolution and tend to be small companies, with concentrated assets across 2 or maximum 3 counties in Pennsylvania.

Larger oil and gas companies tend to be more diversified, with operations across 6 or more Pennsylvania counties which decrease the risks of community opposition interrupting company operations.

Furthermore, Figure 15 illustrates the geographical density of both conventional and unconventional drilled wells in Pennsylvania in the period 2000 – H1 2013. Shale gas wells are located mostly as expected in the North East and South West of Pennsylvania while conventional wells are situated in the Central--West region and the North West of Pennsylvania. In Central-West Pennsylvania, given the high density of both conventional and unconventional wells, community opposition to new shale gas development might be stronger than in other parts of Pennsylvania. On the other hand, those companies that have initially had conventional oil and gas operations and proved to be responsible and earned the trust of the local communities, might be favoured if they pursue shale gas development.

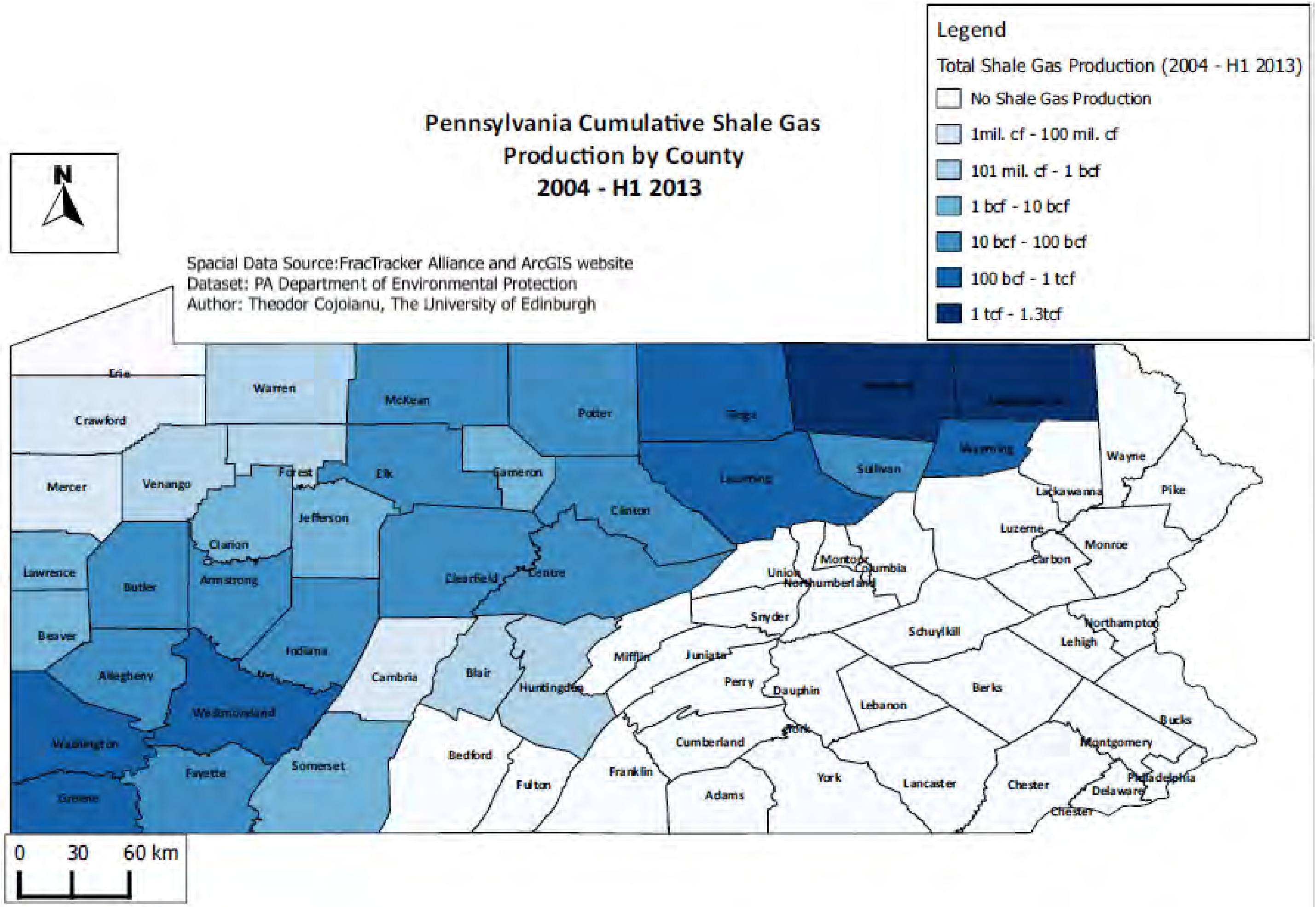

Figure 14: Pennsylvania Cumulative Shale Gas Production Map. Theodor Cojoianu: Quantum GIS Analysis.

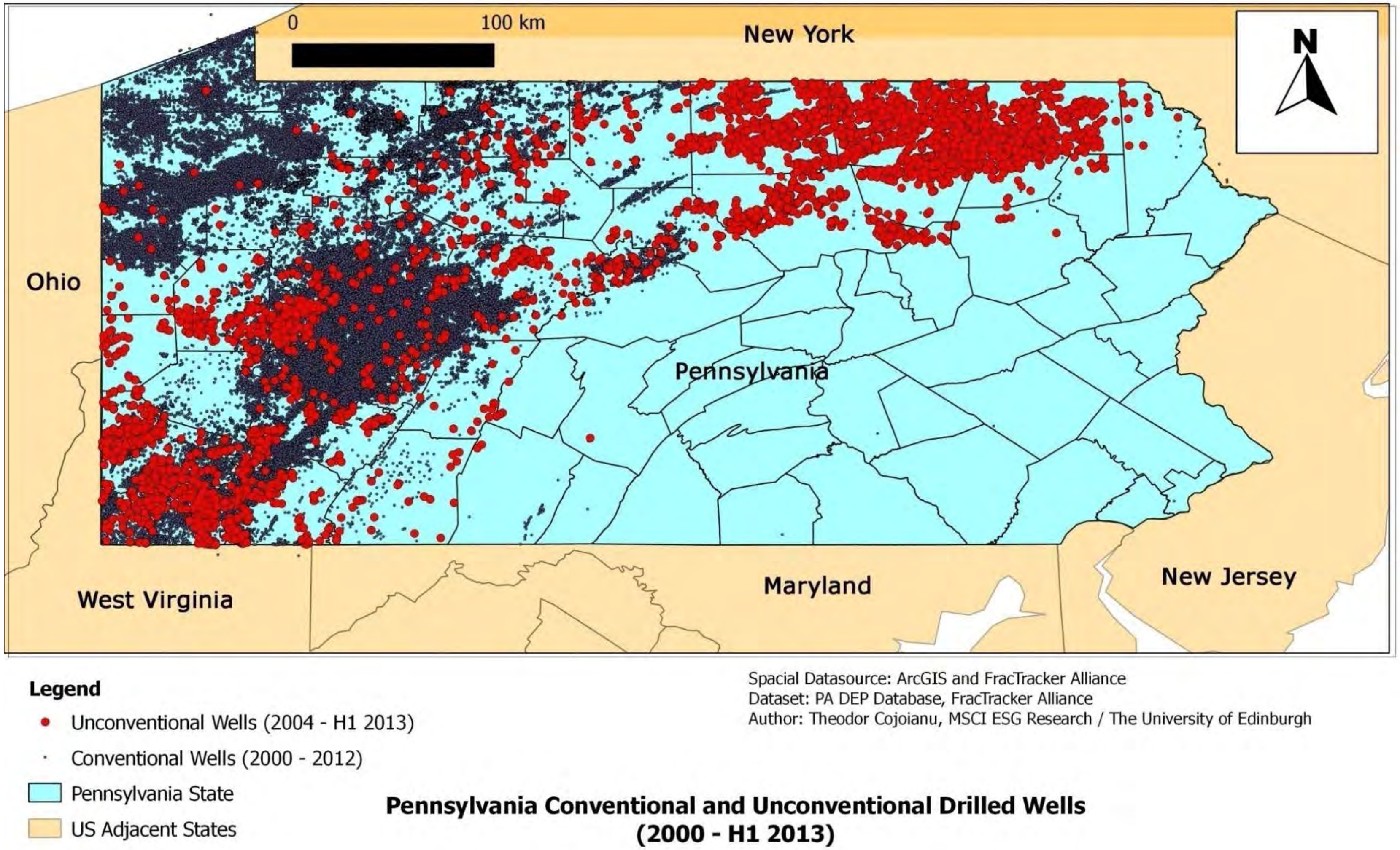

Figure 15: Pennsylvania Conventional and Unconventional Drilled Wells (2000 - H1 2013). Theodor Cojoianu, Quantum GIS Analysis.

3.4 Wastewater Management Analysis in Pennsylvania (2000 – 2013)

3.4.1 Pennsylvania Waste Dataset Introduction

The Pennsylvania wastewater management datasets have been aggregated in a similar manner to the production datasets from the PA DEP website. The wastewater management datasets do not require corrections for the new data management system which the DEP put in place in 2009/2010 since according to R. Deitz (private communication with Lutz)[35]there are no duplicates.

However, there were several identical wastewater volumes during a particular year and marked as going to different waste treatment facilities. In this respect, the yearly wastewater coming from a well was reported as a total for the year rather than the wastewater which every treatment facility would receive from a given well. Hence, the assumption used for these entries was that each industrial facility would receive an equal amount of wastewater from a given well. Lutz[35] confirms that by applying this kind of correction, an overestimation of wastewater volumes of up to 45% is avoided. Finally, given the fact that the PA DEP had an unrecoverable data loss, no waste records are available for the year 2007.

3.4.2 Pennsylvania Wastewater Volumes (2004 – H1 2013)

Wastewater in oil and gas development is produced throughout the lifetime of a well, during most important development stages: drilling, hydraulic fracturing and production[35].The composition of the waste will vary according to the different stages of the production process. The DEP reports 6 types of waste fluids and solids: brine, drilling fluid, fracking fluid, basic sediment, spent lubricant and servicing fluid.

The **drilling fluid,** also called **drilling mud**, is used during the drilling process to control the pressure in the well and lubricate the drilling end [30]. According to Pennsylvania regulation, the distance from the surface to 50 feet under the fresh groundwater source has to be drilled with air, freshwater or drilling fluid based on freshwater. Below this depth, any type of drilling fluid can be used. Drilling fluid quantity used in conventional wells grew from 129,000 barrels in 2004 to approximately 329,000 barrels in 2010 to fall approx. 100,000 barrels in 2012. For unconventional wells, from 2,080 barrels in 2004 drilling fluid usage increased to 1.83 million barrels in 2012. This trend can be explained through the number of new well permits (conventional and unconventional) as presented in previously, which shifted towards unconventional gas development in the 2007 – 2012 period.

The composition of the typical hydraulic fracturing fluid can be observed in Appendix A.3. The fracturing fluid which is recovered from the hydraulic fracturing process is called **flowback fluid**[61]or as it is reported at in the PA DEP database: **fracking fluid**. Fracking fluid is generally recovered in a 2 to 8 week interval after the hydraulic fracturing process has occurred[30], however it is up to the well operator to distinguish the separation between the fracking fluid and a fluid that is recovered over the lifetime of the well called brine[62].

Brine usually originates from the oil or gas formation for conventional wells and is produced during the lifetime of a well [62]. During unconventional oil and gas development, brine is a mix of naturally occurring liquid and fracking fluid and has high salinity levels. Basic sediments, spent lubricants and servicing fluids are excluded from our analysis since they represent a small percentage out of the total wastewater amount (less than 0.04%).

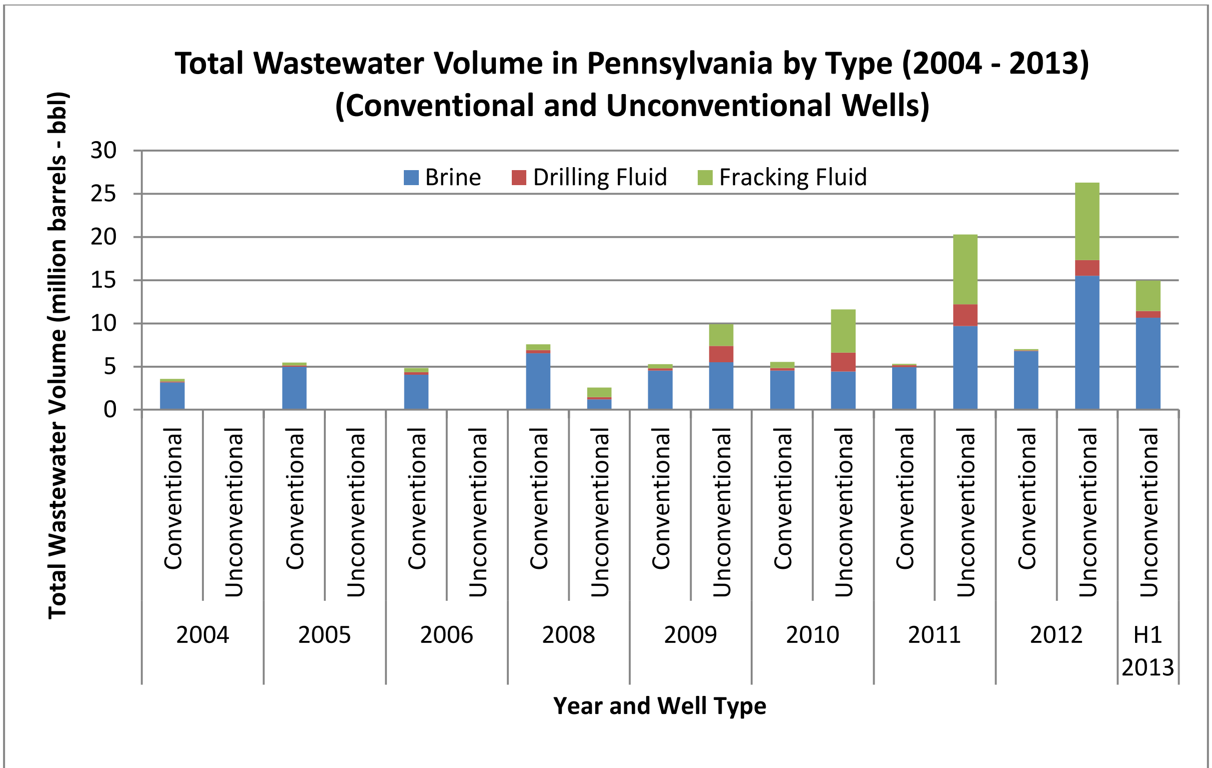

Figure 16: Total Oil and Gas Wastewater Volume in Pennsylvania (2004 - 2013). Dataset: PA DEP

Figure 16 illustrates the yearly brine, drilling fluid and fracking fluid volumes for both conventional and unconventional wells in PA in the period 2004 – H1 2013 (no 2007 data included due to PA data loss). For both conventional and unconventional oil and gas development, brine is the waste type produced in the largest quantity year on year. In 2012, conventional wells waste was 96.5 % brine, 1.43% drilling fluid and 2.07% fracturing fluid. For unconventional wells, the statistics are more skewed towards flowback (frac fluid) and drilling fluid (58.95% - brine, 6.98% - drilling fluid and 34.07% flowback fluid). According to Lutz this is due to the fact that most unconventional wells are in their first 2 years of production,hence brine will be a dominant waste when the number of new unconventional wells drilled each year will stabilise.

There has been a 10 fold increase in total wastewater (aggregate conventional and unconventional wells) in the period 2004 – 2014, which, as it will be noted in a subsequent section, has posed a huge stress on both Pennsylvania's water treatment capacity and the environment.

3.4.3 Company Waste to Gas Ratio Analysis

For this part of the analysis, a gas production to waste generated ratio has been calculated for each company which had active wells in Pennsylvania in the period 2004 – 2013 H1. The cumulative gas production for each company has been divided by the companies' cumulative waste production. A high gas to waste ratio of a company relative to peers indicates that the company has historically benefited from shale gas production while having very efficient environmental and wastewater management systems. This metric is built on the assumption that the 2 datasets: Pennsylvania historical shale gas production and associated wastewater figures are robust.

Figure 17 illustrates the companies which benefited mostly from shale gas production while having a small environmental and wastewater footprint, as well as a distribution of the gas to wastewater ratio across all operators. Please see Appendix A.5, for the associated statistics for all operators.

The company with by far the best shale gas production to wastewater in Pennsylvania is Southwestern Energy Production, who is the fifth largest natural gas producer in the US and the 9^{th} shale gas producer in the state of Pennsylvania. Given its 80 year track record in oil and gas exploration and production, Southwestern has the advantage of having the right infrastructure in place, the geological and technical knowhow and the community buy-in to support the 158 bcf of shale gas produced in Pennsylvania in the 2004 – H1 2013 period while having a relatively small environmental footprint.

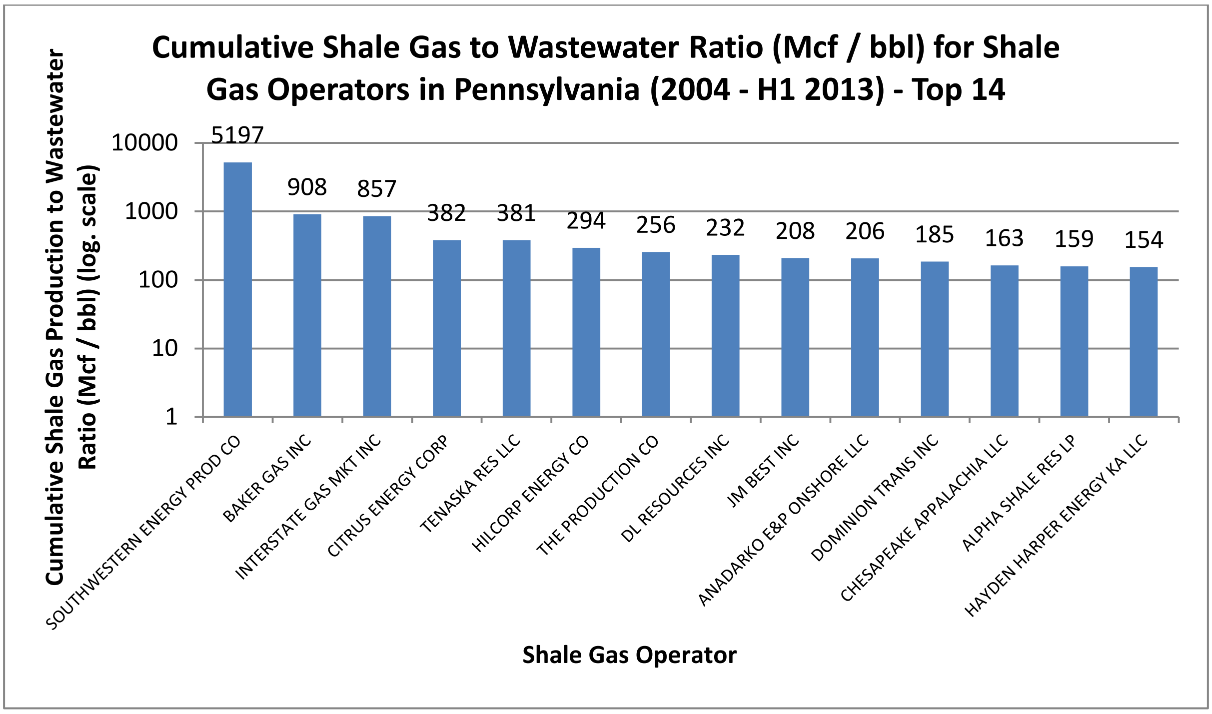

Figure 17: Cumulative Shale Gas to Wastewater Ratio (Mcf / bbl) for Shale Gas Operator in PA (2004 - H1 2013). Dataset: PA DEP

10 out of the top 14 companies with best shale gas to wastewater ratios are however small companies who tend to have a small number of highly productive shale gas wells in the North East or South West of Pennsylvania which are managed responsibly. Such companies are Baker Gas, Interstate Gas, Citrus Energy, DL Resources, Alpha Shale Resources etc. Larger players include Southwestern Energy Production Company, Anadarko and Chesapeake Appalachia which is a subsidiary of Chesapeake Energy Corporation.

The average gas to waste ratio for PA shale gas operators is 144 Mcf of Gas / bbl of wastewater over the studied period compared to 39.5 Mcf of Gas / bbl of wastewater for operators involved in conventional oil and gas development. This proves that in Pennsylvania, the shale gas industry manages to recover more gas per waterwater produced than the conventional oil and gas development industry. However, the cumulative effects of wastewater volumes in Pennsylvania caused the 10 times increase in wastewater volumes over the past 10 years and poses significant challenges for effective environmental and social risk management.

3.4.4 Pennsylvania Shale Gas Wastewater Disposal Discussion

Across the US, 95% of total oil and gas related wastewater is disposed through underground injection wells [34]. However, in Pennsylvania the geology does not allow for high volumes of oil and gas wastewater disposal[35]. Hence, there are 4 alternative ways for wastewater treatment which have been used in the period 2000 – 2012 for both conventional and unconventional waste water development: (1) treatment at a municipal or county wastewater treatment; (2) centralised water treatment facility or private industrial treatment plant; (3) transportation to available injection wells in Pennsylvania or in other states and (4) partial treatment followed by recycling.

In the PA DEP wastewater reporting system, an additional option appears to be the road spreading of brines for ice and dust control, however, according to the Marcellus Shale Advisory Commission(MSAC)[63] this is not permitted for unconventional oil and gas wastewater. The shale gas industry still reported as using 372 barrels of brine from unconventional gas development as road spreading in 2012 despite the MSAC guidance.

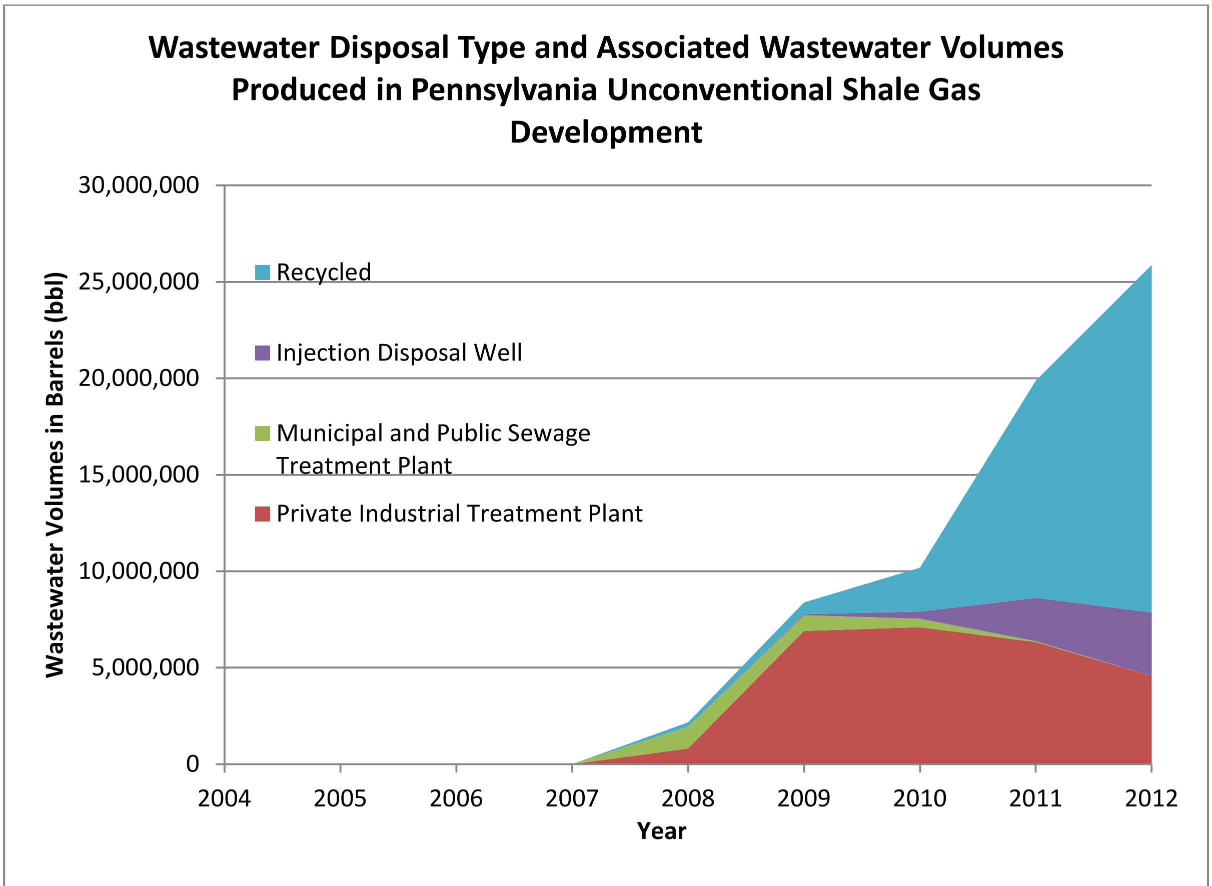

Figure 18: Wastewater Disposal Type and Wastewater Volumes in PA Unconventional Shale Gas.

Figure 18 illustrates the volumes of wastewater from shale gas development in Pennsylvania and their associated disposal type over the 2007 – 2012 period. From 2008, when Municipal and Public Sewage Treatment Plants took in more that 50% of the total wastewater, there has been a shift towards disposing wastewater to Private Industrial Treatment Plants and recycling. According to the EPA, wastewater is disposed as non-hazardous waste, although there are situations when these contain hazardous material and are damaging to humans. This is a consequence of the fact that the US Congress exempted wastewater coming from oil and gas development from being classified as hazardous in the Solid Waste Disposal Act Amendments. The reason there was a sudden shift in disposal from Municipal Treatment facilities to Industrial facilities after 2008, is that the PA DEP limited Municipal treatment facilities intake of oil and gas wastewater to 1%, after received numerous reports regarding the increase in Total Dissolved Solids (TDS) concentration in the Monogahela River in PA, which appeared to be caused by wastewater from shale gas development[64].

Soon afterwards, it seemed that most Industrial facilities were incapable of treating oil and gas wastewater with TDS concentration above 500mg/L when new regulation has been put in place to limit wastewater intake to Industrial facilities as well. Eventually, this led to an effort of the whole shale gas industry to recycle and reuse a higher proportion of its wastewater. Before being reused in other hydraulic fracturing operations, fracturing fluid has to be treated for high salt concentration, chemicals and metals, which prevent the effectiveness of hydraulic fracturing chemicals [65].

Figure 19 shows the location of wastewater treatment facilities and injection wells across Pennsylvania and neighbouring states, as they were included in the PA DEP wastewater records and further processed using Quantum GIS. The map confirms Lutz's statement that there is limited capacity for injection wells in Pennsylvania and shows that should companies choose to dispose wastewater through injection wells, the state of Ohio would have the capacity for it. This poses significant risks for companies in face of changing regulation regarding the disposal of shale gas development wastewater by increasing transportation costs and the probability of road wastewater spills.

Industrial Treatment facilities and Municipal treatment facilities have better coverage of the South West region of Pennsylvania, however, there seem to be less disposal options for operators in the North East, which is also the area with the highest shale gas production and associated wastewater volumes in Pennsylvania.

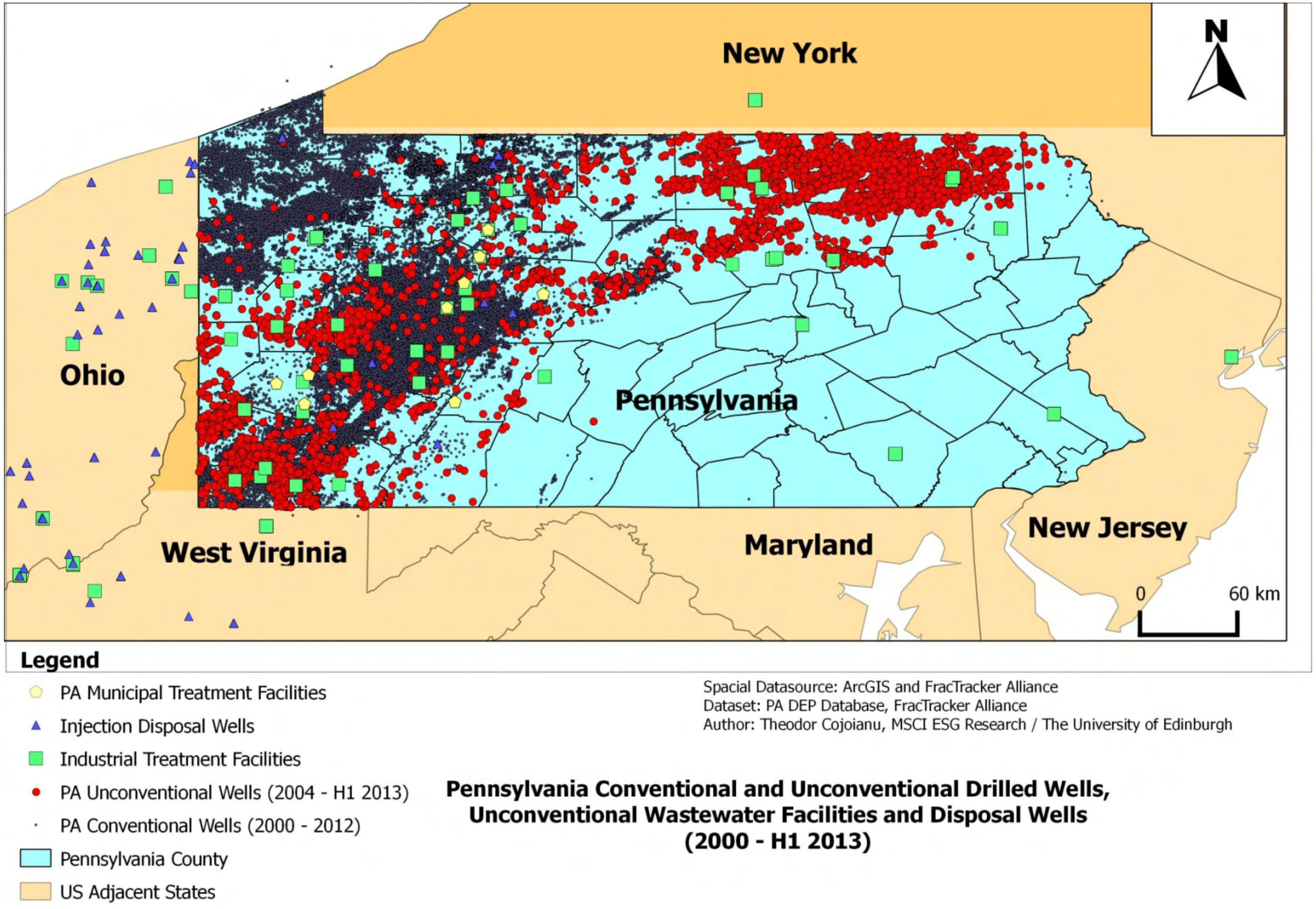

Figure 19: Pennsylvania Conventional and Unconventional Drilled Wells and Wastewater and Disposal Facilities. Theodor Cojoianu, Quatum GIS.

3.5 Pennsylvania Unconventional Oil and Gas Violations

3.5.1 Pennsylvania Violations Introduction

This particular dataset has been made available through the FracTracker Alliance and contains data with respect to the violations of shale gas development operators in Pennsylvania in the interval 1st January 2004 – 29th July 2013.

3.5.2 Pennsylvania Violations Analysis

In the above mentioned period, there have been a total of 202 fines given by the Pennsylvania DEP to unconventional well operators which totalled USD 4,522,345. Each fine is an aggregate amount for several violations of an operator. Historically, the total amount of shale gas extracted from Pennsylvania was 4.91 trillion cubic feet, which at September 2013 industrial gas prices would have an approximate value of USD 19.27 billion. This means that for every USD 1,000 in revenue for the shale gas industry in Pennsylvania, USD 0.2 was paid in fines to the DEP, which is an insignificant price to be paid for environmental, health and safety and compliance related violations. The database does not include any litigation expenses which arise from company wrongdoings such as the case of Cabot Oil and Gas who paid USD 4.1 million to settle the litigation for groundwater contamination in Dimock, PA[55]– it is solely limited to the inspections of the PA DEP to the well sites and their subsequent decision whether the operator has committed any violations or not.

Although shale gas production began in Pennsylvania as early as 2004, the first fine was given to Phillips Exploration Inc. (USD 11,028) in September 2006 for improperly casing a well to protect fresh groundwater contamination in Butler County. The highest fine historically given by the PA DEP was in 2010 to EOG Resources Inc (USD 353,419). According to the incident report, the operator failed to install safety devices, the blowout prevention equipment has failed, an uncontrolled discharge of natural gas and flowback fluids occurred and the operator lost control of the well.

By analyzing qualitatively and quantitatively the notes associated with unconventional shale gas development violations in Pennsylvania, we find that from the total of 5176 violations in the period 2004 – July 2013, the most common violations are:

- Inadequate or missing Environmental and Health & Safety Plan (9.3% of cases)
- Failure to properly store, transport or dispose of residual waste (7.9%)
- Discharge of polluting material to waters of Commonwealth (4.6%)
- Failure to adopt pollution prevention measures required or prescribed by the DEP (4.5%)

- Pit and tanks are not constructed with sufficient capacity to contain hazardous substances (4.1%)
- Failure to report defective, insufficient or improperly cemented casing within 24 hours or failure to submit plan to correct within 30 days (3.1%)

Despite the important nature of violations (polluting material discharge in state waters, cement casing failures etc.) and the frequency with which these types of violations occur, shale oil and gas operators pay insignificant fines which do not affect their financial wellbeing. Figure 20 illustrates how the total number of fines and violations for shale gas operators in Pennsylvania is increasing year on year. Surprisingly, the total associated fine amount has peaked in 2010 and is decreasing ever since.

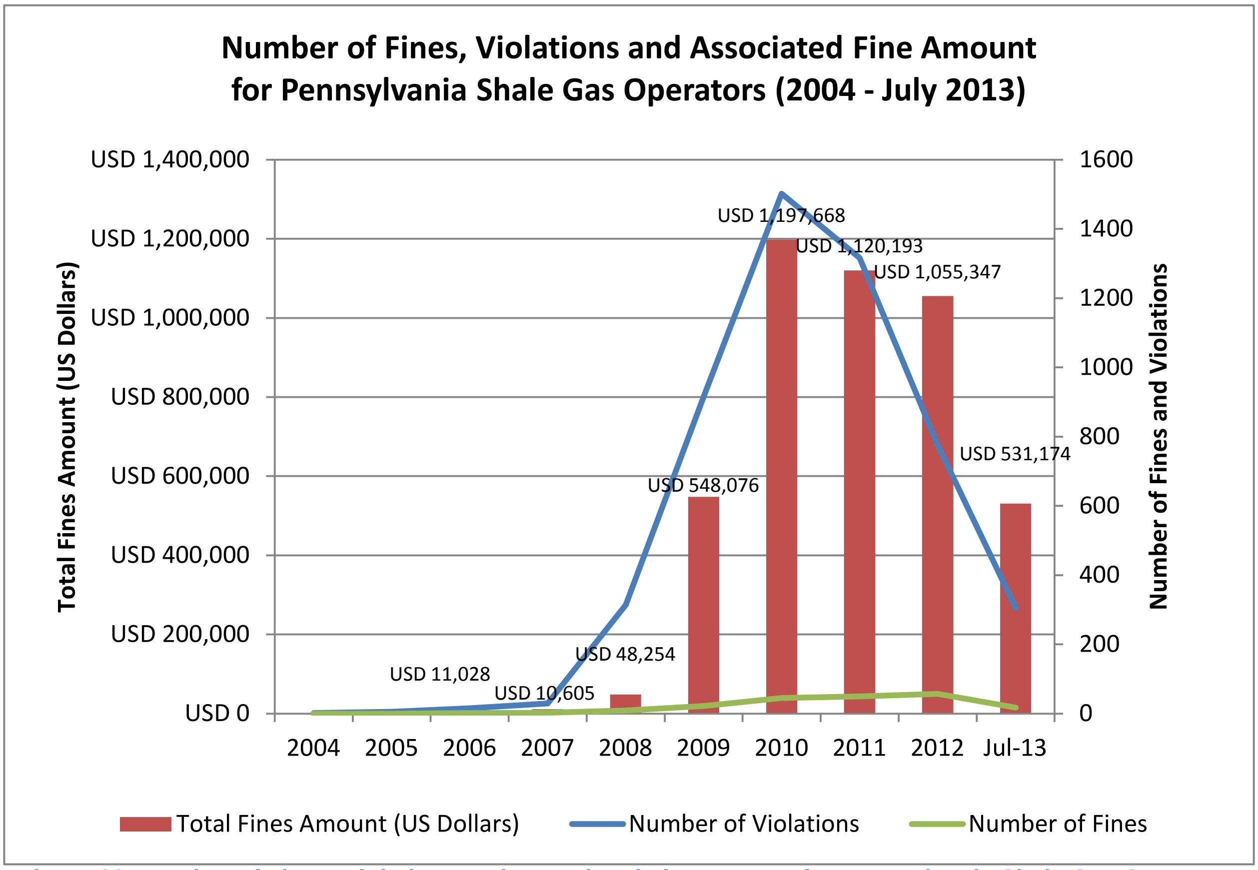

Figure 20: Number of Fines, Violations and Associated Fine Amount for Pennsylvania Shale Gas Operators (2004 - H1 2013).

A valid explanation into the violations and inspection trends in the oil and gas industry in Pennsylvania is offered by the Earthworks Oil and Gas Accountability Project report [57]published in Sep 2012. In the 2010/11 period the DEP quadrupled its enforcement the size of its enforcement staff including its environmental inspectors division which totalled 83 inspectors in 2012.

Despite the efforts to increase the number of inspectors, the report reveals that the DEP is lacking inspection capacity. In 2011, the Pennsylvania DEP failed to inspect 86% out of the approximately 66,000 active operating wells (conventional and unconventional). Given resource constraints and exponential growth in new shale wells, a similar or higher percentage of uninspected wells is expected for 2012. One implication for this is that a higher well inspection coverage and tighter enforcement of penalties on behalf of the PA DEP would result in a significantly higher financial and reputational impact on both conventional and unconventional operators.

According to the analysis in shale gas production section, there were 40,199 new conventional well permits and 14,267 new unconventional well permits issued by the DEP in the period 2004 – H1 2013. According to the DEP "Inspection Policy for Oil and Gas Well Activities"[57]a well should be inspected 7 times before it commences production and every year onward if it is an active well. In 2012, according to our analysis, there were 83,930 active conventional wells and 13,918 active unconventional active wells in PA. This would mean that at least 95,000 + inspections should have been carried out in 2012 by the 83 DEP inspectors, which is a highly unrealistic expectation if 100% of the wells are to be verified according to the Pennsylvania State Code.

Companies that had high number of violations in the past are likely to be in the spotlight as inspection coverage increases in Pennsylvania and bear higher regulatory and litigation risk. Below, the companies with most violations per inspected well in Pennsylvania are presented (Figure 21). The ranking is illustrated only for the companies who had more than 20 unique wells inspected across the years. In Appendix A.6, the results for all the companies can be observed. An interesting trend is that for the top 5 companies with most violations in Figure 21, violations peaked in 2010/2011 with an average of 135.3 violations and plummeted in 2012 to an average of 48.8 violations which signals an improvement in environmental and health and safety management in 2012.

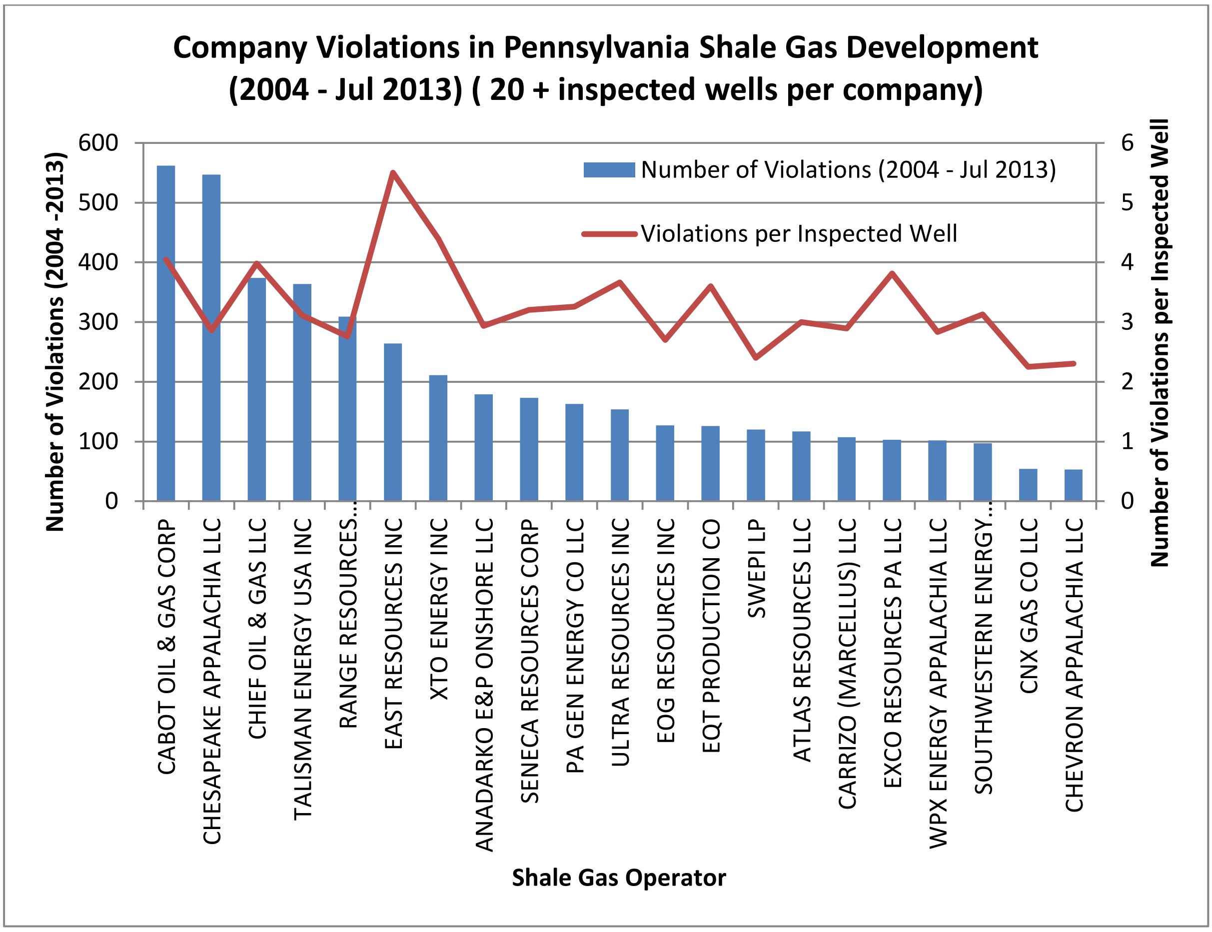

Figure 21: Company Violations in Pennsylvania Shale Gas Development (2004 - Jul 2013).

3.5.3 Conclusions

The above findings lead us to several conclusions and recommendations:

The PA DEP constraints on inspection staff and other resources prevent the regulatory landscape and environmental law enforcement from being effective. This resulted in a 86% gap in the well inspection coverage which can have a significant impact on the environmental and health and safety practices of companies operating in the state, as well as the communities of PA and the environment.

The most common violations among inspected wells are related to the robustness of a company's environmental and health and safety plan, transport and storage of hydraulic fracturing waste and well cement casing. If the same percentage of violations holds for both the inspected and uninspected wells, then there are high risks for both the industry and communities given the expected growth in well numbers in future years.

The Pennsylvania DEP should develop inspection protocols that would ensure robust coverage of both active and new wells.

The penalties associated with environmental, health and safety and compliance violations are insignificant and hence it appears that from a financial standpoint it is more costly to comply rather than paying the fine associated with not complying with the DEP.

3.6 Pennsylvania Shale Gas Production, Wastewater Management and Violations Conclusions

This chapter is a comprehensive case study on shale gas production, unconventional wastewater management and company violations related in shale operations in Pennsylvania.

Pennsylvania is the 5th shale gas producing state in the US by cumulative estimations between 2004 and 2013. The number of permits awarded for unconventional wells has recently surpassed those for conventional wells; however the number of active producing unconventional wells in Pennsylvania is still well behind conventional ones. Companies which benefitted mostly from shale gas development have been identified. These vary by size and by county of operation in Pennsylvania.

A similar analysis was performed on the wastewater and company violations dataset which unveiled interesting findings. The cumulative unconventional wastewater volumes in PA have been 6 times larger than wastewater coming from conventional oil and gas activities. This has deep implications for the PA DEP's ability to effectively manage wastewater and adapt to this fast increasing industry which is shale gas development.

Given the constraints that the PA DEP is facing in terms of staffing numbers, it is challenging to have good inspection coverage of both conventional and unconventional wells. Hence, over 80% of active wells remain uninspected during the year, which can potentially have major impacts on the environment. The number of fines awarded for company wrongdoings are insignificant and do not affect the financial wellbeing of the operators. Hence, companies would pay rather than comply with Pennsylvania environmental regulation.

4 Quantifying Company Risk in Pennsylvania Shale Gas Development

4.1 Introduction

In previous sections several statistics on shale gas operators in Pennsylvania were presented: shale gas production, wastewater volumes, shale gas produced to wastewater volumes ratio and company violations per inspected shale gas well.

In this section, a methodology to quantify aggregate company risk relative to peers is presented together with the aggregate statistics for each company. In addition to aggregating the risk for companies arising from wastewater management and violations, the MSCI ESG Research database with company environmental, social and governance risk scores is leveraged to add a further layer which helps differentiate between the leaders and the laggards in shale gas development[66].

First, the top level risk methodology is shown. The methodology illustrates how the total risk score for a shale gas operator is calculated from the following metrics: wastewater volume to shale gas ratio, company violations per inspected well and MSCI ESG Research Intangible Value Assessment (IVA) score. Afterwards the focus will be shifted towards the data manipulation techniques used and the IVA score methodology which will provide a better understanding of the top level risk methodology used. Finally, the shale gas operator risk benchmarking analysis is presented where we identify the leaders and the laggards in the industry and discuss their business models and industry best practices.

4.2 Top Level Risk Methodology

4.2.1 Introduction

In order to provide a holistic picture of the risk exposure of shale gas operators, operators are relatively benchmarked with respect to peers on 3 indicators. The percentages are then aggregated for each indicator to form the aggregate risk score or percentage. The 3 indicators are: wastewater volume to produced shale gas ratio, company violations per inspected shale gas well and MSCI ESG Research IVA ESG scores. The MSCI ESG Research IVA ESG Company score is based on the research of the 90+ analysts at MSCI who rank companies' on their overall environmental, social and governance practices. This score will help put the company in the wider oil and gas industry context and includes an assessment of a company's global operations and business segments. The other 2 indicators are shale gas specific only. The aggregation of these particular indicators provides a holistic picture of both shale gas and global operations, and represents a robust measure of the environmental, social and governance risk management of shale gas operators in Pennsylvania.

4.2.2 Wastewater to Gas Ratio and Company Violations Indicators

For both the wastewater to gas ratio indicator and the company violations per inspected shale gas well indicator, a 0% risk threshold is set to the best performing company, 50% threshold to the average company score for the respective indicator and 100% to the worst performing company.

If the company score for a given indicator is less than the industry average, then a linear interpolation is carried out between 0% (best performing company) and 50% (industry average) to find the risk exposure for the respective company. Alternatively, if the company score is higher than the industry average, then a linear interpolation is calculated between 50% (industry average) and 100% (worst performing company). When calculating the industry average, outliers which might skew the result heavily are excluded. For example, for the wastewater to shale gas ratio (bbl/cf) the industry average calculation excludes any company with the ratio >300, since 90% of the companies have ratio values between 0 – 300, and the rest of 8 companies (c. 10%) are outliers with extremely high ratios (between 1000 – 5162). To such outliers 100% risk exposure is given for the particular indicator.

In the Pennsylvania wastewater management section, the performance of companies with respect to the shale gas production to wastewater ratio was analysed. This illustrated the opportunity of companies to develop shale gas with a minimal environmental footprint. If the ratio is inverted, the risk profile of a company can be interpreted as follows: companies with high wastewater volumes per unit of shale gas produced are at higher risk than those who manage to develop shale gas resources with a smaller wastewater footprint.

In the case of the company violations per inspected shale as well statistic, there are 71 companies which are comprised in the dataset, with an average of 3.25 violations per well. The outliers here are the companies who have a violation per well ratio greater than 11 (3 in total) which skew the average and to which 100% risk exposure was awarded.

4.3 MSCI ESG Research Intangible Value Assessment (IVA) Methodology

The MSCI methodology was briefly presented during Phase I of the MEng project. In this section, a more in depth explanation will be provided as to how MSCI ESG Research analysts rate companies involved in oil and gas development as well as how the MSCI scores can be incorporated in the top level shale gas risk methodology.

The IVA research methodology is looking to assess environmental, social and governance (ESG) risks and opportunities of companies in a medium to long term. The model hierarchy on which the assessment is based can be observed in Appendix A.6. ESG issues are contextual depending on the industry assessed [67] and hence, not all the issues in the IVA model hierarchy feed into the ESG risk and opportunity of a company.

It is then a select number of key issues on which companies are ranked and based on which the benchmarking exercise is carried out. The key issues are selected for each of the 154 GICS (Global Industry Classification Standard[68]) sub-industries and are limited to between 4 to 7 issues for each sub-industry. One of the key issues is Corporate Governance which is included in the rating of every company. The other key issues from the hierarchy model (Appendix A.6) are selected based on their high potential impact on the business model of companies within a sub industry.

For the Oil & Gas (O&G) Drilling companies, O&G Equipment and Services companies, Integrated O&G companies, O&G Exploration and Production, O&G Refining and Marketing, Storage and Transportation companies, the key issues are: carbon emissions, biodiversity and land use, toxic emissions and waste, health and safety, corruption and instability and corporate governance.

The final ESG score for each company is obtained by applying a weighted average across the key issue scores and it is a number between 0 and 10, where a score closer to 0 means that company has a poor ESG rating and a score closer to 10 means that the company has a good ESG performance.

In order to incorporate the ESG scores into the risk methodology, the complement score percentage is used (Complement Score Percentage = (10 – ESG Score) x 10). In this way, a company with a low complement percentage is a best performer (a company which faces less risk) and a company with a high complement percentage is a poor ESG performer.

4.3.1 Indicator Weight in Risk Methodology

The aggregated risk exposure of shale gas operators in Pennsylvania is presented in Figure 22. The Shale Gas Operator Risk score is obtained by applying a weighted average across the 3 indicators: Wastewater to Shale Gas Ratio (40% weight), Violations per Shale Well (40% weight), MSCI ESG Research ESG score (20% weight). By using these weights, a holistic risk quantification approach is presented, which is slightly skewed towards risks of shale gas operators arising from operations in Pennsylvania. The wastewater to gas ratio and company violations will provide the regional company risk exposure while the MSCI ESG scores encompass a quantification of risk across all company businesses and geographies (e.g. Chevron is a global O&G company with operations across multiple geographies) and across multiple key issues.

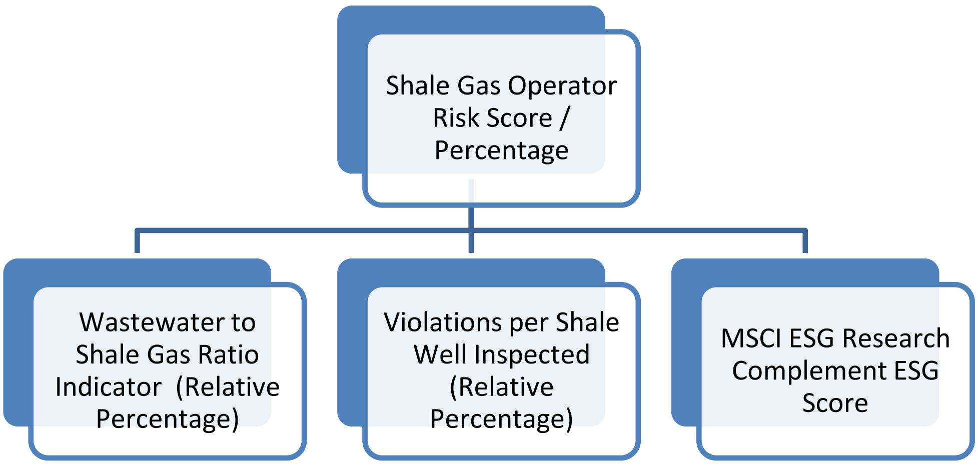

Figure 22: Shale Gas Operator Risk Aggregation Model

4.3.2 Shale Gas Company Risk Analysis

In order to match the 3 indicators to each of our target companies, it is ensured that all companies have the same names across all the datasets and that the values of one or more subsidiaries are matched to the parent company. For example, East Resources Management LLC operates as a subsidiary of East Resources Inc and both companies appear as having shale gas operations in Pennsylvania. In this case, the values of both East Resources Management LLC and East Resources Inc. are aggregated under East Resources Inc.

In the shale gas production dataset there are 84 parent companies which are matched with the 81 companies in the wastewater database. Given a match rate of 92.5%, the risk percentages for 75 parent companies are obtained. Further, the 71 companies in the violations dataset are matched with the 75 companies with calculated waste to shale gas ratios. A 78.8% match rate leads to the aggregated risk quantification for 56 shale gas operations in Pennsylvania as presented in Figure 23. For the purpose of the illustration in Figure 23, only 2 indicators are aggregated (waste to shale gas ratio risk percentage and violations per well ratio risk percentage with 0.5 weights each). When further adding the MSCI ESG Research scores layer, the company number for which total risk is quantified, drops to 18 (Figure 24).

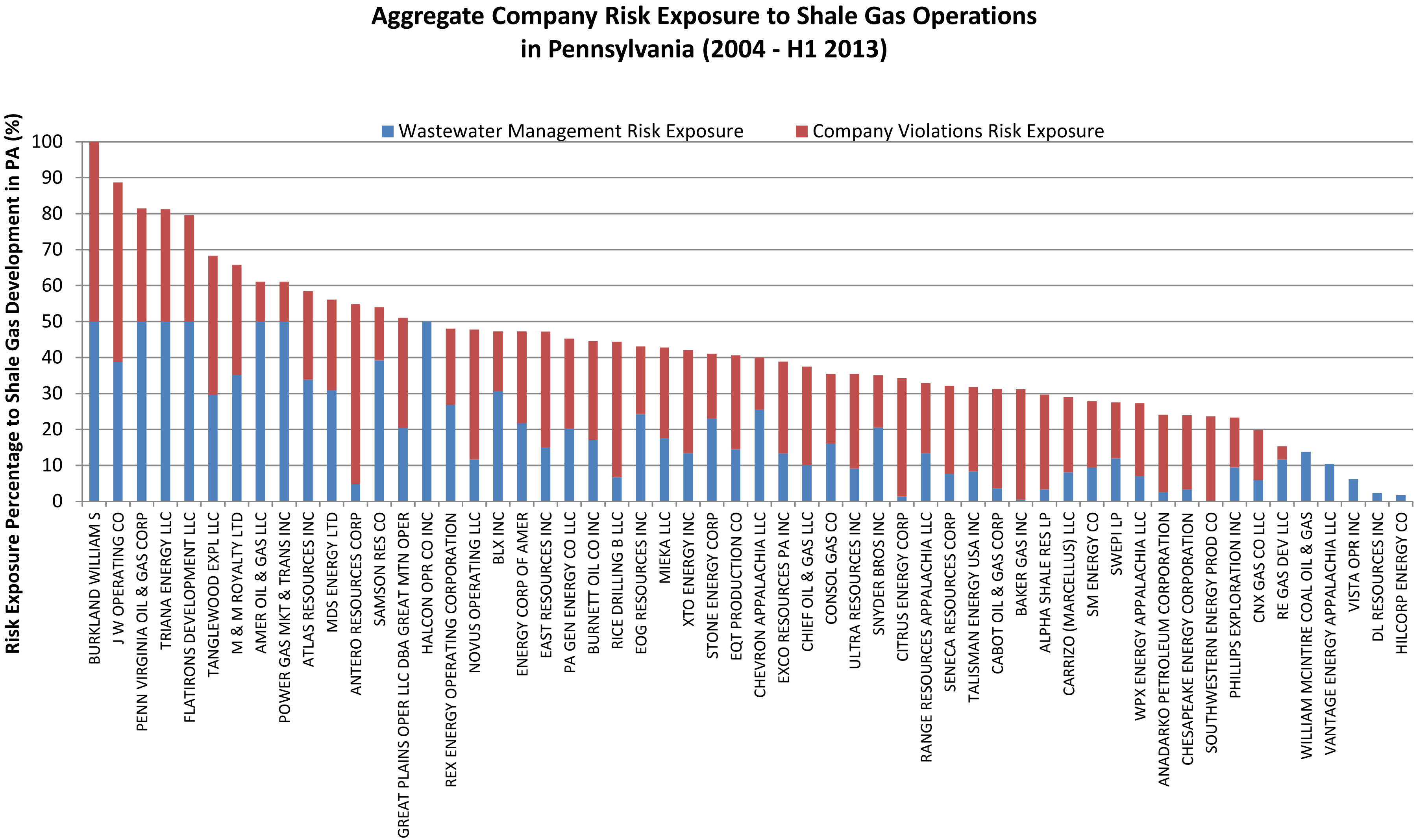

Figure 23: Aggregate Company Risk Exposure to Shale Gas Operations

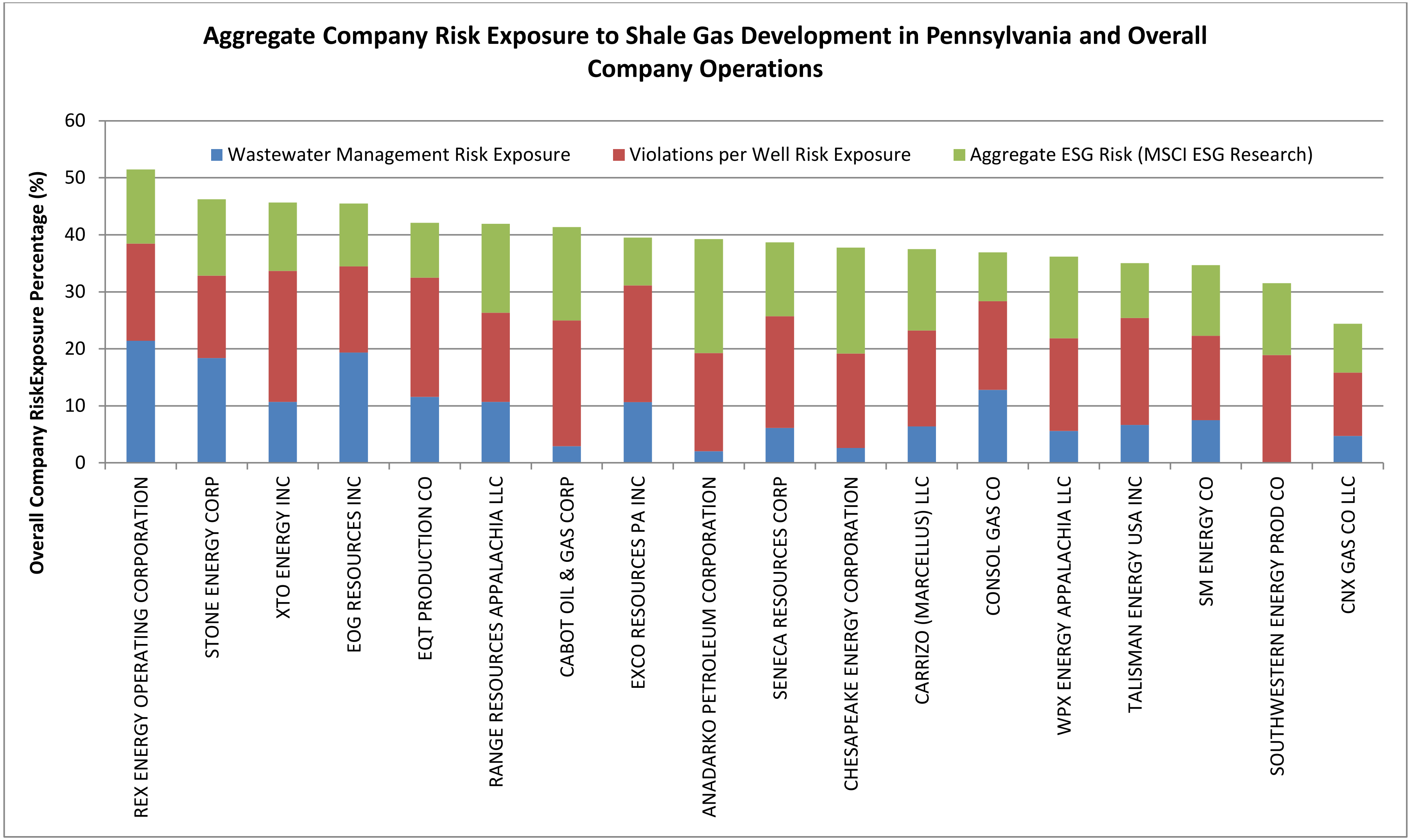

Figure 24: Aggregate Company Risk Exposure to Shale Gas Development in Pennsylvania and Overall Company Operations

Figure 23 also illustrates the fact that companies with higher risk exposure in Pennsylvania shale gas development tend to have a poorer wastewater to gas production ratio which leads to higher wastewater management costs and also indicates a small gas production rate which translate into fewer financial rewards in the short to medium term. Furthermore, small companies who are 100% invested in shale gas operations tend to have less experience into managing risks and face the highest risk exposure, while large integrated oil and gas producers are able to diversify their operations across different counties in Pennsylvania, where historically there have been sweet spots for gas production and suitable wastewater infrastructure.

In Figure 24, the extra ESG risk layer is added, as calculated based on the MSCI ESG Research IVA score. The ESG risk exposure is a result of the aggregation of a specific company risk with respect to carbon emissions, biodiversity and land use, health and safety practices, toxic emissions and waste and corporate governance. Given the fact that MSCI covers only mid and large cap listed companies, unlisted companies and small listed companies involved in shale gas development are not covered by standard ESG research. Hence the company set is narrowed to 18 companies. In this respect, Figure 23 is a useful insight which reveals the risk of both listed and unlisted companies on 2 important and material metrics.

Given the fact that the aggregate risk can be quantified for 18 companies, which tend to be large integrated oil and gas companies or have diversified businesses across the oil and gas industry and operate across multiple counties in Pennsylvania, it is expected that a moderate difference between the best performing and worst performing company from and environmental and social risk perspective. This is confirmed by Figure 24, where the difference in risk exposure between the worst performing company (Rex Energy Operating Corporation) and the best performing company (CNX Gas – recently acquired by ConsolEnergy) is 27%. Most companies perform well on wastewater risk exposure; however they tend to have a higher violation rate per shale gas well inspected. While most companies have a comparable MSCI ESG Research risk exposure score, there are some poor ESG performers on which several observations are presented below based on MSCI ESG Research company reports, annual reports and company website research.

Anadarko Petroleum Corporation, who is a former partner of BP, owned 25% non-operating interest in the BP Macondo well[69] and still faces reputational and financial risks in relation to the Deepwater Horizon explosion. Anadarko has a presence in geographic regions where H&S performance is poor, which combined with a H&S management strategy and poor performance, places the company behind most peer companies. The company's oil and gas reserves are 90% booked in the US[70]where federal greenhouse gas (GHG) regulations are targeting a 17% reduction by 2020 from 2005 levels. The oil and gas reserve split (46% oil and 54% gas) does not provide a competitive advantage for the company in a carbon-restricted economy[54].

Chesapeake Energy Corporation has benefited most from shale gas development in Pennsylvania in the period (2004 – H1 2013) through its subsidiary Chesapeake Appalachia LLC . However, the recent controversies it has been involved in, together with poor company performance on managing biodiversity and land use and health and safety risks, make Chesapeake one of the least responsible companies in oil and gas development according to MSCI's scoring methodology[71].

5 US Wide Hydraulic Fracturing Case Study

5.1 Introduction

In order to provide a top level analysis of the state of hydraulic fracturing usage across the United States, the FracFocus Chemical Registry Database[72] has been leveraged. The case study explores the distribution of hydraulic fractured in the US, the amount of water employed in the hydraulic fracturing process (where reported) and provide estimations of shale gas development associated wastewater and violations by extrapolating the results from the Pennsylvania case study. Finally, having identified the operators who employ hydraulic fracturing processes as part of the development of their oil and gas wells, an ESG risk assessment is presented based on the MSCI ESG Research proprietary ESG scores database.

5.2 FracFocus National Registry

The registry has been launched in 2011 by the Ground Water Protection Council (GWPC) and the Interstate Oil and Gas Compact Commission and it is an online repository of information regarding the chemical composition of fracturing fluids, together with the geo-location, operator details and fracturing fluid volumes of hydraulically fractured oil and gas wells[40].

On 1st of January 2011, FracFocus began as a voluntary program. As of 9th of July 2012, 10 states required 3 different fracturing fluid disclosure types in FracFocus:(1) *frac fluid volume disclosure*: New Mexico, Ohio, Oklahoma, Maryland, Michigan; (2) *concentration disclosure*: Wyoming; (3) *volume and concentration:* Arkansas, Louisiana, Montana and Pennsylvania.

5.2.1 FracFocus Data

According to the Ground Water Protection Council data in FracFocus are entered by oil and gas operators and service companies. The registry does not hold itself accountable for any inaccuracy in the dataset. Hence, several quality assurance checks were performed on the dataset. These are presented in the next section.

The data in FracFocus can be downloaded only in individual PDF formats per well (Appendix A.10). Since downloads are possible only for single well disclosure records, a web crawler has been designed in C# programming language to automatically parse the website and download the associated data. However, according to a private communication with Sam Malone, Officer at the FrackTracker Alliance[73], FracFocus has restricted the use of crawlers and automatic download programmes on its website as of May 2013. This was the cause for which the C# program was unsuccessful on the FracFocus site. The C# program was tested on a website with a similar architecture (Google Trends / Google Insights for search) on which the program was successful. The code for both attempts is presented in Appendix A.7.

The data download was made possible with the help of SkyTruth [74], an NGO that uses software engineering, remote sensing and digital mapping to create insights that expose the risks to ecosystems posed by mining and oil and gas development activities. SkyTruth designed a web crawler with the same purpose and managed to download the data from the FracFocus website before May 2013, when the FracFocus website design changed. SkyTruth kindly shared the downloaded dataset, which now is also available to the wider public.

5.2.2 Quality Assurance, Data Corrections and Data Visualisation

The quality of the FracFocus dataset has been assessed through manual and automated methods and the necessary adjustments have been performed in order to obtain a more robust dataset. Duplicate records and well fracture date records outside the interval 1st Jan 2011 – 1st May 2013 have been excluded. Companies were allowed to submit hydraulic fracturing records from previous years which explains why the database contained entries from as early as 2008, however given the fact that this was a voluntary submission, it is considered that data from years before the target period is not reliable or robust.

The location of the wells has been validated by using the Quantum GIS software and the well latitude and longitude coordinates as reported in the individual well reports. State location, shale basin and shale play location information has been used to spatially validate the well location. Since the reporting framework does not distinguish between conventional and unconventional hydraulic fractured wells, a further data correction has been applied in order to be able to estimate the water amount that is used in shale gas and oil development across the US. The correction consists in eliminating any wells which are located outside the boundaries of shale basins across the US, since shale oil and gas are unlikely to be found outside the boundaries of a shale basin[1].

5.2.3 FracFocus Dataset Analysis

Further to the data adjustments, a distribution of estimated wells fractured between 1st Jan 2011 – 1st May 2013,is represented in Figure 25.In total, we obtain 16,081 hydraulic fracturing records for 15,928 wells (149 wells have been hydraulically fractured twice and 2 wells have been fractured 3 times).

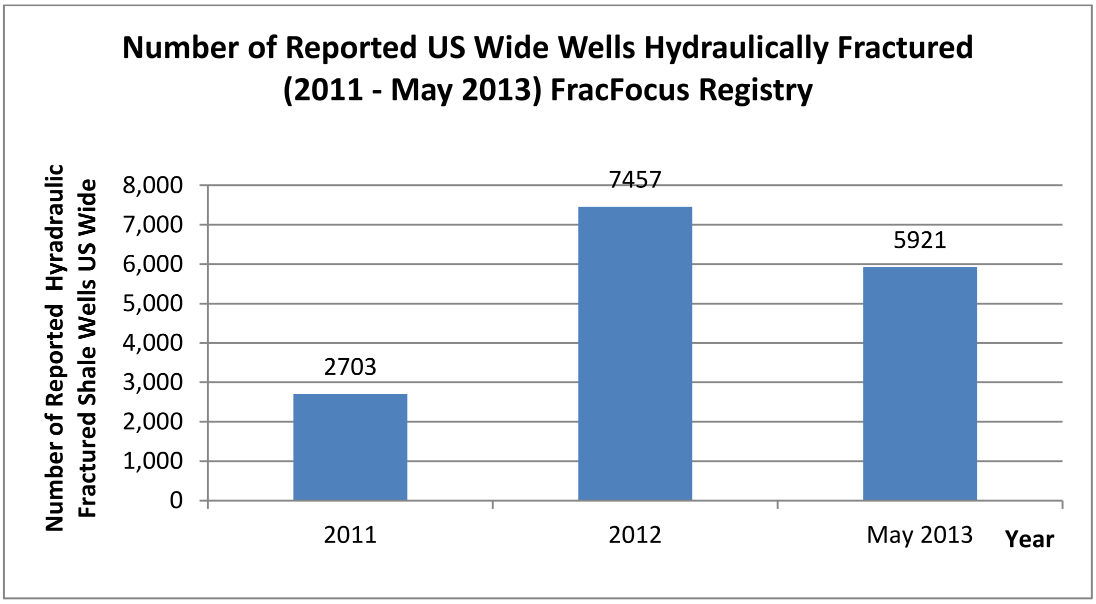

Figure 25: Number of Reported US Wide Wells Hydraulically Fractured (2011 - May 2013) FracFocus Registry

The small number of reported hydraulic fractured wells in 2011 is explained by the fact that in 2011 the reporting scheme was voluntary for all states. It was during 2012 that several states started gradually to introduce reporting to FracFocus as being mandatory. According to the EPA[40], the analysed FracFocus dataset can be seen as a representation or estimation of the wells hydraulically fractured in the United States for the 2011 – May 2013 period(Figure 26), however the database is far from being a complete representation of the extent to which hydraulic fracturing is used in oil and gas development operations. For this reason, the dataset is used for estimation purposes and it is considered to be less robust than the datasets used for analysis in Pennsylvania[75].

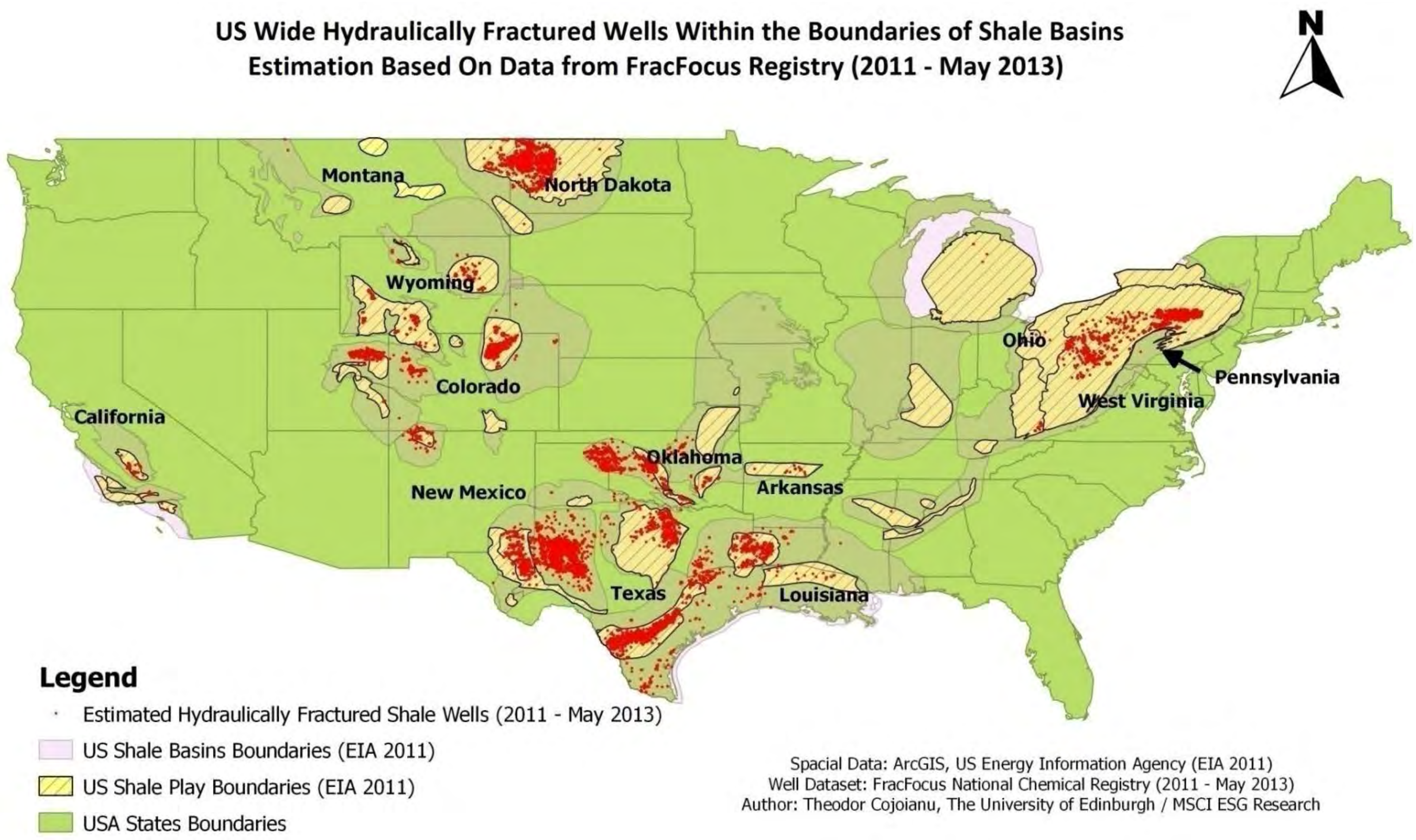

Figure 26: US Wide Hydraulically Fractured Wells Estimation. Theodor Cojoianu, Quantum GIS.

The amount of water reported as being used in hydraulic fracturing operations is consistent with the estimation of the GWPC and EPA that between 1 and 9 million gallons of water are required for the drilling and hydraulic fracturing process of unconventional wells(Figure 27)[40].

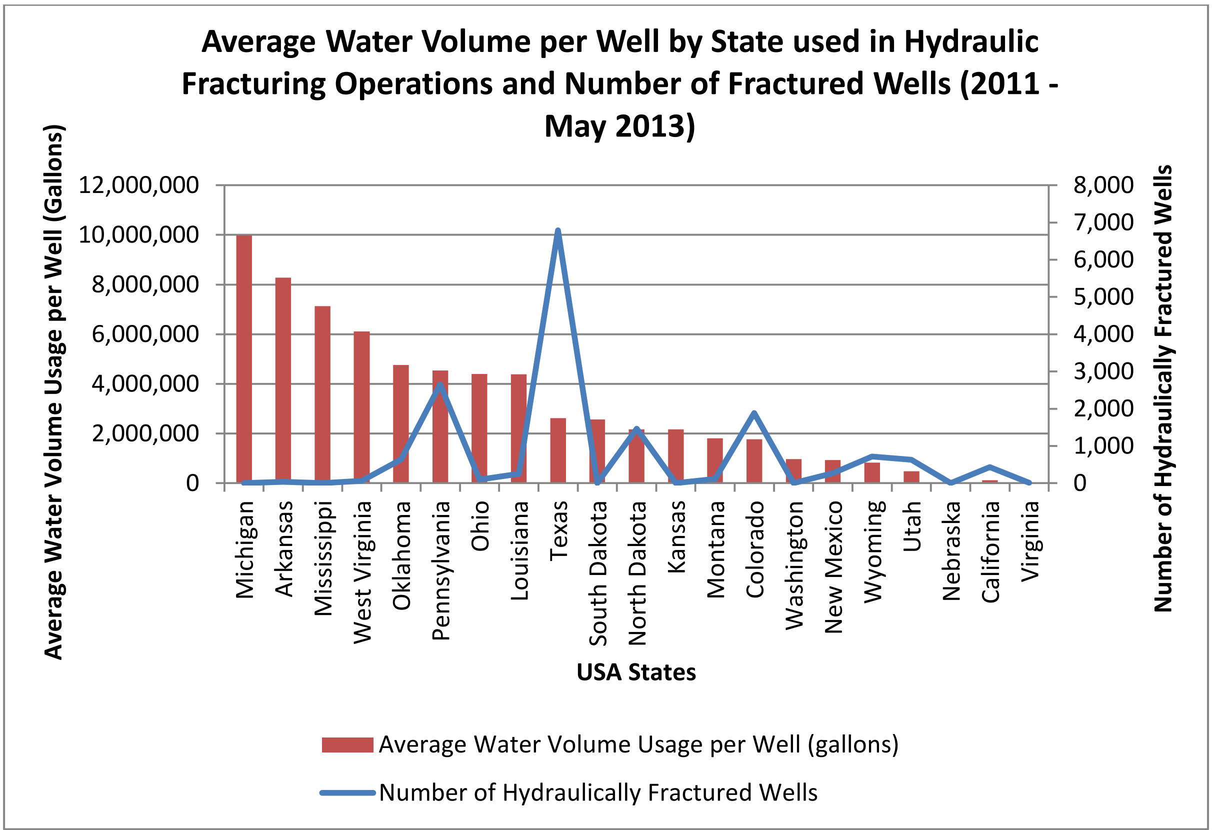

Figure 27: Average Water Volume per Well by State used in Hydraulic Fracturing Operations and Number of Fractured Wells (2011 - May 2013)

The outliers are, Wyoming, Utah, Nebraska, California and Virginia who seem to have less robust reporting of their hydraulic fracturing operations and report an average water usage per well under 900,000 gallons (1 barrel = 42 US gal = 159 L). This is due to the fact that Wyoming is only required to disclose the concentration of the frac fluid used and not the volumes, while Utah, Nebraska and California are not included yet in mandatory FracFocus disclosure. In total, across the 15,928 wells contained within the FracFocus registry between 1st of Jan 2011 – 1st of May 2013 there were 47.137 billion gallons of water reported as being used for hydraulic fracturing purposes or 55.35 million gallons / day.

Estimations of the US wide shale well wastewater volumes between 2011 and May 2013 are calculated based on the extrapolation of the numbers associated with shale operations in Pennsylvania and the number of hydraulically fractured wells US wide within the boundary of a shale basin, as reported in the FracFocus Registry. The average wastewater volume per well in Pennsylvania in the period 2011 – H1 2013 is: 442,860 gallons per well. This statistic, together with the estimated 4.5 million gallons of water usage per fractured well in Pennsylvania(Figure 27) give a water recovery rate (wastewater/water usage rate) of 10% which is consistent with the recovery rate estimation offered by Lutz(between 10% and 70%) or ANL(10% and 300%)[36].

In order to account for the variation of wastewater volumes per fractured well across different US states, we apply different weights to the Pennsylvania wastewater volume per well average. The weights are the ratios between the average water usage per fractured well in Pennsylvania and the average water usage per fractured well in the respective state as they appear in Figure 27.This exercise assumes a similar distribution of fractured wells across the period 2011 – May/June 2013 across all states since wastewater volumes are being extracted across the lifetime of a well, brine being the most prominent type of wastewater for both conventional and unconventional wells. Nebraska, California and Virginia are excluded from this exercise given the non-mandatory reporting requirements in these states.

By using the number of wells reported in FracFocus for Pennsylvania and the average wastewater volume per well in Pennsylvania during the period 2011 – H1 2013, the total wastewater volume over the period comes out as 1,173 million gallons, which is an underestimation of up to 43% of the actual volume which was calculated as part of the Pennsylvania case study – 2,698 million gallons for the same period. Assuming that the number of reported wells in FracFocus not being reported is the same across all states, we correct all the wastewater results for the 43% underestimation. This leads to having the actual shale wells wastewater generated in Pennsylvania in the studied period and more robust wastewater estimation for the other states. The results are presented in Figure 28.

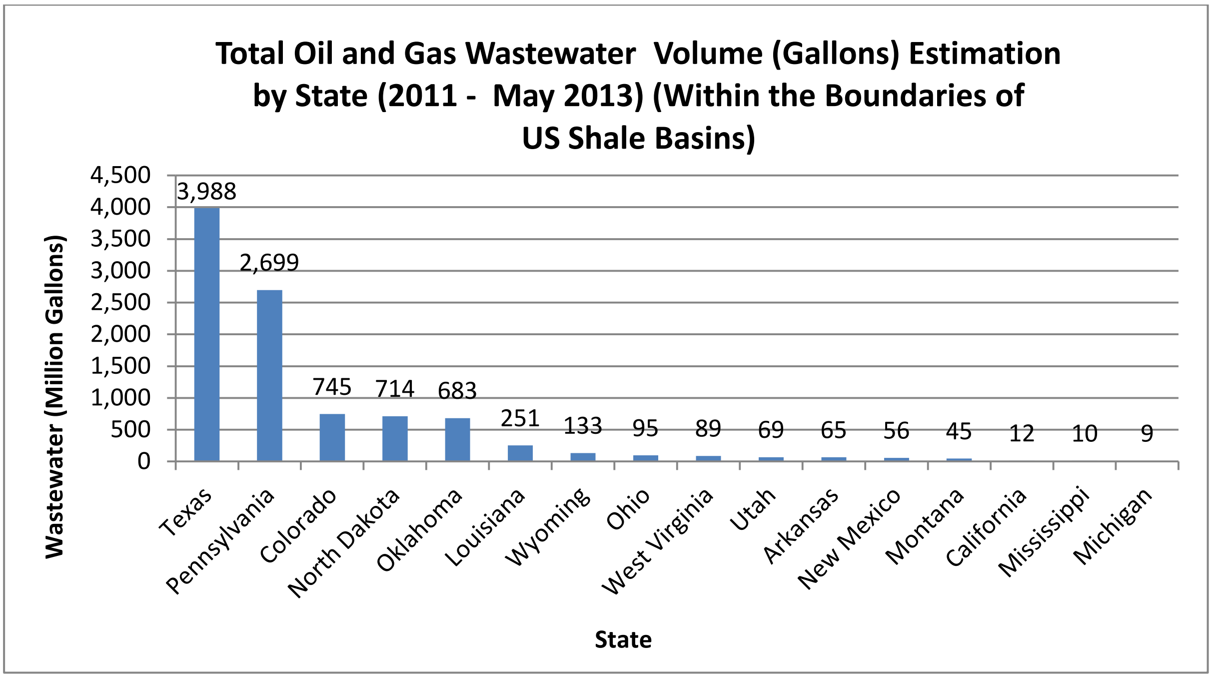

Figure 28: Total Oil and Gas Wastewater Volume (Gallons) Estimation

Texas, having the highest shale gas production historically, appears as having the highest value for wastewater generated which was expected. Pennsylvania is the runner-up which indicates the exponential increase in new shale wells in the state post 2011. North Dakota is mostly known for its shale oil production in the Bakken Shale Play, whose associated wastewater brings North Dakota in the spotlight. Arkansas and Michigan, states which historically have high shale gas production (top 5 across the US) have very low estimations due to the fact that very few wells have been reported to FracFocus, which poises concerns over the reporting reinforcement that should be in place for a registry like FracFocus[75].

5.2.4 US Wide Shale Gas Operator Risk Analysis

The water usage in hydraulic fracturing operations per operator are more challenging to quantify given the fact that companies have operations across multiple states with different reporting requirements. Hence, an operator that has operations mostly in Wyoming, where only fluid chemical composition is mandatory, will appear as having a better water usage performance than other operators who have to mandatory disclose the water volume and concentration in a state like Pennsylvania. In addition to this, the FracFocus dataset is indicative of the aggregate hydraulic fracturing trends but not robust enough to ensure a comprehensive comparison across operators.

Hence, as a proxy for water, carbon, health and safety and toxic emissions related company risks, the MSCI ESG Research disaggregated score database is leveraged. The disaggregated environmental, social and governance scores are used to illustrate a top level risk exposure of oil and gas companies involved in shale gas development.

This is achieved by combining a list of shale operators from both the FracFocus (US wide) dataset and the Pennsylvania dataset. The list of shale operators is then matched with the MSCI ESG Research company list and key issue scores, which leads to the classification in Figure 29 for 60 shale gas operators. The MSCI ESG disaggregated scores have been inverted by using the Complement Score Percentage (CSP = (10 – ESG Score) x10).An equal weight has been given to all disaggregated scores and then aggregated for each company.

The companies with the best risk exposure across the 7 key issues analysed are Seneca Resources, Statoil, Hess Corporation and BHP Billiton, while the high risk companies are Plains Exploration and Production, Approach Resources, Bill Barret Corporation and Carrizo Oil and Gas. The same observation from the Pennsylvania case study is valid here: companies which have the bulk of their assets in shale resource development (Carrizo) are at higher risk than diversified oil and gas companies like Statoil.

A closer look at the disaggregated scores unveils the fact that carbon emission and corporate governance risks are the major differentiators between companies at risk and the ones the ones with lower risk exposure. High risk companies have poor environmental management systems and no emission reduction targets although they operate in industries and geographical areas which are highly likely to be impacted by carbon regulation[76]. Industry leaders have energy efficiency and flaring reduction targets which apply to both the upstream and refining operations. Flaring reduction is particularly important for companies since large amounts of methane are flared during oil and gas operations (mainly to maintain the pressure of an oil and gas well) which accounts for 10 % to 25% of a company's overall GHG emissions[76]. Another aspect worth mentioning is that the oil and gas sector is best positioned to benefit from carbon capture and storage (CCS) given the drilling experience of the industry and availability of depleted reservoirs. Statoil is one of the companies with strong CCS programs and R&D development related to CCS.

Corporate governance risks in the oil and gas industry are related to several aspects: company systems and policies to deal with corruption and political instability, company ethics as well as the responsibilities of the board of directors, compensation and shareholder rights[66]. Poor performers in this area tend to lack evidence of anti-corruption and risk controls and often lack reinforcement of the company code of ethics. Executive compensation should be aligned with long term company performance and other intangible non-financial metrics such as: health and safety (number of fatalities per year) and environmental performance.

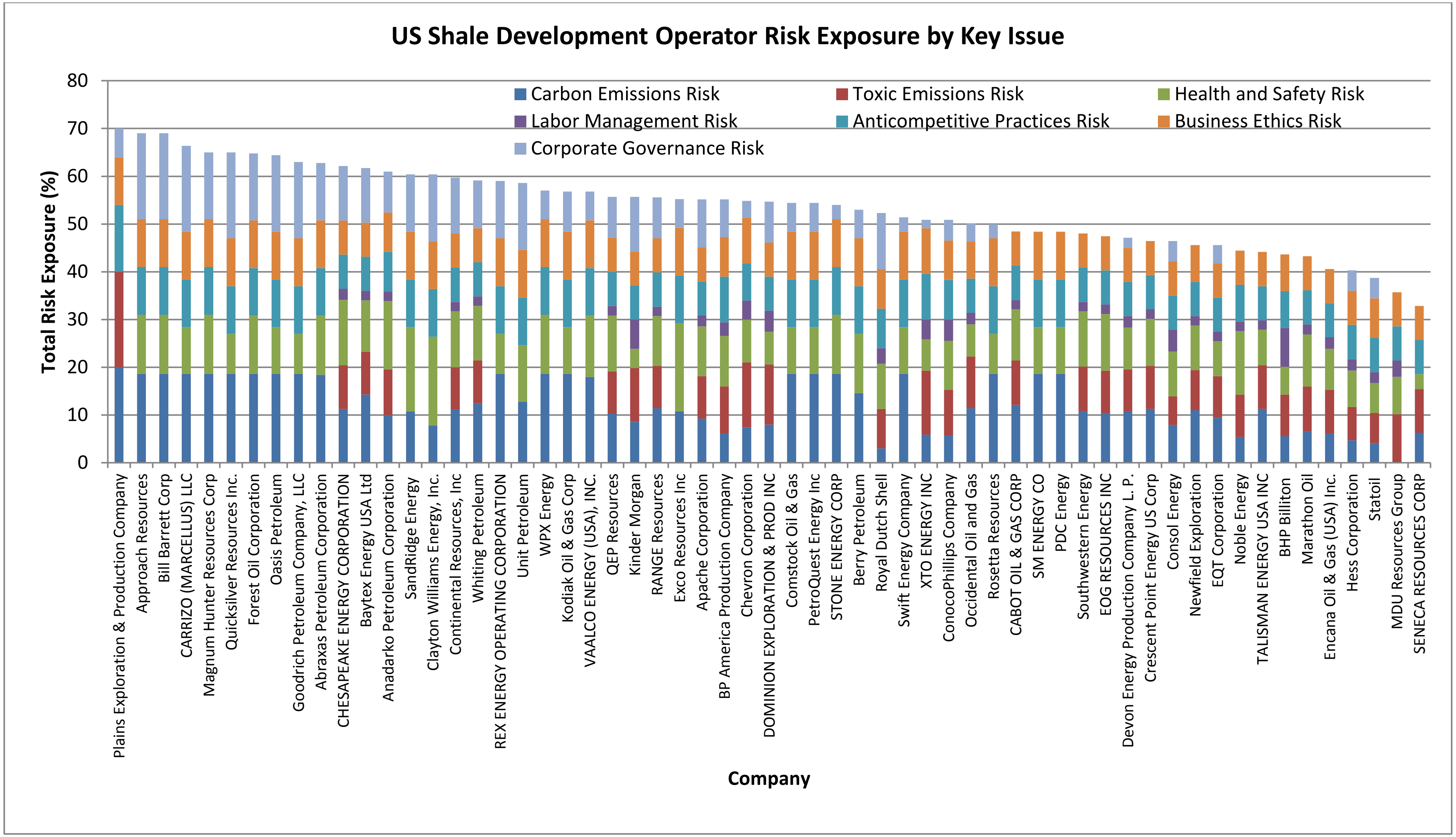

Figure 29: US Shale Oil and Gas Operators Risk Exposure. Dataset: MSCI ESG Research

5.3 Conclusions and Critical Assessment

In this chapter, an analysis was performed on the FracFocus National Chemical Registry database in order to provide an overview of the extent to which hydraulic fracturing is employed in oil and gas operations across the US. Furthermore, estimations on the water usage and wastewater volumes from oil and gas wells within the boundaries of shale basins are provided and further enhanced by robust wastewater figures from the case study on Pennsylvania. Finally, a risk exposure analysis is performed on all shale oil and gas operators which are covered by MSCI ESG Research.

FracFocus started as an NGO led voluntary reporting platform in 2011 and become a mandatory reporting platform for several states across the 2011 – 2013 period. The available dataset is hence a result of mandatory and voluntary reporting patterns across different states which make the FracFocus registry less effective and the analysed dataset less robust. However, the EPA uses the dataset into its own study on hydraulic fracturing risks and mentions it is suitable for offering state wide trends of hydraulic fracturing.

Using the geo-location of wells and Quantum GIS, a visual representation of the distribution of hydraulically fractured wells is illustrated. Based on the well number and water usage estimations, together with wastewater figures from Pennsylvania, wastewater volume estimations by state are performed. Texas is by far the state with the largest wastewater management risks followed closely by Pennsylvania. Arkansas and Michigan consistently underreport hydraulic fracturing volumes, although historically have produced large amounts of shale gas relative to peers and FracFocus is a mandatory disclosure platform for hydraulic fracturing volumes.

Last but not least, a shale operator benchmarking assessment was carried out by using MSCI ESG Research proprietary data, and revealed the fact that the risk profile of shale operators is heavily influenced by the environmental and carbon management practices and systems. Company corporate governance practices, policies related to corruption, code of conduct reinforcements and anti-competitive practices are all of high importance in the oil and gas sector. The lack of appropriate corporate governance reinforcement systems puts companies at risk of operating irresponsibly, negatively impacting the communities they are operating in or losing the chance to establish long term relationships with industry partners.

6 World Shale Gas Outlook

6.1 Introduction

In this chapter, an overview of the global shale gas resource estimates is provided by comparing and contrasting 5 studies[1, 14, 77-80] which provide different estimates for shale gas resources across different regions. McGlade et al.'s methodology[79] is used to distinguish between the different types of resource estimates and to provide a common ground for meaningful comparison. Finally, the chapter presents the challenges countries excluding the US face in developing shale resources.

6.2 Shale Gas Estimates Definitions

According to McGlade et al.[79] there are many inconsistencies in the methodologies which aggregate unconventional gas resources, partly due to the inappropriate use of terminologies, which were formerly used for conventional gas development. There are 5 main terminologies which are currently used to define different estimates of unconventional gas resources: original gas in place (OGIP), ultimately recoverable resources (URR), technically recoverable resources (TRR), economically recoverable resources (ERR) and reserves. The latter term is further split into 3 types of reserves depending on the probability of the estimation being exceeded by the actual value: proved reserves (1P – 90% confidence interval), proved and probable reserves (2P – 50% confidence interval) and probable and possible reserves (3P – 10%)[79, 81].

Original gas in place (OGIP) is quantified as the total volume estimated to be in a given play or basin[79, 82] prior to development. A metric which characterises this estimate is the recovery factor, which indicates the amount of OGIP which can be technically recovered. The recovery factor varies by geography, geology and with technology improvement.

Ultimately recoverable reserves (URR) represent the aggregated sum of gas which is expected to be produced from a region for a given timeframe, excluding technological or economical impediments.

Technically recoverable resources (TRR) is the term which refers to the gas which can be produced using current technology but ignoring any economical constraints. TRR is the term that will be used throughout this chapter when discussing regional and global estimations. Economically recoverable reserves are a subset of TRR and are more sensitive to economical considerations but also more speculative and less robust[79].

6.3 Review of World Shale Gas Assessments

One of the earliest estimates of shale gas resources globally are offered by Rogner (1997) [77], who assumed that gas content of global shales is uniform across the world and similar to the gas content of US shale plays [77, 79]. Rogner used the original gas in place (OGIP) measure to define the estimates, which were subsequently refined by other authors by applying different gas recovery factors (15% and 40%) to translate the OGIP to TRR estimates [1, 14, 79]. By applying the suggested recovery factors, Rogner OGIP estimates lead to TRR estimates of 68 trillion cubic meters (Tcm) (15% recovery factor) or 181.3 Tcm (40% recovery factor) [77, 79]. At the time of this initial assessment, Rogner mentioned that data is sparse and that the numbers should be interpreted as highly speculative[77]. Another study which tackles global shale gas estimations (TRR) is the one of Laherrer (2004)[78], which provides a global estimate of 9.91 Tcm or the equivalent of a 2% recovery factor (RF) applied to Rogner's estimate. McGlade mentiones that the study of Laherrer can be given less weight given the time the study was undertaken[78, 79].

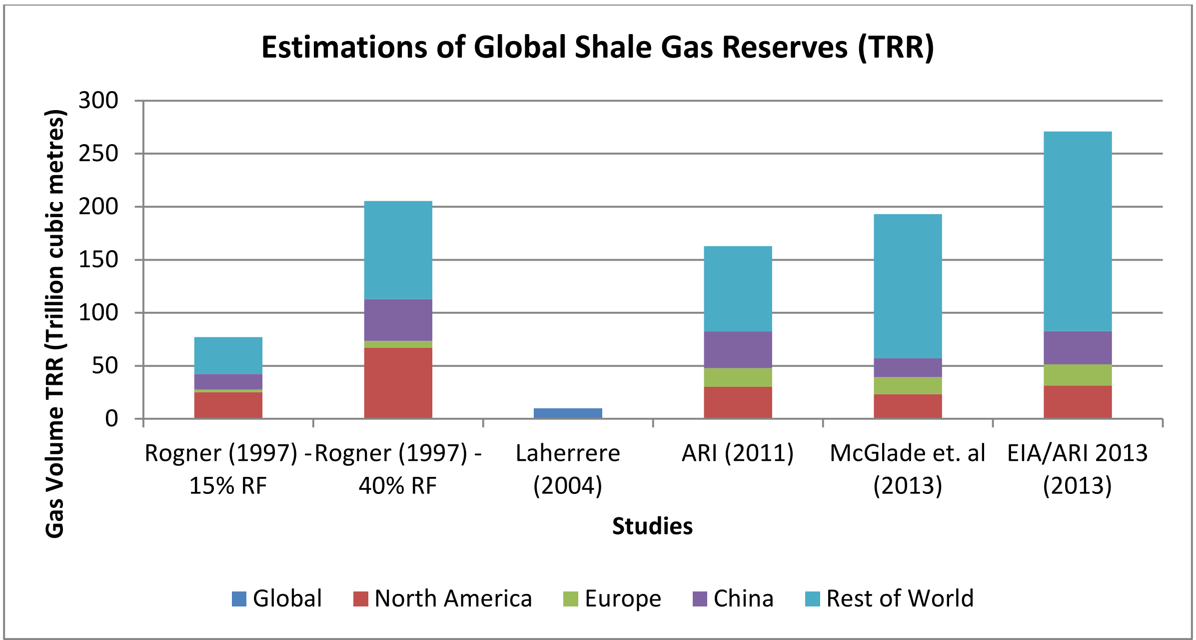

Figure 30: Shale Gas Global Reserve Estimations (Rogner 1997[77], Laherrere 2004[78], ARI 2011[14], McGlade et al. 2013[79] and EIA/ARI 2013[79])

Figure 30 shows the different studies used in the literature review which presented global estimates for shale gas reserves. McGlade et al.[79]performs a statistic interpretation of all previous studies on global resource estimates (including consultancy papers which are not available for public use), and provided the mean estimates for the most robust studies published before October 2012, including ARI (2012). The last study EIA/ARI (2013) was commissioned by the Energy Information Administration (EIA) in collaboration with Advanced Resources International (ARI). This document has become the benchmark for shale gas resource estimations worldwide given the extent of shale basins and plays included from all around the world[1].Appendix A.9 contains the statistics for all studied regions and shale plays. Figure 31 illustrates the Top 10 countries (including US) with the largest shale gas resource estimates (TRR).

Rank	Country	Shale gas (trillion cubic feet)	
1	China	1,115	
2	Argentina	802	
3	Algeria	707	
4	U.S.[1]	665	(1,161)
5	Canada	573	
6	Mexico	545	
7	Australia	437	
8	South Africa	390	
9	Russia	285	
10	Brazil	245	
	World Total	7,299	(7,795)

[1] EIA estimates used for ranking order. ARI estimates in parentheses.

Figure 31: EIA / ARI 2013 Top 10 Countries with Shale Gas Technically Recoverable Reserves

China is topping the chart with 1,115 trillion cubic feet (or 31.57 trillion cubic metres) TRR of shale gas. The top 10 countries are all sweet spots in which shale gas development might flourish given political and community support, as well as the availability of the necessary resources like water.

6.4 Regional Shale Gas Development Outlook and Challenges

In this section, a brief presentation of the state of shale gas development around the globe is given. While several countries are eager to embrace shale gas development, shale gas development through hydraulic fracturing has been banned in 9 regions across the world[83]. France banned shale development which was reinforced by the French Constitutional Court ruling that avoiding hydraulic fracturing is a valid means of protecting the environment[84]. Bulgaria became the first country after France to ban hydraulic fracturing practices, due to environmental protests. In Romania, after initial moratoria on shale gas development, the Romanian government ended the ban hoping that shale development will reduce reliance on gas imported from Russia. This has culminated with numerous protests in December 2013, particularly in the town of Pungesti, Romania, where Chevron has several exploratory wells[85]. Other countries that banned hydraulic fracturing practices include: Germany, the Czech Republic and Luxembourg, together with the Spanish region Cantabria and the Swiss Canton of Fribourg.

One country that embraces shale gas development is **China,** which committed to strong shale gas development targets in its 12th Five Year Plan in 2011[86]. It aims to complete its country shale gas surveying and evaluation by 2015 and develop suitable technology for hydraulic fracturing suitable for China’s geology. According to Bloomberg[87], the Chinese Ministry of Land and Resources declared that shale gas production in China surged from 60 million cubic meters in 2012 to 200 million cubic meters in 2013. According to research from MSCI ESG Research[88], PetroChina and Sinopec, 2 state owned oil and gas companies, are most likely to benefit by shale gas development in China, however, given their track record of multiple environmental and corruption related allegations, their operations are likely to have a big environmental and social impact.

In the **UK**(26 tcf TRR shale gas - Appendix A.9.), 97 Petroleum Exploration and Development licences were awarded for shale gas exploration in the UK. A further licensing round is due in the summer of 2014, where companies like Total, GDF Suez and Centrica are interested to take part in[89]. So far, Cuadrilla, a UK shale gas exploration and production company, was in the spotlight particularly after the seismic events caused by its hydraulic fracturing operations in the Bowland Basin in Lancashire[90]. In Wales, drilling permission was given to Coastal Oil and Gas Ltd., but not for hydraulic fracturing. In Scotland, the Scottish Environment Protection Agency (SEPA) has detailed how the regulatory process regarding shale gas and coal bed methane is handled jointly by SEPA and DECC, however hydraulic fracturing is yet to be employed in Scotland[91]. For environmentally sound shale development practices, the Royal Academy of Engineering recommended that Environmental Risk Assessments (ERA) should involve local communities and should be mandatory for shale operations, considering the entire lifecycle of shale development. This would enhance the public consultation process in environmental decision making which helps make better decisions and avoid community opposition at a later stage[89, 92].

South Africa plans to issue its first shale gas exploration permits in the first quarter of 2014, after having previously banned for a year any hydraulic fracturing operations[93]. The major challenges in South Africa are related to water availability risks and conflict among water intensive industries like mining, agriculture or shale gas development[41]. Shell, among other operators, has applied for exploration permits in South Africa. The companies ESG risk exposure can be observed in Figure 29, where the risk exposure of US operators is illustrated. Shell has a moderate risk exposure, however it’s relatively high corporate governance risk indicates possible improper incentive structures and board oversight which could lead to irresponsible company behaviour in the medium term.

6.5 Conclusions

In this chapter, a literature review on global shale gas estimates was presented. This has led to choosing the best framework to present world shale gas development opportunities.

The most robust studies providing global shale estimations identified are the ones of McGlade et al.[79] and the world shale resource estimate from Advanced Resource International and the US Energy Information Administration[1, 14]. The ARI/EIA 2013 study is the most comprehensive study to date and hence, it was chosen to provide the background statistics for discussion.

China is the country with the highest shale gas reserves (1,115 tcf) and it is looking to effective deveplop its resources over the coming years. On the other hand, several countries like France and Bulgaria banned shale development through hydraulic fracturing over environmental concerns. These decisions were made before any major inquiry of the French or Bulgarian governments into the particularities of hydraulic fracturing risks into their countries were undertaken.

In the UK, both DECC and the EPA, as well as other regulatory bodies, take a precautionary approach to shale wells permitting. Several shale sites across the UK are currently permitted, however no major uptake in production is noticed, given the wide public perception that hydraulic fracturing cannot be developed responsibly[90].

Companies who are likely to benefit from shale gas development across multiple countries are large integrated oil and gas companies, who have the experience of shale development in the United States, who have a global presence and who have strong community relations programs[5].

7 Conclusions

In **Chapter 2**, a comprehensive literature review together with an insight into shale gas research trends and funding were discussed. The literature review focused on 4 key areas: economic impact of shale development, water and wastewater risks and impacts, air and carbon risks and company litigation and reputational risks.

Shale gas had a big impact on US natural gas prices which have fallen to a historical low. The shale gas industry has profound effects on other industries such as the chemical industry, as well as US economic growth. The scale at which the industry is developing emphasises the potential for long term job creation that benefits society. Global gas prices are yet to be affected given the fact that the global gas market is more fragmented.

Most shale gas controversies are related to water usage and wastewater management. Carbon emissions are also important given the threat of climate change. In this respect, shale gas has a big water footprint and according to Cornell University, it should not be considered a transition fuel towards a low carbon economy given its estimated carbon footprint which surpasses coal. Companies are facing high operational risks due to community opposition, litigation and large environmental footprint.

The Pennsylvania case study comprised in **Chapter 3** exposed shale gas industry production, wastewater management and company violations statistics. The number of unconventional well permits has surpassed those awarded for conventional oil and gas development and in addition, shale gas production volumes are 7 times higher than conventional gas production volumes. On the other hand, the cumulative unconventional wastewater volumes in PA have been 6 times larger than wastewater coming from conventional oil and gas activities. On average, the wastewater per gas produced ratio in unconventional wells is lower than conventional ones.

Given the constraints that the PA DEP is facing in terms of staffing numbers, it is challenging to have good inspection coverage of both conventional and unconventional wells. Hence, over 80% of active wells remain uninspected during the year, which can potentially have major impacts on the environment. The number of fines awarded for company wrongdoings are insignificant and do not affect the financial wellbeing of the operators.

To continue with, the risk methodology in **Chapter 4** has effectively highlighted the leaders and laggards in Pennsylvania shale gas development together with insights on the company risk profile. Companies with higher risk exposure in Pennsylvania shale gas development tend to have a poorer wastewater to gas production ratio which leads to higher wastewater management costs Furthermore, small companies who are 100% invested in shale gas operations tend to have less experience into managing risks and face the highest risk exposure, while large integrated oil and gas producers are able to diversify their operations across different counties in Pennsylvania, where historically there have been sweet spots for gas production and suitable wastewater infrastructure.

In **Chapter 5**, an analysis was performed on the FracFocus National Chemical Registry database in order to provide an overview of the extent to which hydraulic fracturing is employed in oil and gas operations across the US. Furthermore, estimations on the water usage and wastewater volumes from oil and gas wells within the boundaries of shale basins were provided and further enhanced by robust wastewater figures from the case study on Pennsylvania. Finally, data from MSCI ESG Research was used to provide a risk exposure assessment of US shale operators. Company environmental management together with corporate governance systems come out as the main differentiators in shale gas risk exposure.

Chapter 6 provides a framework for global shale gas resource estimation which supports the discussion regarding the outlook of shale gas in shale plays outside the US. While hydraulic fracturing has been banned in several countries like France and Bulgaria, China prepares to embrace the shale gas revolution and hopes to replicate the shale gas production success from the US.

To conclude with, the MEng thesis has successfully reached its core aims: to provide a compelling literature review on shale gas development risks and opportunities, to assess both company and shale industry risk exposure (water risks and industry violations) and opportunity (production), to identify leaders and laggards based on specific metrics and scores and finally, to provide a top level discussion on shale gas development in other countries.

8 Statement of Achievement

The overall placement at MSCI ESG Research has been highly rewarding and has allowed me to make a great contribution towards both the thesis research and other company projects. Below, a more detailed account of my achievements and working projects is provided:

- Undertook the thesis work on shale gas development and hydraulic fracturing which involved doing extensive research, database analysis, learning and becoming proficient in Quantum GIS Analysis as well as improving Excel analysis and modelling tools.
- Designed and implemented a risk assessment company methodology.
- Designed and published comprehensive maps
- Participated in a MSCI client call and presented the initial research insights
- Participated in shale gas and energy finance conferences
- Liaised with different industry bodies for datasets: FracTracker Alliance, Ground Water Protection Council, Advanced Resources International.
- Established valuable industry contacts: MSCI ESG Research team, SGH Martineau, Ricardo AEA, Royal HaskoningDHV, JP Morgan Asset Management, Climate Change Capital.
- Assisted with a MSCI wide client engagement project which was presented to the CEO Henry Fernandez.
- Created a dashboard which analyses MSCI webinar and seminar participation statistics
- Co-led the design and implementation of the way Request for Proposals (RFPs) are dealt with in the MSCI ESG Research business unit.

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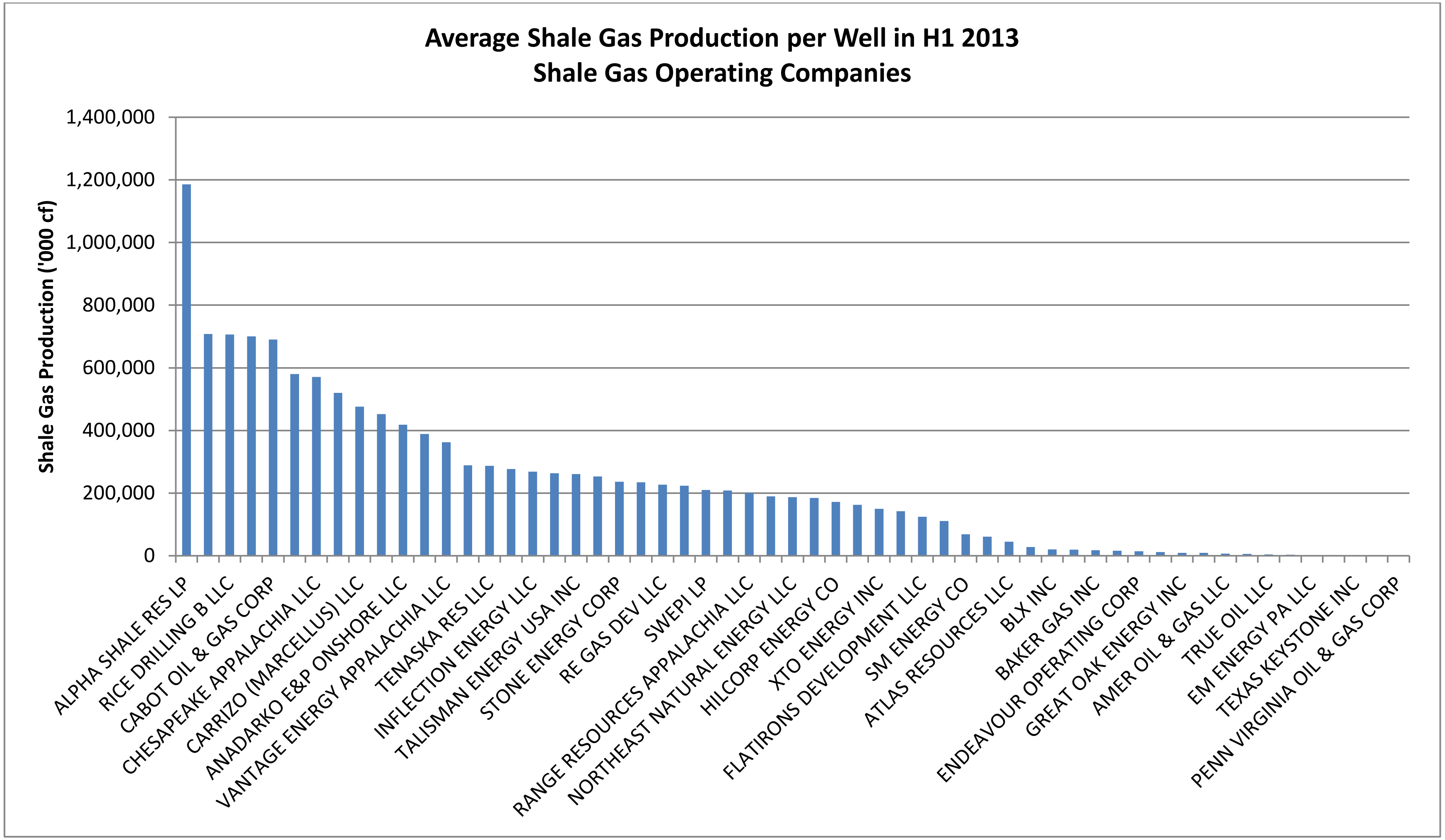
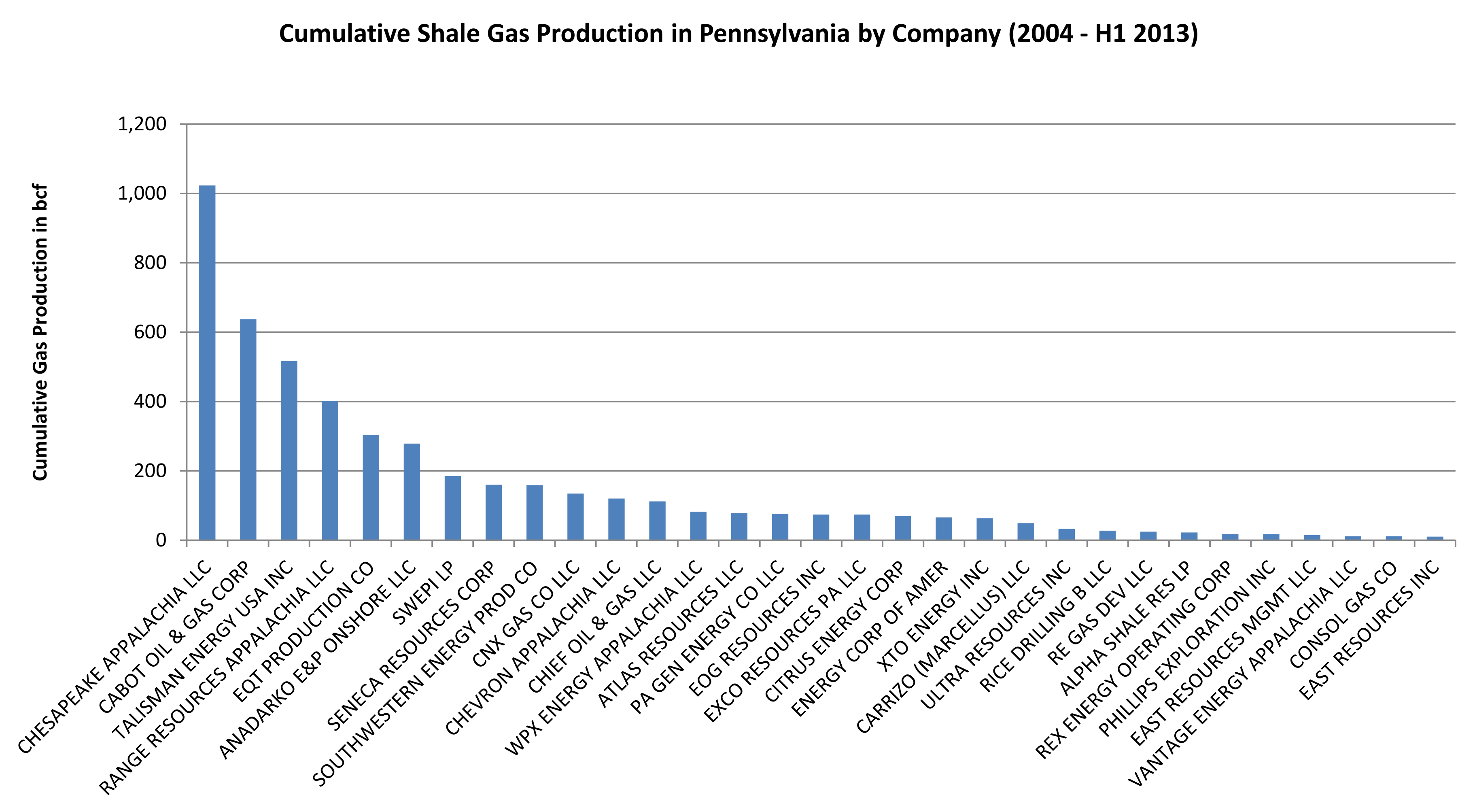
Appendix A.1 - Shale Gas Production per Well H1 2013 (PA)



Appendix A.2 – Cumulative Shale Gas Production in PA by Company



Appendix A.3 – Fracturing Fluid Chemical and Volumetric Composition

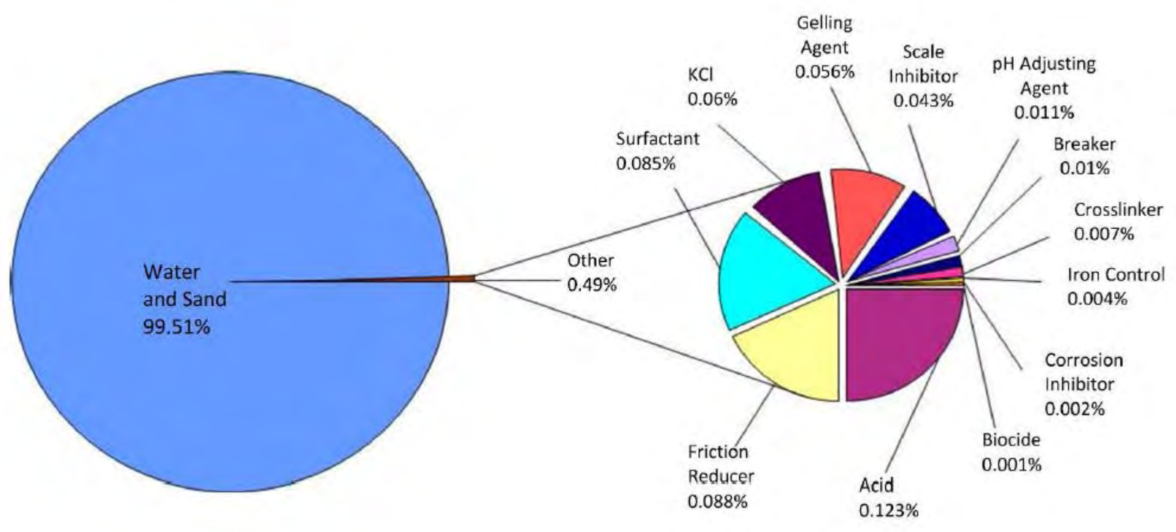
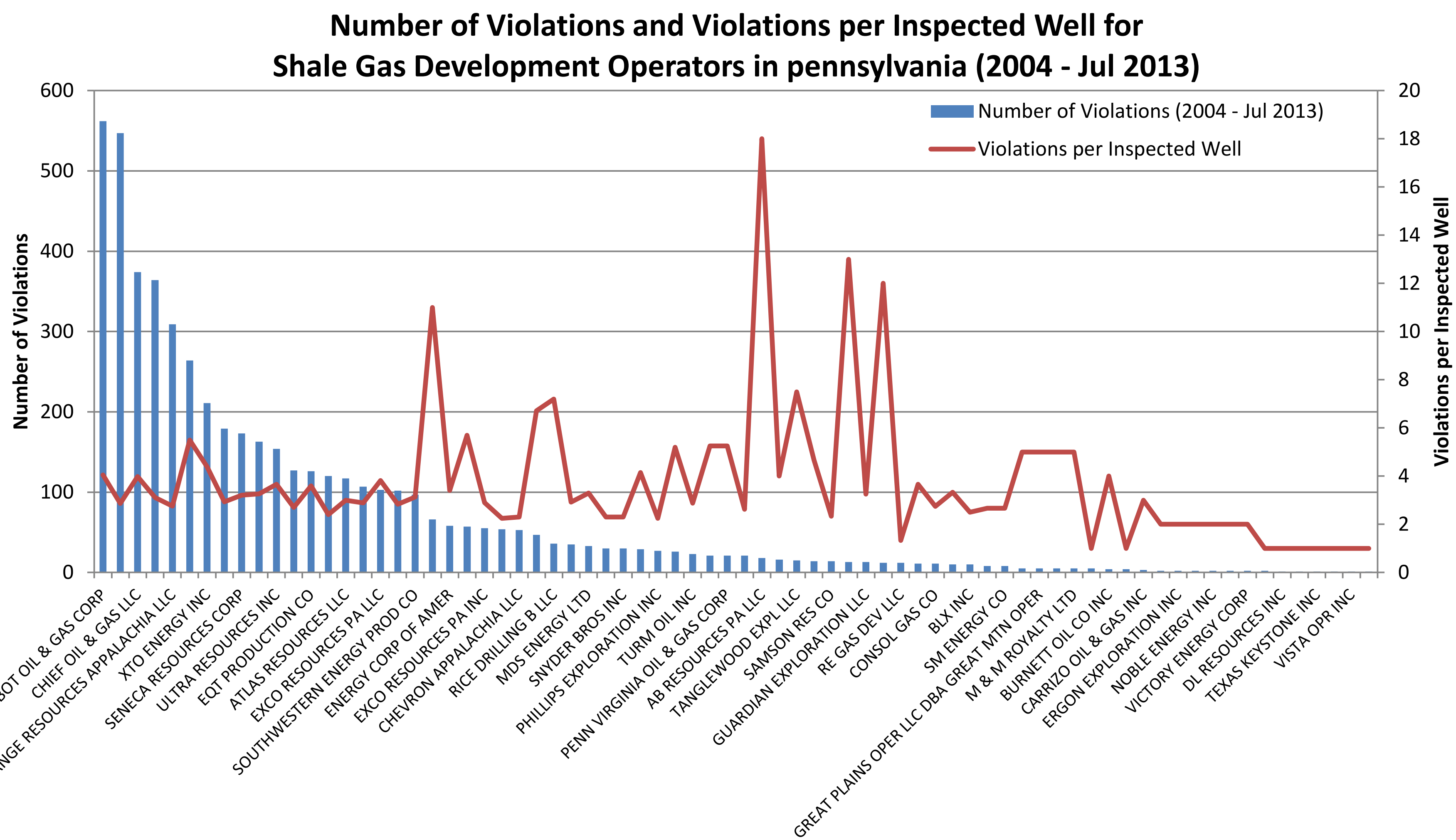
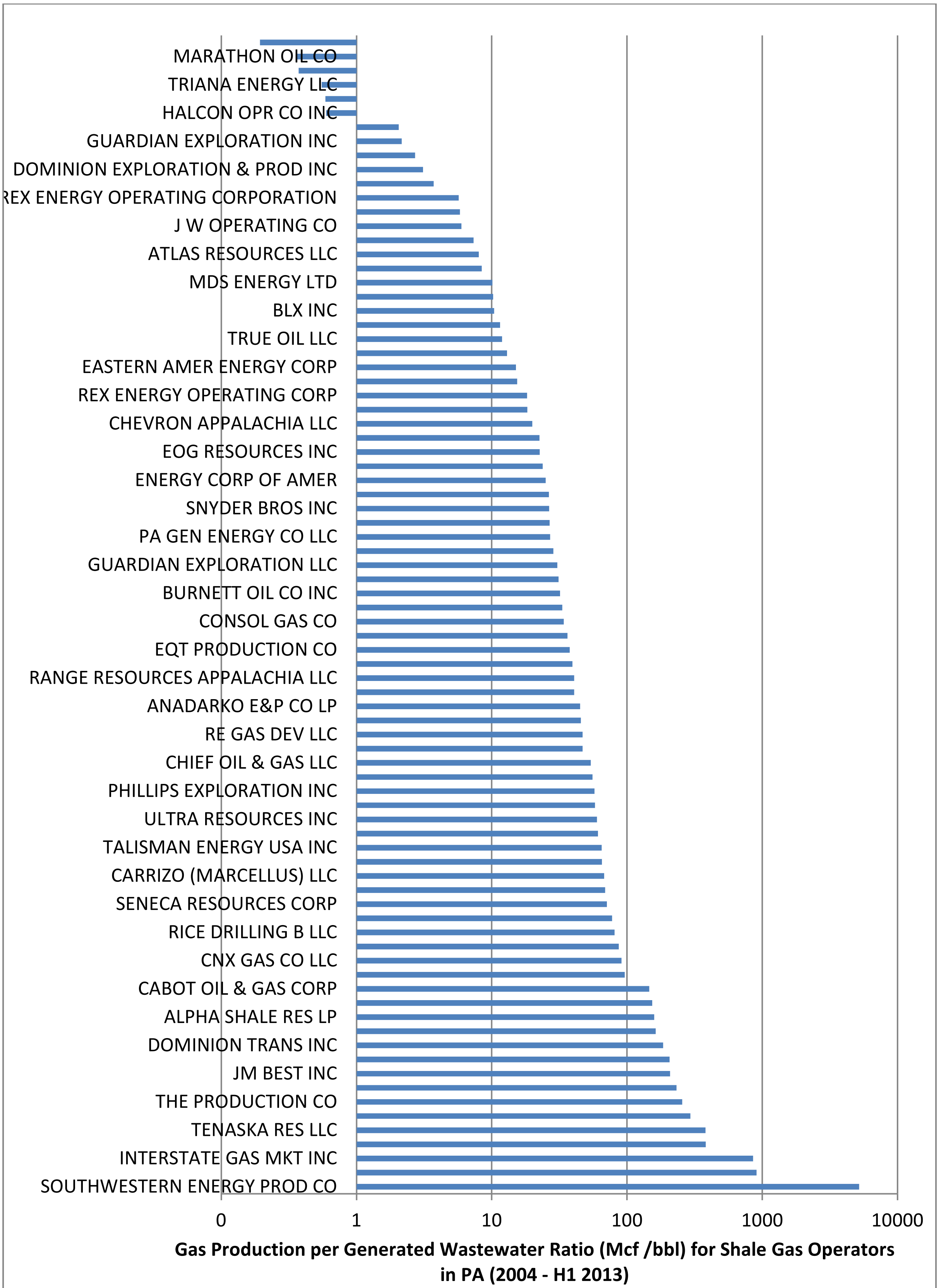


Figure 32: Volumetric Composition of a Fracture Fluid. Source: Ground Water Protection Council and ALL consulting "Modern Shale Gas Development in the United States" A Primer (2009). Based on data from a fracture operation in the Fayetteville Shale 2008.

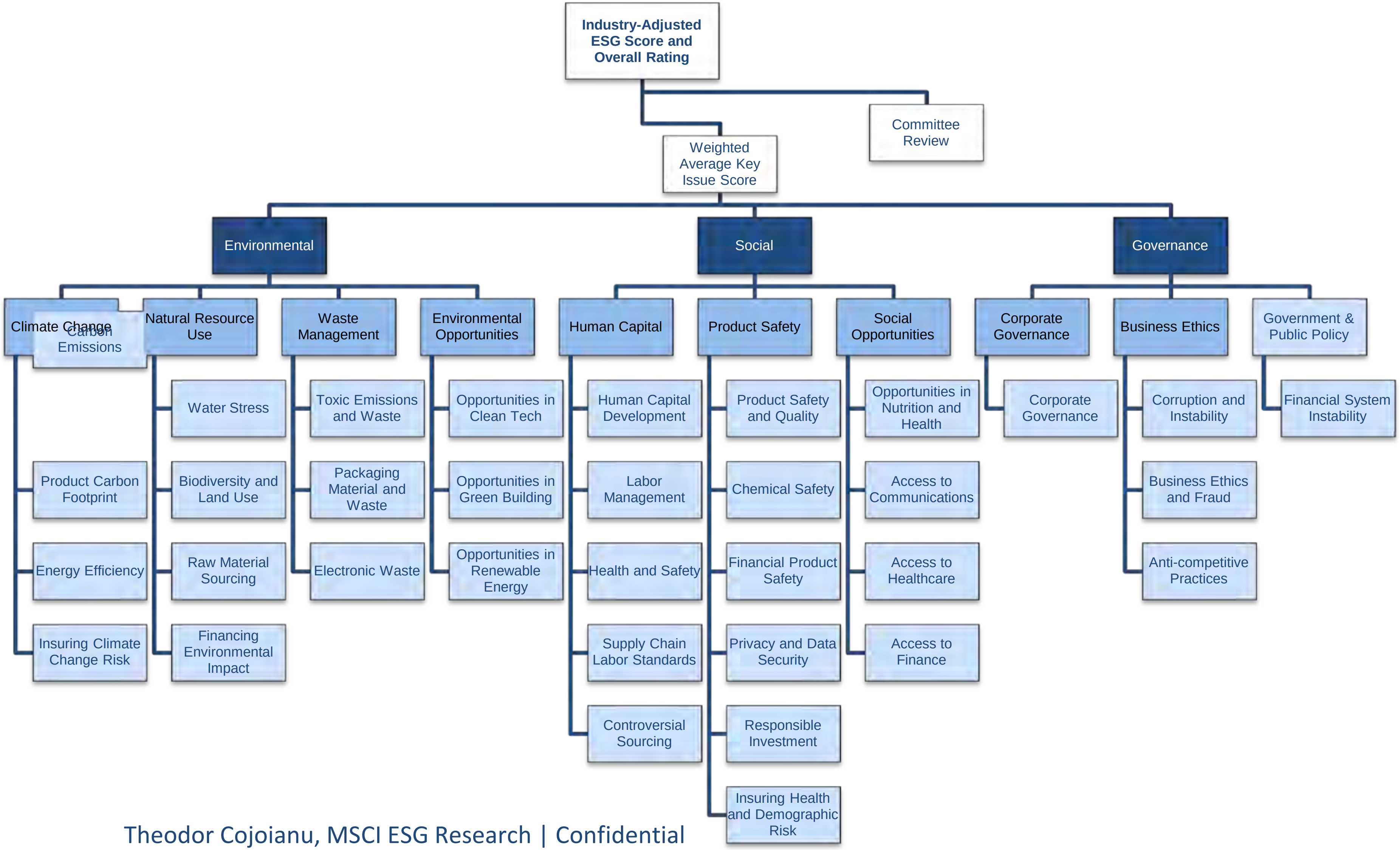
Appendix A.4- Number of Violations per Inspected Well



Appendix A.5 – Gas Production to Wastewater Ratio (PA Shale Operators)



Appendix A.6 MSCI Intangible Value Assessment Hierarchy Model



Appendix A.7 – FracFocus Web Crawler C# Code

```
using System;
using System.IO;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Net;

namespace FracFocus
{
    class Program
    {
        static void Main(string[] args)
        {
            using (var client = new WebClient())
            {

                byte[] csv = client.DownloadData("http://www.fracfocusdata.org/DisclosureSearch/StandardSearch.aspx");

                // TODO: do something with the downloaded csv file:
                Console.WriteLine(Encoding.UTF8.GetString(pdf));
                File.WriteAllBytes("C:\\fracfocus.pdf", pdf);
            }
        }
    }
}
```

Appendix A.8 – Google Trends Crawler C# Code

```
using System;
using System.IO;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Net;

namespace Project1
{
   class Program
   {
      static void Main(string[] args)
      {
         using (var client = new WebClient())
         {
            // TODO: put your real email and password in the request string
            var response =
client.DownloadString("https://www.google.com/accounts/ClientLogin?accountType=GOOGLE&Email=rockpython11@gmail.com&Passwd=pythonftw&ser
vice=trendspro&source=test-test-v1");
            // The Auth line
            var auth = response.Split('\n')[2];
            client.Headers.Add("Authorization", "GoogleLogin " + auth);
            byte[] csv = client.DownloadData("http://www.google.com/insights/search/overviewReport?q=obama&cmpt=q&content=1&export=1");

            // TODO: do something with the downloaded csv file:
            Console.WriteLine(Encoding.UTF8.GetString(csv));
            File.WriteAllBytes("C:\\report5.csv", csv);
         }
      }
   }
}
```

Appendix A.9 – EIA / ARI Assessment of World Shale Formations

Size of Assessed Shale Gas and Shale Oil Resources, at Basin- and Formation-Levels

Continent	Region	Basin	Formation	Risked Gas In-Place (Tcf)	Technically Recoverable (Tcf)	Risked Oil In-Place (Billion bbl)	Technically Recoverable (Billion bbl)
South America	Colombia	Middle Magdalena Valley	La Luna/Tablazo	135	18	79	4.8
		Llanos	Gacheta	18	2	13	0.6
	Colombia/Venezuela	Maracaibo Basin	La Luna/Capacho	970	202	297	14.8
	Argentina	Neuquen	Los Molles	982	275	61	3.7
			Vaca Muerta	1,202	308	270	16.2
		San Jorge Basin	Aguada Bandera	254	51	0	0.0
			Pozo D-129	184	35	17	0.5
		Austral-Magallanes Basin	L. Inoceramus-Magnas Verdes	605	129	131	6.6
		Parana Basin	Ponta Grossa	16	3	0	0.0
	Brazil	Parana Basin	Ponta Grossa	450	80	107	4.3
		Solimoes Basin	Jandiatuba	323	65	7	0.3
		Amazonas Basin	Barreirinha	507	100	19	0.8
	Paraguay	Parana Basin	Ponta Grossa	46	8	14	0.5
	Uruguay		Cordobes	13	2	14	0.6
	Paraguay/Bolivia	Chaco Basin	Los Monos	457	103	75	3.8
	Chile	Austral-Magallanes Basin	Estratos con Favrella	228	48	47	2.3
Eastern Europe	Poland	Baltic Basin/Warsaw Trough	Llandovery	532	105	25	1.2
		Lublin	Llandovery	46	9	0	0.0
		Podlasie	Llandovery	54	10	12	0.6
		Fore Sudetic	Carboniferous	107	21	0	0.0
	Lithuania/Kaliningrad	Baltic Basin	Llandovery	24	2	29	1.4
	Russia	West Siberian Central	Bazhenov Central	1,196	144	965	57.9
		West Siberian North	Bazhenov North	725	141	278	16.7
	Ukraine	Carpathian Foreland Basin	L. Silurian	362	72	0	0.0
		Dniepr-Donets	L. Carboniferous	312	76	23	1.1
	Ukraine/Romania	Moesian Platform	L. Silurian	48	10	2	0.1
	Romania/Bulgaria		Etropole	148	37	8	0.4
Western Europe	UK	N. UK Carboniferous Shale Region	Carboniferous Shale	126	25	0	0.0
		S. UK Jurassic Shale Region	Lias Shale	8	1	17	0.7
	Spain	Cantabrian	Jurassic	42	8	3	0.1
	France	Paris Basin	Lias Shale	24	2	38	1.5
			Permian-Carboniferous	666	127	79	3.2
		Southeast Basin	Lias Shale	37	7	0	0.0
	Germany	Lower Saxony	Posidonia	78	17	11	0.5
			Wealden	2	0	3	0.1
	Netherlands	West Netherlands Basin	Epen	94	15	47	2.4
			Geverik Member	51	10	6	0.3
			Posidonia	7	1	5	0.3
	Sweden	Scandinavia Region	Alum Shale - Sweden	49	10	0	0.0
	Denmark		Alum Shale - Denmark	159	32	0	0.0

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Size of Assessed Shale Gas and Shale Oil Resources, at Basin- and Formation-Levels

Continent	Region	Basin	Formation	Risked Gas In-Place (Tcf)	Technically Recoverable (Tcf)	Risked Oil In-Place (Billion bbl)	Technically Recoverable (Billion bbl)
Africa	Morocco	Tindouf	L. Silurian	75	17	5	0.2
		Tadla	L. Silurian	20	3	0	0.0
	Algeria	Ghadames/Berkine	Frasnian	496	106	78	3.9
			Tannezuft	731	176	9	0.5
		Illizi	Tannezuft	304	56	13	0.5
		Mouydir	Tannezuft	48	10	0	0.0
		Ahnet	Frasnian	50	9	5	0.2
			Tannezuft	256	51	0	0.0
		Timimoun	Frasnian	467	93	0	0.0
			Tannezuft	295	59	0	0.0
		Reggane	Frasnian	94	16	6	0.2
			Tannezuft	542	105	8	0.3
		Tindouf	Tannezuft	135	26	2	0.1
	Tunisia	Ghadames	Tannezuft	45	11	1	0.0
			Frasnian	69	12	28	1.4
	Libya	Ghadames	Tannezuft	240	42	104	5.2
			Frasnian	36	5	26	1.3
		Sirte	Sirte/Rachmat Fms	350	28	406	16.2
			Etel Fm	298	45	51	2.0
		Murzuq	Tannezuft	19	2	27	1.3
	Egypt	Shoushan/Matruh	Khatatba	151	30	17	0.7
		Abu Gharadig	Khatatba	326	65	47	1.9
		Alamein	Khatatba	17	1	14	0.6
		Natrun	Khatatba	42	3	36	1.4
	South Africa	Karoo Basin	Prince Albert	385	96	0	0.0
			Whitehill	845	211	0	0.0
			Collingham	328	82	0	0.0

Appendix A.10 – FracFocus Sample Report

Hydraulic Fracturing Fluid Product Component Information Disclosure

Fracture Date	3/31/2012
State:	PA
County:	Allegheny
API Number:	37-003-22193
Operator Name:	Range Resources
Well Name and Number:	Yute Unit #2-H
Longitude:	-79.806931
Latitude:	40.573081
Long/Lat Projection:	NAD83
Production Type:	Gas
True Vertical Depth (TVD):	7051.96
Total Water Volume (gal)*:	4358736

Hydraulic Fracturing Fluid Composition:

Trade Name	Supplier	Purpose	Ingredients	Chemical Abstract Service Number (CAS #)	Maximum Ingredient Concentration in Additive (% by mass)**	Maximum Ingredient Concentration in HF Fluid (% by mass)**	Comments
37% HCL	FracTech	Cleans perforation	HCL	7647-01-0	37.00%	0.02066%	
CI-100	FracTech	Corrosion Inhibitor	Methanol	67-56-1	95.00%	0.00043%	
CI-100	FracTech	Corrosion Inhibitor	Propargyl Alcohol	107-19-7	5.00%	0.00002%	
MC B-8520	Multichem	Antibacterial Agent	4,4-Dimethyloxazolidine	51200-87-4	78.00%	0.01467%	
MC B-8520	Multichem	Antibacterial Agent	3,4,4-Trimethyloxazolodine	75673-43-7	5.00%	0.00094%	
MC B-8520	Multichem	Antibacterial Agent	2-Amino-2-methyl-1-propanol	124-68-5	1.00%	0.00019%	
MC B-8520	Multichem	Antibacterial Agent	Formaldehyde Amine	56652-26-7	0.50%	0.00009%	
MC B-8650	Multichem	Antibacterial Agent	Glutaraldehyde	111-30-8	50.00%	0.00412%	
MC B-8650	Multichem	Antibacterial Agent	Methanol	67-56-1	0.50%	0.00004%	

* Total Water Volume sources may include fresh water, produced water, and/or recycled water

** Information is based on the maximum potential for concentration and thus the total may be over 100%

Ingredient information for chemicals subject to 29 CFR 1910.1200(i) and Appendix D are obtained from suppliers Material Safety Data Sheets (MSDS)