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Estimating Chance for Success in Shale Gas Development Based on the Case of the United States

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Thesis Summary

In response to rapidly increasing populations in developing countries and increasing industrialization worldwide, the increase in energy demanded is projected to exceed 25% by 2040. The need to reduce reliance on traditional fossil fuels, coal and oil, is generally agreed upon however, renewables are not yet at a state where they can be employed as the world's main energy source. Natural gas, while not a clean energy, is cheaper than traditional fossil fuels, gives off 50% of the emissions, and is widely available. Via hydraulic fracturing, 33 different countries could gain access to a combined 6600 trillion cubic feet (tcf) of shale oil stored in basins beneath them. However, only the United States has done anything with these reserves on a large scale. This paper seeks to determine whether success is possible outside of the United States and, if so, what characteristics would a country need to spur successful development. To do this, three countries that have expressed interest in development of domestic hydraulic fracturing industries, Mexico, China, and Poland, are examined first in terms of their closeness to the United States and second in terms of their success thus far in development of domestic natural gas. Via these examinations, success appears to be possible outside the United States though of the three countries in question, only Poland appears to have real potential.

Abstract

Natural gas, commonly extracted through the hydraulic fracturing of shale basins, has the potential to provide an abundant supply of energy that is more sustainable than other fossil fuels. Due to the complicated and risky nature of the hydraulic fracturing process, only the United States has developed the technology on a large scale. However, in the face of increasing global energy demands and vast supplies worldwide in virtually untapped basins, other countries may want to explore the potential development of this industry. Existing literature on Poland, Mexico, and China are analyzed to assess their similarity to the US in regard to policy, economic, and social qualities, giving an estimate for degree of success. Via weighted comparison to determine expected probability of success, Poland is estimated to perform the best, followed by Mexico and then China. These anticipated results are then compared to data on actual production and emissions levels in the chosen countries, which show that Poland has had the most similar trends. Finally, using method of difference and similarity, the qualities which are truly necessary for successful development of a hydraulic fracturing industry are determined to be economic incentives, private investment, and loose regulation.

1. Introduction

By 2045, population growth and the rapid industrialization of developing nations will drive the global demand for energy to increase by at least 25%, with even higher increases concentrated among Non-Organization for Economic Cooperation and Development (OECD) countries. The need to expand energy capabilities to satisfy rapidly growing demand contrasted with the increasingly accepted multilateral goal of reducing carbon emissions has bred uncertainty as to how that demand will be met.

Ideally, the next quarter century would see a sharp increase in the role of renewables as a percentage of the global energy mix. But while the concept of sustainable and infinite energy is certainly appealing, renewable energy is still more expensive than many developing nations can afford to implement on a large scale. In more developed nations, specifically many of the European OECD countries where the growth rate of energy demand is decelerating, renewables are expected to play a significant role. However, in countries where the growth rate of energy

demand is rapidly accelerating, coal, oil, and natural gas will continue to make up the majority of the energy mix ("World Energy Outlook," 2018).

Compared to other forms of fossil fuels, natural gas provides the most benefits. With over 6600 trillion cubic feet (tcf) of gas in basins across 33 countries, natural gas has to potential to provides a huge energy source that, if extracted in large enough quantities, could reduce price levels. Moreover, when natural gas is burned, it emits only 50% of the carbon dioxide of traditional fossil fuels, making it a more attractive option from an environmental perspective. That being said, natural gas within shales cannot be accessed through traditional drilling methods. Shale gas is accessed via hydraulic fracturing, or as it is more colloquially known, fracking, which is not without risks. In the simplest terms, the process involves drilling deep into the ground and then turning at a 90-degree angle and drilling at least a mile horizontally. Water, sand, and other chemicals are then pumped into the ground, fracturing the rock strata and allowing the low permeability gas to come to the surface **(Appendix Figure 1)**.

Every shale basin is different, even when they are located relatively close together. While the drilling process itself is similar, the depth and difficulty of fracturing the shale varies from basin to basin. Thus, while the technology itself is relatively straightforward, costs associated with fitting the process to different structures can be rather high. Outside of strictly monetary costs, operator errors can cause groundwater contamination and increased pollution in the communities in which the wells are drilled while commonly used practices can have unintended consequences such as increased seismic activity or putting a region under water stress (Sovacool, 2014).

The United States has pioneered fracking technology, starting with small "wildcat" gas firms that began emerging in the 1950s. "Wildcatters" are entrepreneurs who dig exploration

wells in unproved gas fields and, when successful, have been responsible for discoveries such as the East Texas Oil Field. However, it wasn't until 2007 that fracking started to take off on a large scale, due to increased investment in the oil and gas industry as a response to increasing oil prices **(Appendix Figure 2)**. Despite only having about 7% of the world's shale basin reserves, the United States accounts for about two thirds of the world's shale gas production. While the process of hydraulic fracturing itself took a long time to refine, it has been very economically beneficial for the US. Compared to other North American and South American countries, US natural gas bills are on average 50% lower (Sovacool, 2014; Melikoglu, 2014).

The goal of this paper is to answer the following questions: Was successful development of a hydraulic fracturing industry in the United States a result of its unique cocktail of policy, economic, social, and natural conditions? If not, what characteristics would countries interested in development of their own need to potentially mimic US success? To do so, this paper will examine the proposed causes of success in shale gas development in the United States, which can largely be grouped into four categories – policy, economic, natural, and social. Much of the research on the natural characteristics largely include the environmental effects of fracking, which have been fiercely debated. Many suggest that the process is too risky due to its potential to cause groundwater contamination, to increase seismic activity, and to put regions under water stress. However, many of these studies are difficult to verify and such effects are also frequently the result of operator error or negative externalities inherent to the process itself. This makes it difficult to isolate the economic impact when fracking is done correctly or with greater consideration for the externalities it may cause. Therefore, the scope of this paper will only include natural characteristics of the basins themselves and, while certainly not always the case, will operate under the assumption that development of a successful industry will be done in a

manner that limits negative externalities on the environment. Then, three countries – Mexico, Poland, and China – will be assessed on their similarity to the United States in regard to the aforementioned qualities. Via a weighted average of the proposed importance of each of the discussed qualities, estimates for success of the countries will be calculated.

To answer the second research question, the rest of the paper will examine the reality of natural gas production, energy imports and exports, and carbon dioxide emissions in all four countries using time series data from 1990 through 2016. Countries that seem to resemble the trends seen in the United States will then be analyzed using method of difference and countries that do not will be analyzed using method of similarity to draw conclusions about what qualities a country interested in developing a hydraulic fracturing industry would need to be successful.

2. Literature Review

Those who have researched the success of the US fracking industry have proposed criteria that can be lumped into three main categories – government policies, economic conditions, and natural formations of the shales themselves.

2.1 Causes of US Success

2.1.1. Policy and Government

"The world's energy destiny lies with decisions and policies made by governments," said Dr. Fatih Birol, Director of the International Energy Agency in the 2018 World Energy Outlook. History is in a period where the industries that governments choose to support today will vastly affect the energy mix of tomorrow. Therefore, the policy decisions they make are not to be taken lightly and thus have been debated fiercely by scholars. This paper focuses on research on the policy initiatives of the United States government to develop a strong hydraulic fracturing industry.

According to Charles Davis in his paper *Fracking and Environmental Protection*, the fact that the US is a federalist government was crucial for the development of the fracking industry. In a federalist government, federal officials retain a degree of authority to shape environmental regulations, but major decisions are left in the hands of the states. This has been particularly important as social groups have arisen against fracking, with the goal of passing legislation on a national level. However, each time these reforms are pushed on a national level, trade groups such as the Interstate Oil and Gas Compact (IOGC), the American Petroleum Institute (API), and the American Gas Association (AGA) have been able to successfully lobby to keep the major decisions as a right of the states.

Public opinion on fracking varies vastly from state to state. New York banned it altogether, whereas wells in Oklahoma, Texas, and North Dakota produce a combined 7 million barrels of shale oil daily (EIA) **(Appendix Figure 3)**. A heated debate between supporters and opponents of fracking has been going on among academics for decades and a consensus has not yet been reached. Attempting to come to an agreement on a national level with non-experts at the helm of decision making is unlikely. Therefore, the ability of the states to regulate fracking on a local level was absolutely necessary for the US to be able to develop a successful industry.

Davis continues with an analysis of the effect that federalism has had on regulation, which is quite different state to state and narrowly enforced on a national level. Oil and gas lobbyists have proved to be quite effective on both on the state level and nationally. States with large shale reserves have the most to gain economically from loose regulations on the industry. Oil and gas lobbyists appeal to this, promising jobs and economic development in return for loosened regulations. It is not surprising that the majority of their lobbying occurs in states where shale reserves are the largest (and oil industries are already the biggest). Hence states like Texas, Pennsylvania and Oklahoma have among the least restrictive regulations. Environmental regulation on a national level largely overlooks the fracking industry, as found by Barbara Warner and Jen Shapiro in *Fractured, Fragmented, Federalism.* It is not that regulations that would apply to the industry do not exist; but rather that just that they are written in a manner that excludes the industry, due largely in part again to the lobbying strength of the oil and gas industry as well as the fact that the industry has, for all intents and purposes, only taken off in the last decade. With energy being a topic that tends to be heavily polarized along party lines, it is possible policymakers have not yet developed a comprehensive national regulatory framework that still allows the economic benefits while minimizing environmental costs. The Resource

Conservation and Recovery Act, for example, exempts the oil and gas industry altogether, although without that exemption fracking byproducts would most likely be limited. Similarly, the Federal Emergency Planning and Right to Know Act requires companies to report their use of toxic chemicals to the EPA annually, unless they're proprietary. Citing their chemical usage as a trade secret necessary to remain competitive, most fracking companies are able to evade this reporting standard. One of the most notable is the exemption of the fracking industry from the Safe Drinking Water Act through a 2005 provision known as the "Halliburton Loophole" which specifically exempts the fracking industry from the same water contamination standards as other industries. That being said, many states with high numbers of fracking wells have passed their own individual "need to know" acts that require companies engaged in fracking to disclose the chemicals they are using, should health issues arise. However, in 2013 Warner and Shapiro found that the pull of the oil and gas industry in the US has allowed the industry to develop largely without the hindrance of environmental regulation, for better or for worse.

Another notable characteristic of the US government, especially compared to other countries, is their lack of ownership in the oil and gas industry. In many countries, one or two state owned bodies more or less dominate the entire space. However, the US has multiple oil and gas firms, from small wildcat upstream explorers all the way up to gas giants like ExxonMobil and Chevron. Downie and Drahos in their 2017 study *US Institutional Pathways to Clean Coal and Shale Gas*, cite the presence of private industry in the US as necessary to its development. Specifically, they identify the "wildcatter" culture of the US as the industry's defining characteristic. The US has a particularly entrepreneurial and risk tolerant culture in all industries, not just fracking. With that in mind, it's not surprising that the natural gas revolution in the US was led by small independents. After these small independents made advances in the technology,

oil and gas giants began to explore its implementation on a larger scale. Due to their size, they were able to take on more risk than the small independents and were able to drive the fracking industry in the US to the size it is today. Without ignoring the critical role of the small independents in technology development, this paper will assume the majority of investment will come from large oil and gas companies that have the ability to take on more risk due to their size and diversified revenue streams.

These studies are particularly useful for the scope of this paper because they identify policies that are necessary (and if not necessary, certainly helpful) for the development of a successful fracking industry. By pointing to specific actions policy makers may consider taking, such as allowing policy to be handled on a state level or encouraging private enterprise, specific lessons are able to be learned from the United States.

2.1.2 Economic

Energy access and national security are closely related issues. Being energy dependent exposes an economy to disruption and possible external threats as access to oil and gas becomes a bargaining chip that can be withheld (Green, 2010). Many countries, the United States included, have sought to gain energy independence, but many scholars argue that true energy independence is difficult to obtain and impossible to maintain. However, in 2010, David Greene argued in the journal *Energy Policy* that energy independence was not only possible but attainable in the United States through the continued development of the natural gas industry. This is possible, he continues, through redefining the concept of energy independence. Rather than having zero energy imports, a nation can be considered energy independent by decreasing their imports to a level at which they have no effect on economic, military, or foreign policy. Greene postulates that this benchmark would occur at energy imports accounting for about 1% of

GDP. In order to hit this mark, the United States would have to decrease its (2010) level of energy imports by roughly one-third (Greene, 2010).

The incentives for doing so are high. As energy demand grows in the US and worldwide, energy itself becomes more and more valuable. The effects of energy dependence were felt in the 1970's oil crisis. As US oil consumption rose, Americans became more and more reliant on Organization of Petroleum Exporting Countries (OPEC) nations for oil. This left room for OPEC to spike prices by artificially lowering production and placing an embargo on oil exported to the United States, causing prices to skyrocket and shortages to occur nationwide. Faced with growing demand, the US faced a choice: risk another gas shortage determined by the actions of a foreign power or become energy independent. Thus, the economic incentives to develop a fracking industry were quite strong.

Greene's redefinition of energy independence is particularly interesting for this paper. Transitioning from importing the vast majority of a nation's energy to importing none of it is a tall order. However, decreasing it to a level where it no longer allows energy access to be used as a pawn is far more attainable, though admittedly still not without challenges. It also helps to set a measurable yet feasible bar for what constitutes economic success. As of 2019, the United States has actually exceeded this goal and is a net energy exporter (IEA).

2.1.3 Social

In 2010, the movie *Gasland* came out blasting the fracking industry for destroying communities and contaminating water supplies to the point where faucets were running black and the water itself was flammable. This movie took off and almost overnight, everyone had an opinion on fracking. Fracking is a very complex process that is difficult to understand, allowing social opinion to play a very interesting role in its development. Christenson et. al analyzed this

in *The Malleability of Public Support for Fracking.* In their study, they looked at the political affiliation and correlation with support of fracking and found that support was divided along party lines. As American politics grow increasingly polarized, these divides only continue to grow, making people on either side less and less receptive to new information. Their other key finding was that the American public was also largely ignorant about fracking and, therefore, in the absence of political clues, fairly easily molded.

Their study began with a baseline survey of those in favor of or against fracking and found that the support rate was around 30%. However, after hearing both the common arguments for and against, support rose to around the mid 40s. What they found was that this core group of supporters tended to be people who had more knowledge about fracking going into the survey and thus their opinions were difficult to sway either way. However, the remaining 70% largely based their opinion on whether they were presented with solely the economic benefits versus solely the environmental risks (though learning about the environmental risks affected the survey much less than the economic benefits). Most interestingly, they found that support spiked when they used terms such as "shale oil" or "gas development" or even "hydraulic fracturing" rather than fracking, pointing out the a negative connotation the word has developed among the American public.

This study is important in assessing the malleability of the public. Had all of the country been firmly against fracking, an industry likely would not have been able to develop. However, as this study points out, the public, generally speaking, knows very little. Therefore, through careful rhetoric, policy makers in favor of fracking are able to use public opinion to help them garner support, as occurred in the states in which fracking has become an essential part of the economy.

2.1.4 Summary of US Causes of Success

In the mid 2000s, the United States was faced with sky rocketing oil prices. This drove investment in the oil and gas industry, giving it the necessary boost to drive the innovation that allowed "wildcatter" hydraulic fracturing technology to be employed on a large scale. Relatively uninhibited by loose regulation, shale oil boomed in many parts of the country and, while it certainly had (and still has) opponents in other parts of the country, ability to mold public opinion and the fact that states had the right to develop regulations of their own mitigated their impact. All these causes came together to allow the US to go from one of the world's leading energy importers to a net exporter in little over a decade, with expectations of being completely energy independent in the next (EIA).

2.2 Evaluation of Comparison Countries in Terms of Proposed Causes of Success in US

The United States is currently the world's largest producer of natural gas. However, 33 other nations around the world also have sizeable shale basin deposits that could potentially be a source of economic prosperity **(Appendix Figure 4)**. The top ten countries with shale basins with significant potential to release gas are: United States, China, Argentina, Algeria, Canada, Mexico, South Africa, Russia, Brazil, and the European Union. However, many of these nations have either banned the technology, lack the political stability, are already producing mass amounts of petroleum and have less to gain from moving into shale gas, or are well along the road to renewables -- such as in the EU where they make up over 30% of the energy mix -- and thus have been excluded for consideration (Melikoglu, 2014).

When considering the economic benefits of fracking, energy independence, reduced energy costs, and lower greenhouse emissions, three countries stood out from the list of the top ten. Poland, Mexico, and China each stand to gain significantly, and yet in different ways, from

the development of a domestic shale gas industry which makes them an interesting focus for this paper. Poland, who has been exploited by Russia due to their reliance for oil for years, would particularly benefit from energy independence. Energy is currently costing Mexico a small fortune due to the fact that their energy mix is made up of over 50% imported oil. By being able to source energy domestically, they stand to save a significant amount of money. Lastly, pollution has been a huge problem in China for a very long time, as it fuels its growth largely with emission-heavy coal. The government has been trying to address it, and with some success, though as China continues to industrialize, the problem will only continue to grow if they carry on with their heavy reliance on coal. By shifting their focus towards natural gas, they can potentially reduce their carbon footprint while still meeting the energy demands of the country. For this section of the paper, the extent to which Poland, China, and Mexico possess these qualities will be analyzed.

2.2.1 Poland

Poland has a unified government. While state and local governments exist, their purpose is mostly to carry out the policy decisions of the central government. All levels of government and institutions have a fairly uniform narrative. They have not passed regulations limiting fracking. Low levels of regulation have made an excellent breeding ground for private investment in the oil and gas industry. When compared to the United States, from a policy standpoint, Poland is fairly similar. The main difference is Poland's unified government. However, Poland is a much smaller country than the United States. Their land mass is about ⅔ the size of Texas. Therefore, there aren't the same geographical differences between states, like in the United States. This makes the importance of state and local governments smaller than they would be in a larger country. The government has framed energy as a matter of national security

and economic development, promising 60% of royalties generated by fracking to local communities. Because of this, while many other European nations, even those in Eastern Europe, have passed legislation banning or significantly limiting the extent of fracking, Poland has not. Moreover, their close relations to the US will continue to benefit them as they continue to form a fracking industry. The United States' Unconventional Gas Technical Engagement Program is designed to aid Poland in adopting fracking technology by fostering technology transfer (Andreas & Labelle, 2016).

Poland is highly energy dependent on Russia for oil. As of 2012, 96% of Poland's oil was imported from Russia and oil made up over half of the country's energy mix. Poland's heavy reliance on a country as controlling and unpredictable as Russia has opened them up to numerous national security issues because of Russia's ability to withhold oil to pressure Poland into allying with them (or at least acting as Russia would like. Not only does energy dependence put Poland at risk, it puts all of Europe in danger due to the fact that multiple EU nations rely on Russian oil sourced through Poland (Greene, 2010). Just one of several examples occurred in 2014 when, in an effort to discourage the growing relationship between Poland and Russia, Russia cut GAZPROM's oil exports to Poland by almost 25%. They blamed the shortage on "pipeline maintenance" despite the fact that no other Eastern European nation sourcing oil directly from Russia had their supply affected (Rahm, 2011). As Warsaw continues to lobby for stricter sanctions against Russia, they only stand to be further victimized by Russian oil; therefore, energy independence is a strong goal of the country. Within the last six years, Poland decreased their Russian imports of oil 76% in an effort to work towards this goal, though this was largely paired with an equal increase in gas imports from the United States (Reede, 2019). However, Poland has shale reserves that, if extracted, are projected to be able to cover the country's energy

needs for the next 250 years and may provide a more promising option (Greene, 2011). The question remains as to whether or not they will be able to develop the industry successfully.

Resistance to fracking exists in Poland but rather than being strictly against, social groups tend to be more cautious and call for closer monitoring. The media has largely shaped fracking as positive and the government has long framed fracking as an opportunity to tighten national security. To be anti-fracking in Poland is considered by many to be anti-Poland. As seen from the example of the United States, the public is fairly malleable when forming opinions about fracking. Due to the tight unification between Poland's government and institutions, as reflected in the media, social pressures are far less than in the United States. Social resistance is not expected to play a negative role in Poland's efforts to develop a fracking industry (Andreas & Labelle, 2016).

2.2.2 Mexico

According to the constitution of the Estados Unidos Mexicanos, or as more commonly known, Mexico, the country is a union of federal states similar to the United States of America. However, the federal government controls 80% of the country's funds. With the exception of Mexico City, states are only able to raise about 10% of their total spending through taxes. The rest is appropriated by the central government, meaning states lose autonomy over the vast majority of their funds. Returning power to the states is a common promise made by politicians of Mexico's major political parties since the late 1980s and the fall of Mexico's one-party system. However, these promises remain primarily rhetorical as raising more revenue and gaining a higher degree of autonomy on a state level would require rewriting the country's fiscal coordination laws, which is a tall order ("Redrawing the Federal Map", 2003).

Until 2013, state-owned Petroleos Mexicanos (PEMEX) had enjoyed a 75-year legal monopoly on the Mexican oil and gas market. In 2013, however, the Mexican government rolled back energy regulation and with it opened the oil and gas market to private investment for the first time. With these reforms, the Mexican government signaled their strong encouragement of the development of unconventional energy, most notably shale gas. Because of this, private investment exists and is unencumbered by regulation. It should be noted that Mexico's newly elected president, Andrés Manuel López Obrador, who took office in December of 2018, wants to outlaw fracking. However, development of a national fracking industry is supported in other branches of government, and Obrador and his administration's rhetoric have calmed down significantly since his election in August (Alpizar-Castro & Rodríguez-Monroy, 2016).

Before the 2013 energy reforms, 53% of Mexico's energy mix was oil, 40% of which was being imported. Their dependence on oil was higher than even most Middle Eastern countries. As PEMEX's production dropped annually, due mostly in part to poor management and general inefficiency, Mexico's energy imports were quickly increasing. Today, Mexico has somewhat reduced their reliance on oil and increased their use of natural gas, but not because of their own production. Rather, Mexico imports upwards of 65% of their oil and gas from the United States. Energy trade has been a key part of the Trump Administration's and Mexico's NAFTA negotiations due to the fact that the Mexico imports the majority of their energy from the United States (Clemente, 2018). Were Mexico to develop a large-scale fracking industry, the US would lose a major LNG buyer, causing US natural gas prices to drop as supply increases. (Clemente, 2018). Therefore, generally speaking, the United States is unsupportive of Mexican fracking.

A social group named Proyectos de Muerte, literally "projects of death," emerged against unconventional gas development soon after Mexico began allowing private investment in the industry. Originating in Northern Mexico, they resist foreign and private companies coming into local communities under the guise of economic development only to exploit and threaten regional resources. To them, PEMEX wasn't a stagnant economic drain but rather a source of sovereignty and national pride. By breaking their monopoly, the government broke their social contract with the people of Mexico. In this way, they more so oppose the ideological shift in the government, rather than fracking (Ontiveros, Munro, & Zurita, 2018). By focusing on sustainable development of a fracking industry within the local communities, the government may be able to turn the tide on social resistance to fracking. However, without oversight of these private companies, social resistance will only continue to grow.

2.2.3 China

For much of China's history, the country has operated as several regional states, each with different cultures, economic needs, and political opinions. Unlike other countries that ºare constitutionally federalist, policymaking in China is centralized and the role of local governments is technically to carry out these policies while being responsible for economic development within their region. However, due to the size and regional differences in China, implementation of central policies typically proves quite difficult. Moreover, the pseudo economic autonomy of the local governments means that policies can be designed on a local level that directly contradict national policies (Wang & Chang, 1998). If fracking is to be successfully developed in China, the country is so regionally diverse, and implementation of central legislation is so cumbersome that it would need to be designed on a local level (Lu &

Zhao, 2014). Though technically that is unable to occur under a unified government, China's political reality says differently.

China's oil and gas industry is dominated by three state-owned enterprises -- China Natural Petroleum Corporation (CNPC), Sinopec, and China National Offshore Oil Corporation (CNOOC). Both CNPC and Sinopec have shown great interest in expanding natural gas capacities in China, especially in terms of shale gas production, with natural gas production rates increasing 9% per year over the past 5 years (Lu & Zhao, 2015). However, China's energy demand is expected to grow among the fastest in the world, nearly doubling by 2040 ("World Energy Outlook: China", 2017) . Therefore, while China is second only to the US in shale gas extraction, in order to achieve their internal goals, extraction needs to be done on a much larger scale that private investment could help expedite. With trade tensions between the US and China increasing throughout 2018 and tariffs placed by China on US LNG, China cannot expect to receive any support from the US (Lu & Zhao, 2015).

China alone counts for roughly one-third of the world's total carbon dioxide emissions due to their heavy reliance on coal ("World Energy Outlook: China", 2017). However, a goal of the government has been, and continues to be, reducing these emissions. Efforts in the energy sector have been overshadowed by China's focus on their "Made in China" initiative, which focuses on growing the countries advanced manufacturing industry. This is obviously a carbon dioxide intensive process ("World Energy Outlook: China", 2017). Compared to other fossil fuels, usage of natural gas has about one half the emissions (Melikoglu, 2015). Therefore, it has potential to help China offset some of the increased emissions cause in the manufacturing industry.

Whereas in many other countries, there are notable social movements resisting expansion of fracking activity, no notable social resistance is known of in China. This is not to say it does not exist, but rather that it has not been reported on in existing research. Whether it exists and people just have not, or are unable, to report on it or whether it does not exist at all, it does not appear to be hindering industry expansion in any meaningful way.

3. Comparison Based on Existing Research

Of the criteria discussed above and described below, not all bear the same weight. While some are necessary for fracking to achieve any degree of success, others simply serve to amplify a nation's chance of success. Each factor received a rating of A, B, or C with corresponding weights. Due to certain criteria that only affect larger countries, the weights are slightly different. For large countries (population greater than 50 million), the weights are A=1 (if completely necessary), B=0.25 (if important), or C=0.125 (if simply helpful). For small countries (population less than 50 million) the weights are 1, 0.375, and 0.125, respectively. Criteria with an A rating are assigned values of either 0 (the criteria is not met) or 1 (the criteria is met). Criteria with a B or C rating are assigned values between 0 and 1 depending on where the country falls on the scale of that criteria. The criteria discussed and their relative importance is as follows:

1. Economic: Does the country have an economic incentive to gain from increased shale gas production (either energy independence, reduced energy costs, or lower carbon dioxide emissions)? If a country has nothing, or relatively little, to gain from fracking, they should not engage. Rating: A

2. Government Type: Do local governments have the autonomy to develop industry on a state by state basis without central government oversight? This is rated on a scale from 0 (a completely unified government) to 1 (a completely federalist government). However, this is really only an important criterion for large countries where geographic differences make national policy difficult. Therefore, it is not included in the model for small countries. Rating: B
3. Regulation: To what extent does environmental legislation limit the potential of hydraulic fracturing? Strict environmental legislation and oversight may limit incentives for investment in fracking, making adoption more difficult. This is rated on a scale from 0 (regulation has no impact) to 1 (heavy regulation). Rating: B
4. Investment Type: Is the oil and gas industry state owned or privately owned? Private companies looking to increase market share tend to increase the rate of development. This is rated on a scale from 0 (state owned) to 1 (privately owned and heavily fragmented). Rating: B
5. Aid of US: Does the US support the industry's development? Technology transfer and joint ventures with the United States facilitate large scale adoption. This is rated on a scale from 0 (zero US support) to 1 (active US support). Rating: C
6. Social: Do social groups against fracking facilitate policies that are unfavorable to its development? This is rated on a scale from 0 (powerful social resistance) to 1 (no social resistance). Rating: C

These criteria were then used to develop a model by which countries can predict their chance of success based on their similarity to the United States (P = 1). It should be noted that these are not

the exact probabilities of success but rather a means of comparing one countries chance of success to another.

Large Countries

P(Success) = (Economic)(Government Type*0.25+Regulation*0.25+Investment Type*0.25+Aid of US*.125+Social*0.125)

Small Countries

P(Success) = (Economic)(Regulation*0.375+Investment Type*0.375+Aid of US*0.125+Social*0.125)

	United States	**Poland**	**Mexico**	**China**
Economic	1	1	1	1
Government Type	1	N/A	0.5	0.25

Regulation	1	1	1	.75
Investment Type	1	1	1	0.75
Support of the US	1	1	0	0
Social	1	0.5	0	1
TOTAL	1	0.9375	0.625	0.5625

Table 1: Presence of Causes of Success Evaluation

4. Expected Results Based on US Success

Based on the criteria that helped the United States develop a successful fracking industry, Poland is the most similar and therefore has the highest chance of succeeding, followed by Mexico and then China. However, the model used to calculate these chances is not all encompassing. Natural qualities of the shale basins themselves play a role, such as the amount of gas contained within the shale, the depth of the gas containing horizons, the quality of gas, etc. Additionally, some factors, such as the power of social movements, are difficult to know with certainty until after the industry has developed, or at the very least attempted to. For that reason, this model should generally serve as a starting point for other countries considering investing in developing an industry for domestically produced shale gas, to gauge whether or not the investment would be worth it. Due to the high costs of capital and the difficulty of developing the technology, unless a country has at least a 0.5 by this model, investment is not recommended.

For those scoring above a 0.5, shale gas provides an exciting alternative to other fossil fuels due to its ability to lower costs of energy imports, wide availability, and decreased greenhouse gas emissions. Faced with swiftly increasing energy demand, policy makers should consider investment to shape their energy futures.

5. Evaluation of Present Day Production

Due to the fact that a model based solely off existing research cannot be all encompassing, the following section, analyzing the reality of the fracking industries in China, Poland and Mexico, aims to find the holes in existing literature on the development of fracking technology. By pointing out the gaps between what academics believe under the assumption that the United States is the gold standard of the fracking industry and the reality of the industry's development in other countries, this section should serve to highlight areas for potential future research.

5.1 Feasibility of Development based on Geological Characteristics of Shale Plays

One of the greatest difficulties in the development of fracking technology is that, from a geological standpoint, each shale play is different. Therefore, firms cannot make the assumption that technology they have developed will be able to be used for all other deposits. The general technology is transferable, but each basin has unique properties. For that reason, an important criteria firms or countries interested in expanding natural gas extraction activities need to consider are the geological qualities of the shale plays they are interested in developing.

Resources of shale plays are broken into four general categories that aim to measure the amount of oil and gas contained within the shale. They are described below (EIA):

- Remaining Gas-In-Place: Equal to the original (estimated) amount of gas minus cumulative production. Because of the difficulty of accurately estimating the amount of gas within a shale, this is the most uncertain category.
- Technically Recoverable Resources: gas that, with current knowledge, technology, and industry capabilities, can be extracted. As understanding of the geology of a shale increases, technically recoverable resources increases. This is the most commonly used metric for description of resources within a shale.
- Economically Recoverable Resources: equal to the estimated quantity that can be extracted profitably. Since this varies directly with oil and gas prices which tend to be volatile, this is not a preferred measure.
- Proved Resources: quantity a firm knows with a reasonable degree of certainty can be extracted profitably. Increases as knowledge and technology increase and as new wells are drilled. This is the smallest but most accurate quantity.

5.1.1 Poland

Poland has three large shale plays, the Baltic Basin, the Podlasie Basin, and the Lublin Basin (Figure **X).** Of the three, the Baltic basin is thought to be the most easily developed. Its relatively simple structure gives it better prospects for success, compared to the others whose structural complexity and closely spaced faults could limit horizontal drilling potential. It has estimated technically recoverable resources of 105 trillion cubic feet (tcf) of shale gas and 1.2 billion barrels of shale oil. Also, over 200 petroleum wells have already been drilled there increasing industry knowledge about the unique geological characteristics of the basin.

The original wells were dug by small Polish independent firms, most notable Lane Energy, BNK Petroleum, and San Leon Energy. More recently, large multinationals such as

ConocoPhilips, Marathon, and Talisman have been exploring in the area though thus far have not been able to quickly turn a profit and therefore have been focusing their efforts in other areas. To help reinvigorate activity in the Baltic Basin, PNGiG (national oil and gas of Poland) has issued 15 shale gas exploration licenses and plan to invest 0.5 billion USD in technology development with other polish-owned partners. The relative simplicity of the basin combined with the degree of knowledge interested parties already have about the basin makes it a strong prospect for continuing development efforts.

5.1.2 Mexico

Mexico is home to two promising shale plays: the Tampico-Misantla basin, in the north east on the coast of the Gulf of Mexico, and the Agua Nueva, the Mexican counterpart to the Eagle Ford basin, running from Southwest Texas through Northern Mexico. The Tampico-Misantla has been classified by IHS Markit as a "super-basin." To receive this classification, a basin must have multiple reservoirs and source rocks, diverse play types, existing infrastructure, access to markets, and developed supply chains. As far as the contents of the basin itself, a super basin must have had at least 5 billion barrels of oil (BBO) or gas already extracted as well as 5 BBO of technically recoverable barrels remaining. Experts see opportunities for many different types of investors in the Tampico-Misantla given its reserves in existing fields as well as in shale and tight oil reservoirs. However, thus far, activity in the basin has been slow with the last discovery being in 1988. While it has significant potential, it faces challenges due to lack of current investment, regional uncertainty for foreign investors in particular, and aging infrastructure that would need to be addressed before profitable activity can be expected.

The Agua Nueva, like the Tampico-Misantla had also been relatively unexplored up until recently, despite the successful activity on the United States side. However, in late March of

2018, Petroleos Mexicanos (PEMEX) signed a deal forming a Mexican subsidiary of Texas-based Lewis Energy, the third largest producer in the Eagle Ford. Together, they set the goal of extracting 117 million cubic feet (mcf) of natural gas per day by 2021.

5.1.3 China

While information on the actual contents of the shale plays within mainland China are not heavily reported, the Sichuan Basin in Southwest China is the most heavily regarded as the country's most promising play. However, the head of SINOPEC (one of the two state-owned oil and gas companies) recently referenced the geological differences between the US shale reserves and those in the Sichuan Basin, referring to the US's reserves as a plate and those in China as a plate that had been smashed and therefore is far more difficult to work with. What is known about the Sichuan Basin is that the shale formations are located further in the ground than those in the US and that the reserves are more broken up, requiring more wells to be drilled deeper in order to extract the same amount of gas.

5.2 Results of Development so far

While all three countries have begun developments of fracking industries, none have done so to the level of the United States. Therefore, the threshold for success has to be redefined but because no country has yet to come close to US levels of production, it is difficult to know what the most telling measure would be. The following potential measures will be observed from time series data aggregated from the World Bank and the International Energy Agency on energy statistics and general economic indicators for China, Poland, Mexico, and the United States (for a benchmark to see what success would ideally look like): natural gas production rate, carbon dioxide emission rate, energy expenditure as a percent of GDP, and energy imports as a percent of GDP per capita. If a country seems to mimic US trends in two or more of these categories

(because theoretically all should be showing an increase in natural gas production rates), that will be considered success for the scope of this paper.

5.2.1 Natural Gas Production

5.2.1.1 United States

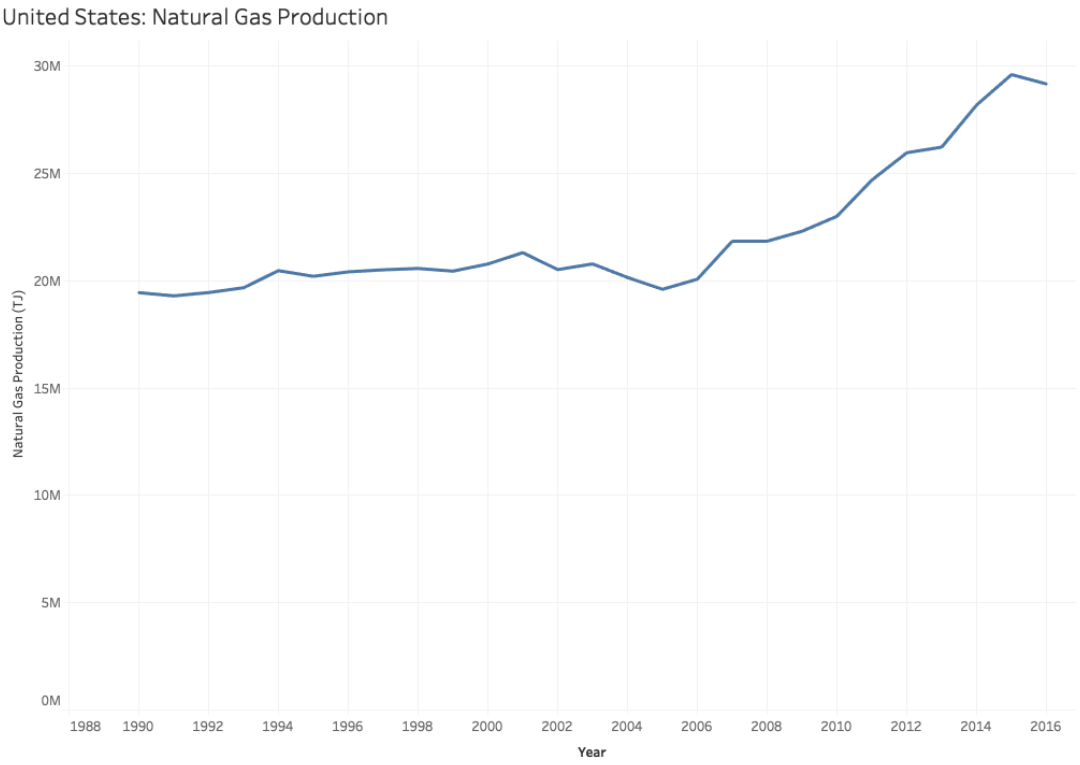

Figure 1: United States Natural Gas Production

Beginning with the US as a general model for a trend in potential success in natural gas production, IEA data indicates that the US has, since 1990 increased their natural gas production by roughly 50%. Average annual growth rate over the entire period is about 500,000 TJ per year however, from 2007 on, the production rates were growing by more like 5 million TJ annually. This is not surprising, given the trends towards heavy production in the United States in the past decade.

5.2.1.2 Mexico

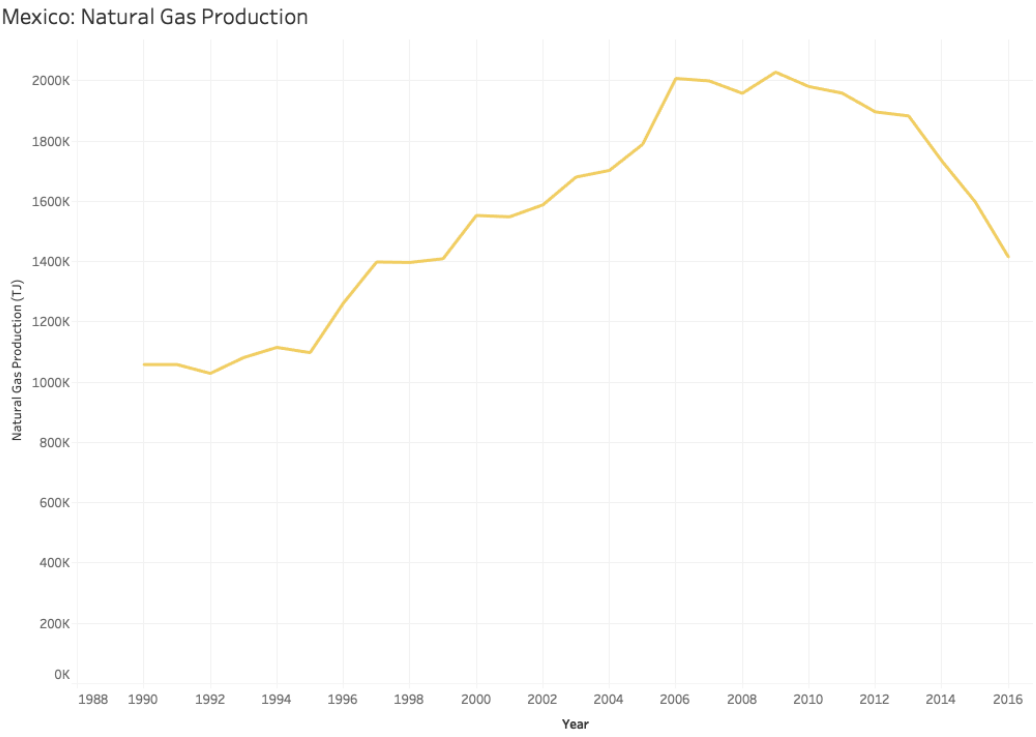

Figure 2: Mexico Natural Gas Production

While volumes of gas produced in Mexico were far lower even at their peaks than in the United States, the domestic natural gas industry has grown by 40% since 1990 and are today around 1.4M Tj annually. This is down, however, from peak production rates (2M Tj) in 2006 – 2008. From 2009 on, natural production rates have decreased. This may be the result of outside factors, such as a change in presidential administration. However, the fact that production rates were higher in recent history shows promise for the country that, should external factors be resolved, production could continue to grow.

5.2.1.3 China

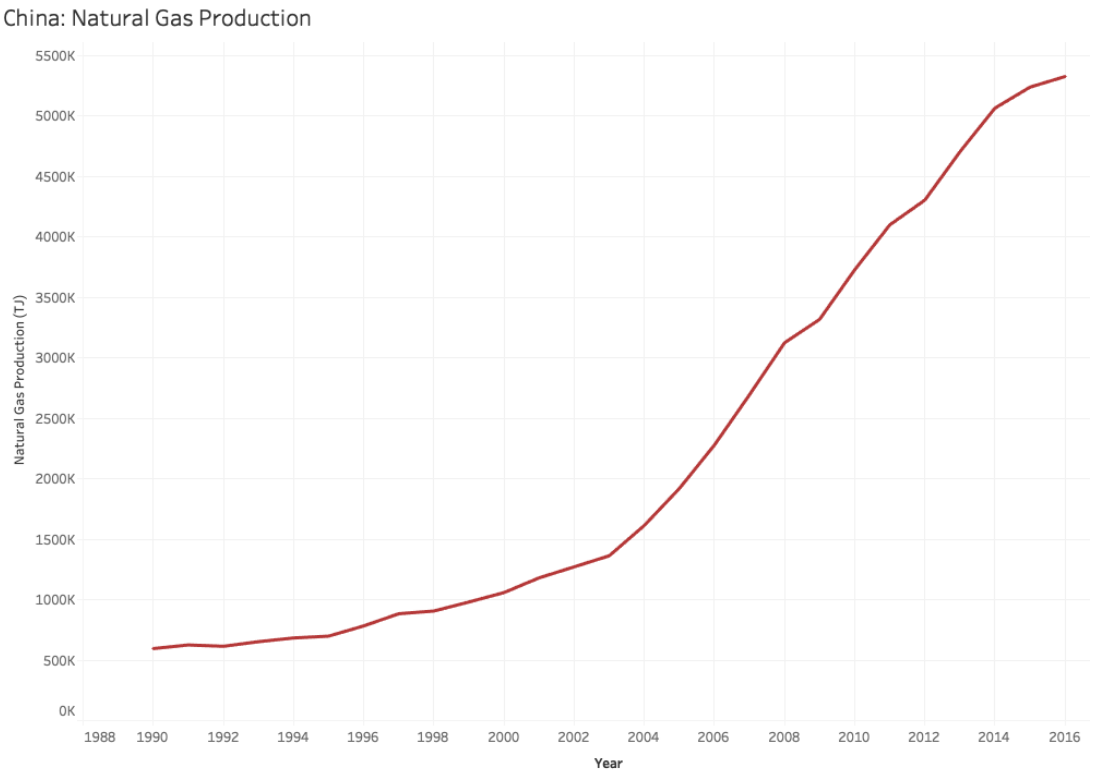

Figure 3: China Natural Gas Production

China has experienced a growth rate of natural gas production faster than even that of the United States since 1990. In 1990, production levels were low – roughly 500,000 Tj per year. Since then, however, production levels in China have increased by 1000% to over 5 million Tj in 2016. While this increase is enormous, it is worth noting that present day production levels are still a fraction of those in the United States, in a country that requires a lot of energy.

5.2.1.4 Poland

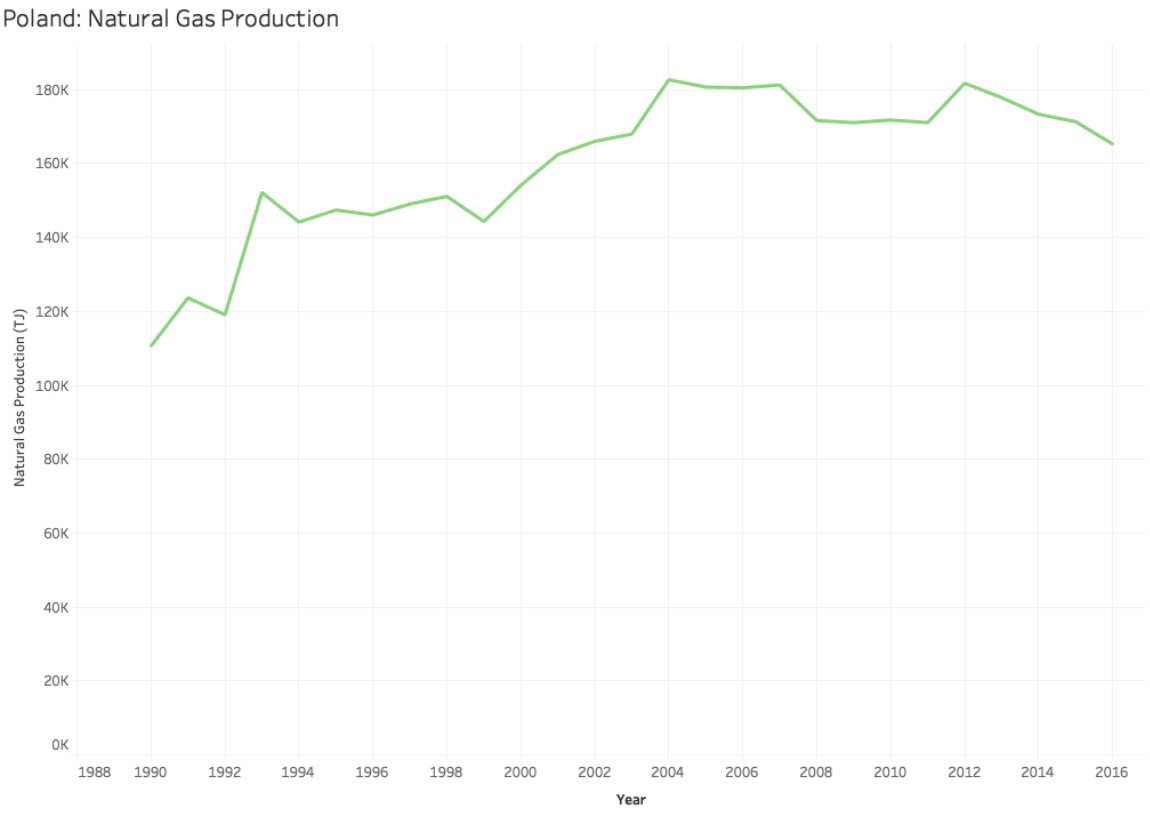

Figure 4: Poland Natural Gas Production

Growth rates of production in Poland have been low but slowly increasing since the 1990s, beginning at just over 100K Tj per year to peaking at over 180K. There has, however, been a slight downturn in production rates in the past three years, with 2016 production rates falling to 160K Tj. Over the entire period, production levels have increased by 45%.

5.2.1.5 Evaluation of Metric

It seems obvious that countries interested in the development of a successful fracking industry would have a continuously increasing production growth rate. However, there are two main flaws with production alone as an indicator of potential success. First, a country may have a desire to increase extraction activity, but actual activity levels may be out of the hands of the government. Other factors, such as external political risks, play a large role in investor behavior

in a region and therefore, a country may be continuing to encourage increased fracking development that may not be reflected in production rates alone. Second, increased rates of natural gas production alone do not demonstrate how efficiently activity is taking place. For example, if production is being encouraged at any cost, failure rates may be high as might emissions resulting from careless methods. Lastly, changes in production levels over a period of time may be misleading. An enormous growth rate, such as is seen in China, may be a sign that the industry is thriving, or it can just demonstrate the inception of an industry. It is difficult to draw meaningful conclusions based on production levels alone. Therefore, while a good base point for identifying countries interested in growing their domestic fracking industries, production rates alone do not make for an effective measure.

5.2.2 Comparing Carbon Dioxide Emissions to Natural Gas Production

5.2.2.1 United States

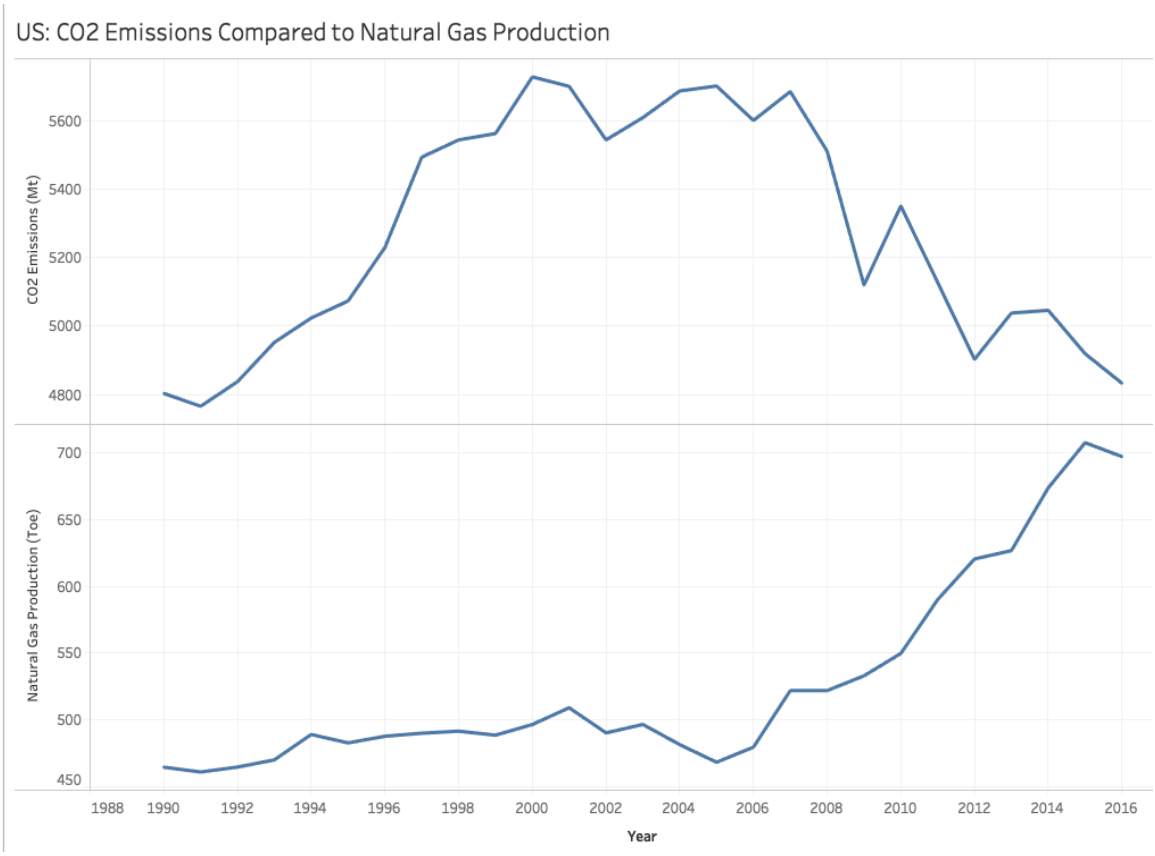

Figure 5: US CO2 Emissions Compared to Natural Gas Production

One of the biggest proposed benefits of developing a domestic natural gas industry is that countries with a high reliance on the combustion of traditional fossil fuels for energy could see a reduction in their carbon dioxide emissions of up to 50%. While not a "clean" energy, the emissions released when using natural gas are substantially lower than that of traditional fossil fuels. Therefore, the trend seen in the US, where CO2 emissions and natural gas production seem to be indirectly correlated is what is expected in a country that has had a relatively large degree of success in fracking. In the United States, since 2007 when the industry has seen the biggest growth, a 4% increase in natural gas production levels has been matched a 1% decrease in emissions. When emissions peaked and gas levels remained low in 2002, the ratio between

emissions and production was 11 Mt to 1 toe of gas. However, at peak production levels and minimum emissions in 2015, the same ratio was 6 to 1.

5.2.2.2 Mexico

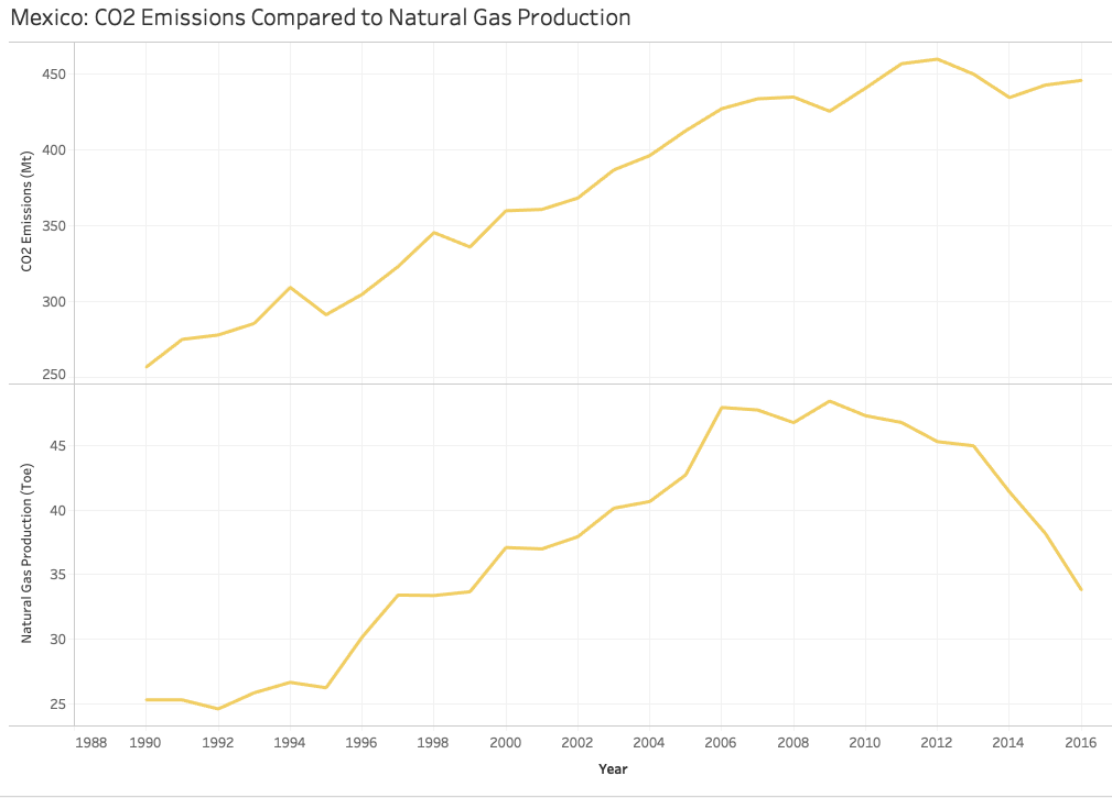

Figure 6: Mexico CO2 Emissions Compared to Natural Gas Production

Up through 2004, CO2 emissions correlated positively with natural gas production, potentially implying that fracking is either not being done successfully or maybe being done on a large enough scale that the benefits are being seen on a more macro environmental level. Over the same time period, emissions rose by 44% and production rose by 46%, indicating a relationship between the two of roughly positive one, not the negative relationship seen in the United States. The lowest production level is coupled with the lowest emissions level, in 1990, where the ratio between the two is 10.6 Mt to 1 Toe of gas. At the peak, of gas production in 2009, the ratio is 10.24. The lack of reduction in this ratio further supports the fact that Mexico is

not seeing a reduction in carbon emissions as a result of increased natural gas production. Since 2010 or so, when natural gas production levels started to decline, the increase in emissions continued. However, it is difficult whether to say that production levels and emissions have been indirectly correlated in the past eight years or if emissions were simply following the same trend as they had been for the past 30 years, behaving independently of natural gas production levels.

5.2.2.3 China

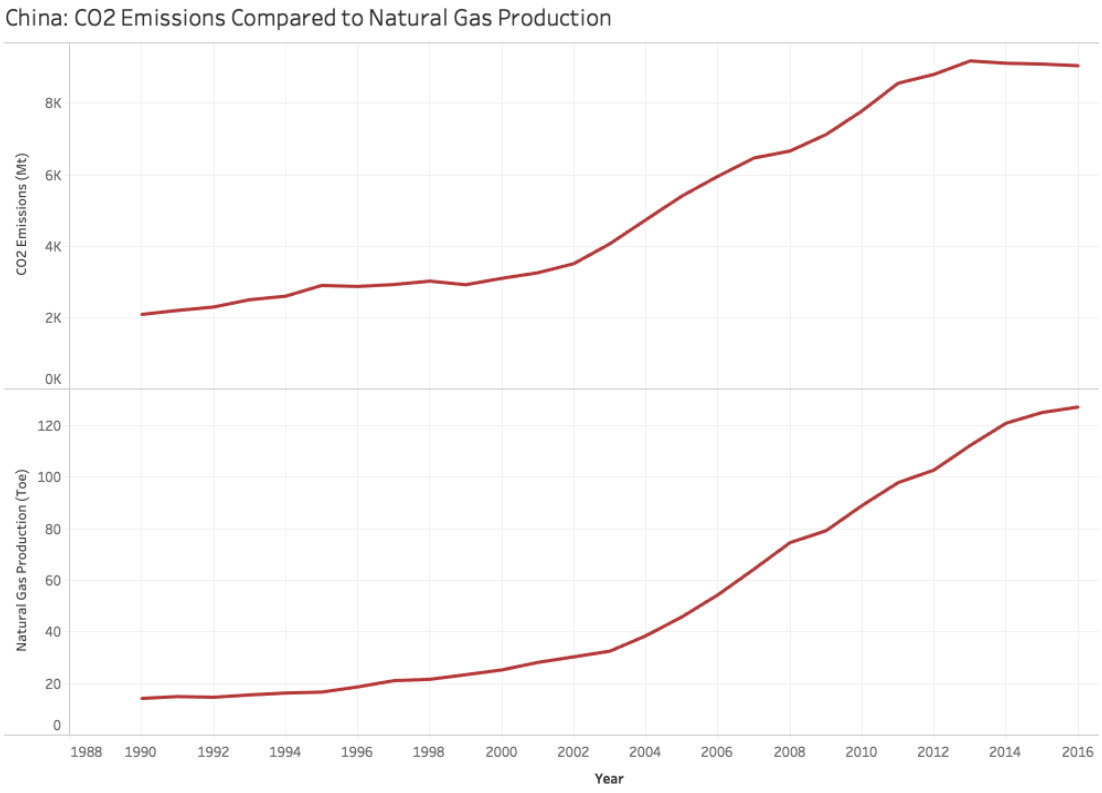

Figure 6: China CO2 Emissions Compared to Natural Gas Production

In China, natural gas production and CO2 emissions seem have a near perfect correlation. The total growth of each are 81% and 77% respectively, indicating they have been growing very similarly. Unlike other countries where volatility from year to year tends to be different even if overall trend seems to be similar, China seems to experience the same smooth growth in both emissions and production, with very little volatility at all. This could be a potential indicator that while natural gas production is increasing in China, it is not being done in an environmentally responsible manner. It is also possible that the government happened to start encouraging fracking development with more rigor around the same time they were pushing extreme economic growth and industrialization in all parts of the country. With this strong push for

growth in the early 2000s, a regard for emissions was largely overlooked and therefore it is possible that the correlation is just an indicator of external factors in the Chinese economy.

5.2.2.4 Poland

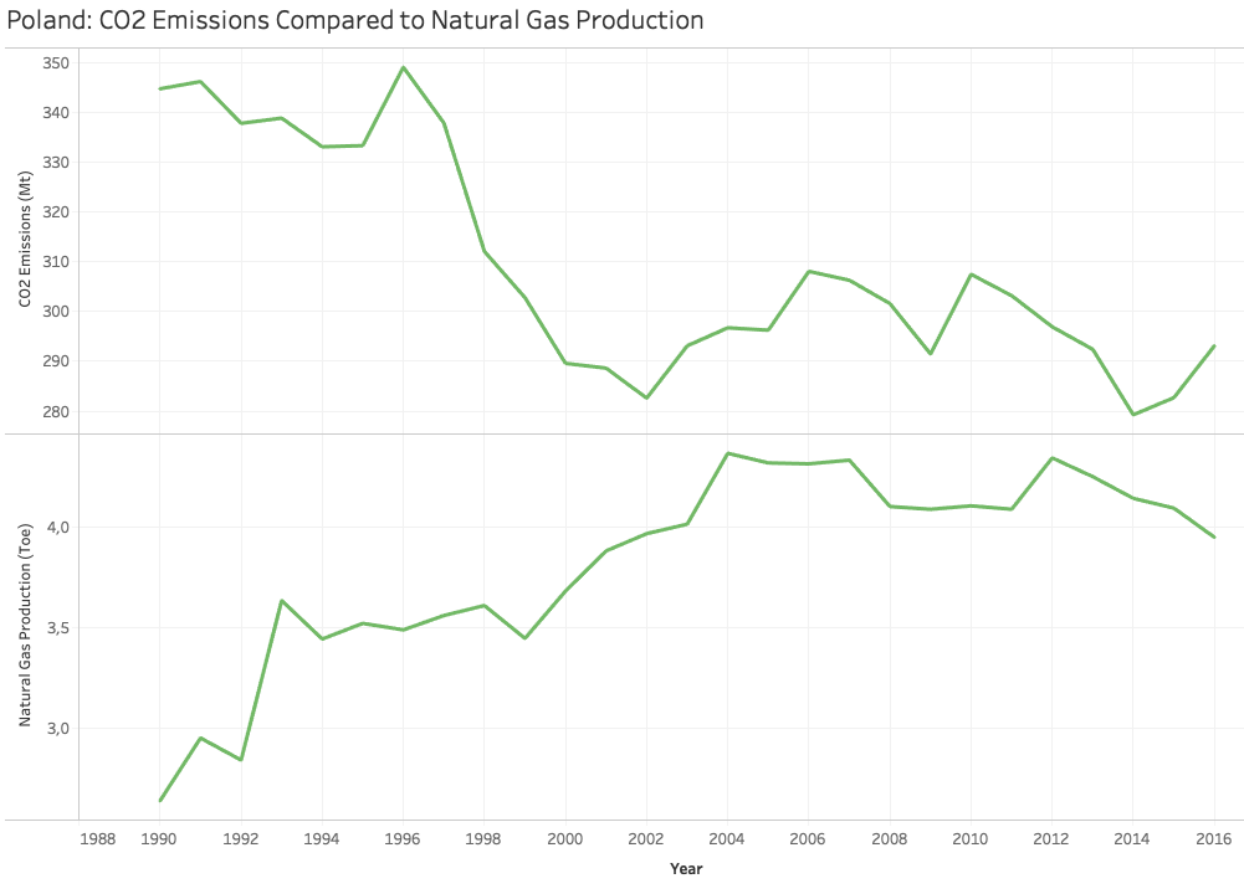

Figure 7: Poland CO2 Emissions Compared to Natural Gas Production

Poland appears to follow the US trend for expected success most closely. From 1990 to 2016, emissions have dropped by 22% while production has increased by 48%. This indicates that, generally speaking, for every 2% increase in production, there is a 1% decrease in emissions. In this time frame the ratio at the peak of emissions was 145 mt to 1 toe whereas at the peak of production (and minimum of emissions), the ratio was 72.5 to 1. Like in the United States, the ratio between the two is decreasing. Even in the past couple years, where there has been a slight decrease in production rates, there has been a slight upturn in emissions, further

highlighting the indirect correlation between the two. Based on this metric, Poland shows the strongest signs of potential success.

6.2.2.5 Evaluation of Metric

While comparing CO2 emissions to natural gas production rates seems like a good indicator for success, it is a hard indicator to show failure. This is due to the fact that there could be completely independent events occurring within a country that are affecting emission rates or could just indicate that while fracking is occurring, it is not making up a large enough segment of the national energy mix to actually reduce emissions. Also, while it is relatively easy to observe correlation from data, it is quite difficult to prove causation. There is still the possibility that there is an omitted variable that this metric would not take into consideration.

5.2.3 Energy Mix

In order to verify if changes in CO2 emissions are tied to natural gas production levels, it is useful to look at a country's energy mix. In theory, if a country is developing fracking technology successfully, it would be reflected by natural gas taking up an increasing portion while portions of traditional fossil fuels start to decrease (or at least stay the same). The IEA aggregates data on national energy mixes annually, the results of which will be shown below:

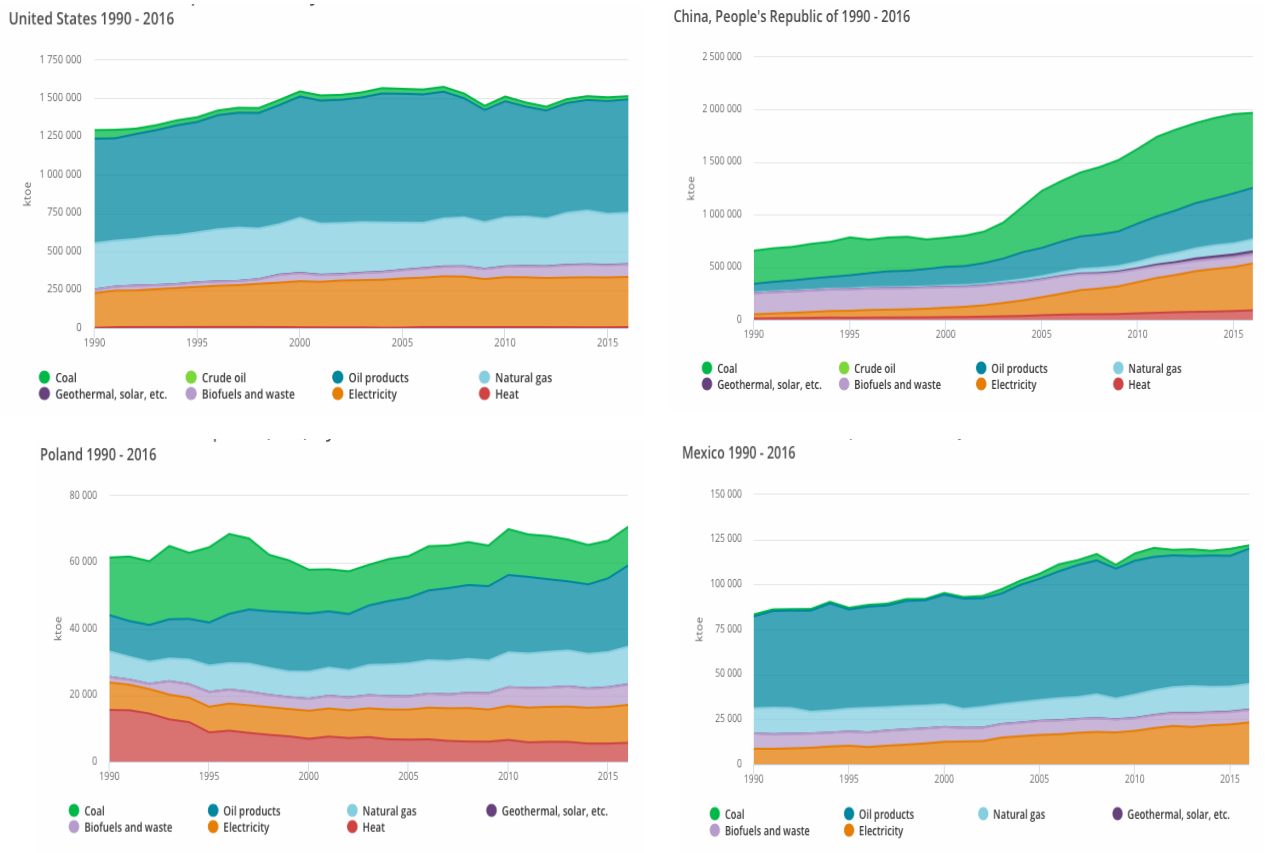

Figure 8: 1990-2016 Energy Mix Trends

The energy mixes of these countries shed some light on the relationship between CO2 emissions and natural gas production. In only Poland and the United States does natural gas appear to be an increasing or stable portion of the energy mix while traditional fossil fuels (coal and oil products in these charts) stay relatively constant. Mexico and China both have slightly increasing portions of gas in their energy mix, but traditional fossil fuels are still playing an increasing role as well, hence why although natural gas production is growing, emissions are still increasing.

5.2.4 Energy Imports as a Percent of GDP

The general threshold for success in development in a domestic fracking industry energy imports equaling 5% or less of GDP. However, this is a difficult measure to actually calculate (?)

observe because many countries do not publish their energy expenditures. While data is available on net energy balance, this is units of oil or gas not in dollars. Since oil and gas prices vary so frequently and are dependent on so many other factors, this does not make for a good indicator of success.

5.2.5 Key Takeaways from Data Analysis

After looking at several different metrics to attempt to interpret level of success in fracking, Poland seems to be the only one who has had any success thus far. Their levels of natural gas production are generally increasing and while they are doing so, emissions are, for the most part, decreasing. The reduction in emissions being a result of increasing the gas supply by successful fracking operations is corroborated by Poland's energy mix, in which natural gas is accounting for an increasing portion while traditional fuels are either decreasing or remaining constant. This mimics the trends that would be expected based on the proposed benefits of fracking but also the trends seen in the United States, which serves as our model for success.

Of the other two countries, Mexico seems to show greater potential than China. While CO2 emissions have not been decreasing while natural gas production in Mexico has increased, there appears to be very little correlation between the two in general. Therefore, it is difficult to conclude that Mexico cannot have success in fracking, just that any success they might have had so far is overshadowed by their continued heavy reliance on traditional fossil fuels.

While natural gas production rates are growing in China, China is demanding energy at such a rate that make their prospects for success slim. At the rate the Chinese economy is growing, the need for energy is high, which does not leave them the room to experiment and develop a fracking technology in the slow careful way that is necessary to do it successfully.

6. Method of Difference

Knowing that Poland has had the most success in developing a domestic fracking industry, method of difference can be used to isolate the factors that are not necessary for success. This method lines up two countries with similar outcomes and looks for differences among several test variables. The test variables that will be used are taken from existing research, as further defined and interpreted in Section 3.

	Power of States?	Economic Incentives?	Private Investment?	Low regulation?	Entrepreneurs?	Social Barriers?	Outcome
United States	Yes	yes	yes	yes	yes	no	success
Poland	No	yes	yes*	yes	yes	yes	success

Table 2: Method of Difference Results

6.1 Method of Difference Results

The results from method of difference largely match what was estimated based on existing research. As predicted, success in the fracking industry for the extraction of gas was possible despite lack of state power and with or without social barriers. One interesting note was regarding private investment. While Poland's oil and gas industry is mostly dominated by private investment, fracking in particular is heavily encouraged by the government and therefore research and development is subsidized and joint ventures with the government and private industry are pursued. For the sake of this comparison, it was coded as having private investment, since the majority of exploration thus far has been done by large private oil and gas firms.

However, it is worth noting that before the government stepped in with subsidies, many of these firms had been prepared to quit when they had not been immediately successful.

7. Method of Similarity

Since Mexico and China have not shown signs of successful development of a domestic fracking industry, via method of similarity, conditions which are not sufficient for success can be isolated- In the results chart, they would appear as commonalities between the United States and the other country. This method lines up two countries with varying outcomes and looks for ways which they are similar. The logic is that if any of the conditions upon which the two countries are similar was a sufficient quality for success, the country would have succeeded. Since that is not the case, the conclusion can be drawn that said quality (or qualities) are not sufficient.

	Power of States?	Economic Incentives?	Private Investment?	Low regulation?	Entrepreneurs?	Social Barriers?	Outcome
United States	Yes	yes	yes	yes	yes	no	success
Mexico	No	yes	yes	yes	no	yes	failure

Table 3: Method of Similarity with Mexico Results

	Power of States?	Economic Incentives?	Private Investment?	Low regulation?	Entrepreneurs?	Social Barriers?	Outcome
United States	Yes	yes	yes	yes	yes	no	success
China	No	yes	no	yes	no	no	failure

Table 4: Method of Similarity with China Results

7.1 Method of Similarity Results

Method of similarity shows similar results in both Mexico in China, with the only exception being the presence of private investment in Mexico. The conclusions can be drawn that economic incentives, low regulation, and private investment are not sufficient. However, via method of difference we drew the conclusion that those three were all necessary. Therefore, via both methods we can conclude that economic incentives, private investment, and low regulation are all necessary but no combination of the three is sufficient.

8. Conclusion

With energy demand increasing every day and the past year being the first-time percent of the world population with sufficient energy access decreased, many countries are struggling to either import or produce the amount of energy necessary to keep their economy afloat. One potential option that has worked in the United States is hydraulic fracturing for natural gas. In 10 years, fracking turned the United States from being one of the world's largest energy importers to a net exporter. Natural gas as an alternative to traditional fossil fuels gives off less emissions, is widely available, and, because of the vast availability, has potential to decrease energy costs for both the average consumer and for the country as a whole. However, despite vast reserves, the technology for extraction has proved to be difficult to develop.

Of the top ten countries with untapped shale gas reserves, China, Poland, and Mexico held the most potential due to external economic factors that would allow them to reap the highest benefits from successful development. However, many scholars proposed that successful development could only occur in the United States, due to its unique combination of entrepreneurial spirit, private investment, loose regulation, and malleable population. While none of these three countries had the exact same cocktail of conditions as the United States, by coding

the degree to which each of them had these characteristics (between 0 and 1), we were able to estimate that Poland would be the most successful, followed by Mexico, and then China. However, if scholars were correct, it would not matter that Poland was the "most similar." Unless it was, for all intents and purposes identical, even Poland would not have a true chance at success.

Time series data on natural gas production, emissions, total energy mix, and net energy imports and exports was analyzed to reveal if any of the countries had had similar trends to that seen in the United States. Poland alone had. Over the period from 1999 to 2016, emissions decreased by 22%. Over that same period, production had increased by 48%. This mirrored the trend in the US of emissions decreasing (albeit at a slower rate than the change in production) while production levels increased. Finally, using method of similarity and difference, the characteristics that were necessary, necessary but not sufficient, and unnecessary were found. Power of states and malleability of the public were found to be unnecessary. Economic incentive for development, private investment, and loose environmental regulations were found to be necessary but not sufficient. None were found to be necessary and sufficient though perhaps if we looked at more countries, these characteristics would be uncovered.

Among the most interesting of these conclusions is that private investment is necessary. For other countries interested in developing domestic fracking industries, this finding holds the most weight. In China, where the government wanted to frack successfully and tried to do it all themselves, they failed. Therefore, the difficulty for governments is navigating encouraging private investment while not playing too heavy a role. Poland seems to be doing this well, where the government is involved in some joint ventures with private companies and also subsidizes

research and development. For policymakers in other countries that may be considering their own investment, the biggest lessons can be learned here.

In further research, it would be valuable to examine other countries amongst those with the largest reserves in terms of their own similarity to see if success has been found anywhere else. Because no conditions were found to be necessary and sufficient, it would be useful to research what conditions, in the presence of the other necessary conditions, can help guarantee success.

Appendix

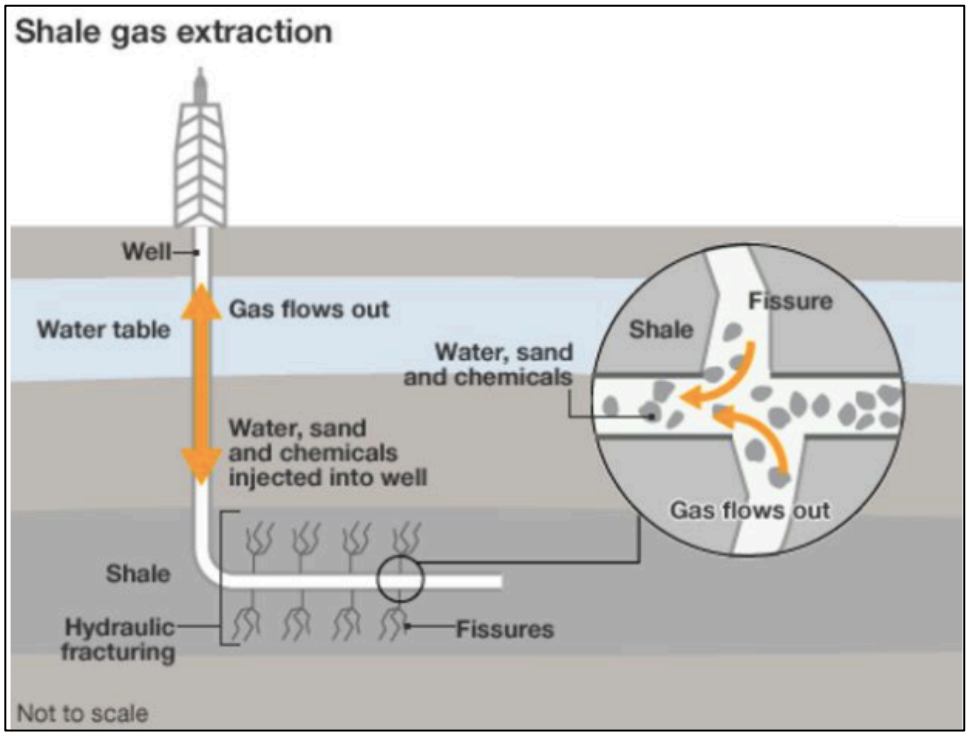

Figure 1: Hydraulic Fracturing Process Visualization
(Source: BBC)

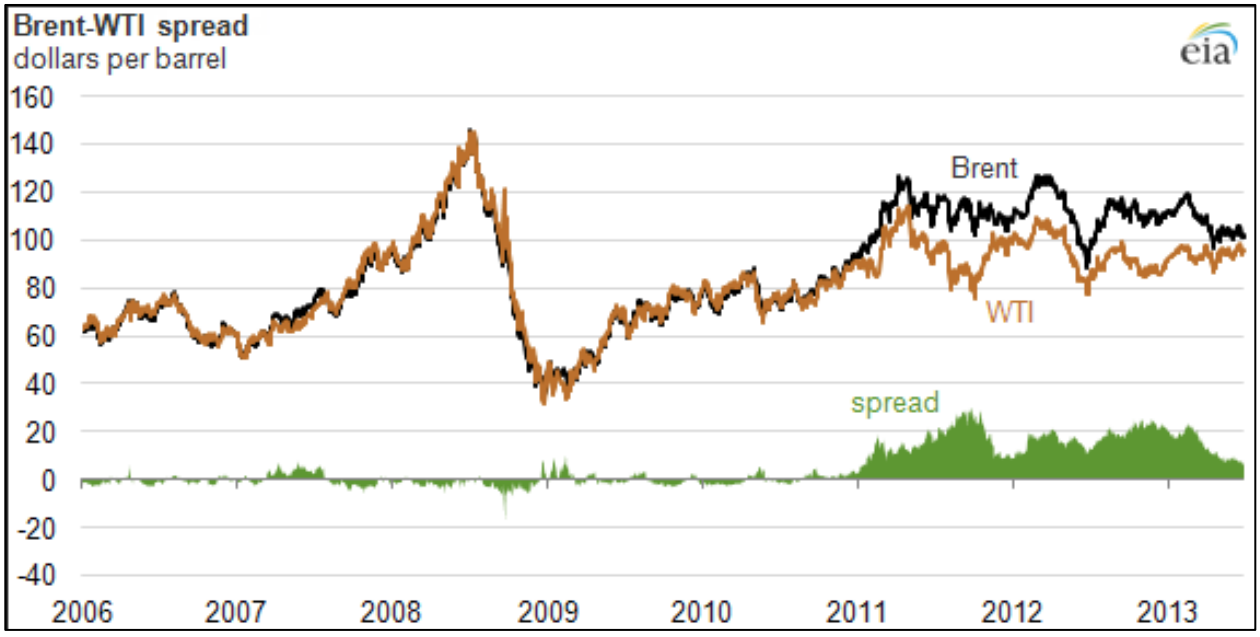

Figure 2: Brent-WTI Price Trends 2006 – 2015
(Source: EIA Crude Oil Outlook)

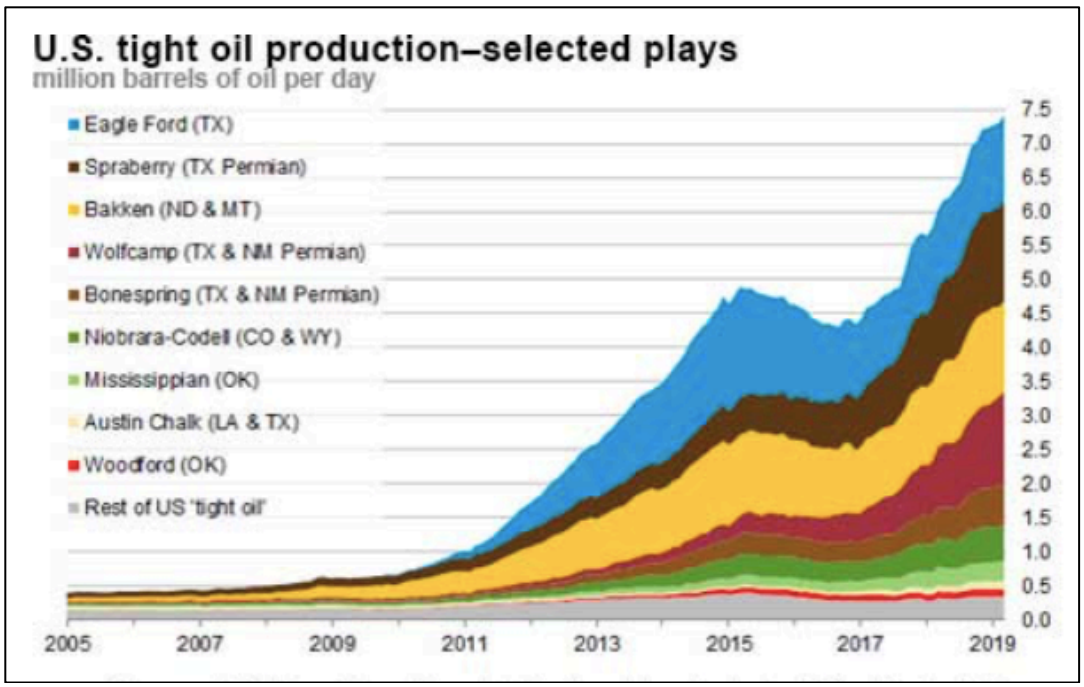

Figure 3: US Daily Tight Oil Production (in million barrels of oil) 2005 – 2019
(Source: EIA Tight Oil Production per Play)

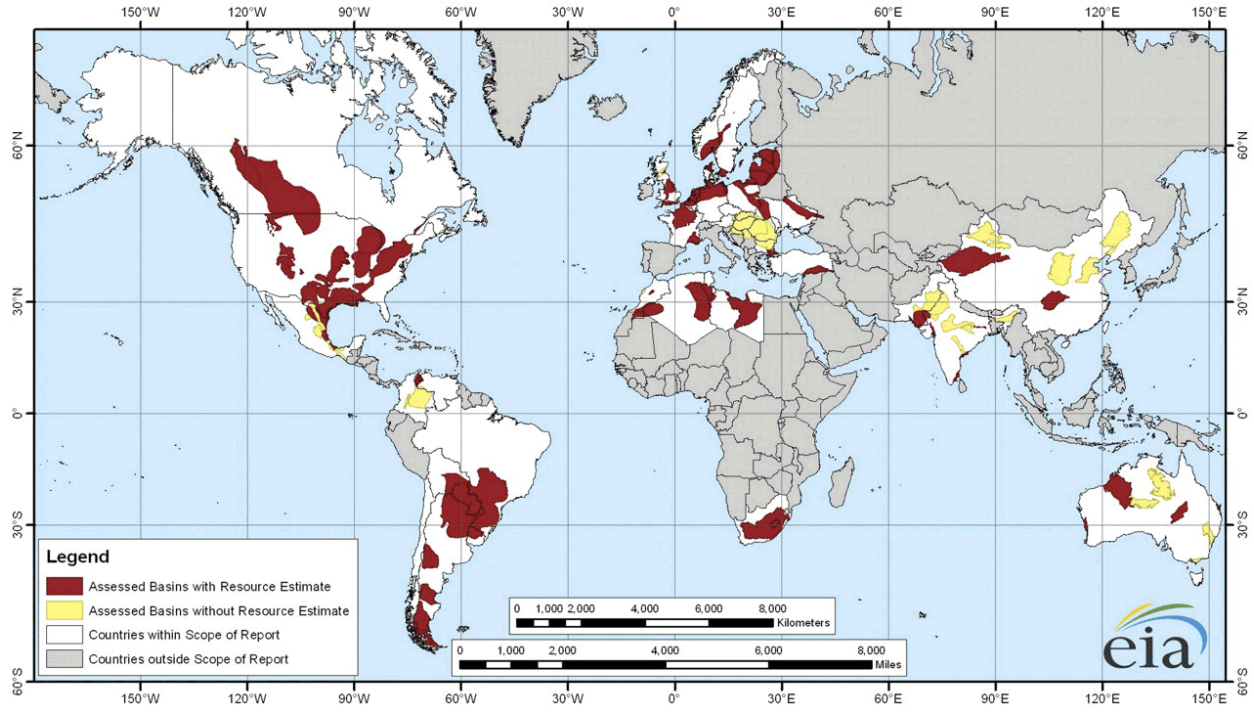

Figure 4: Map of Global Shale Plays
(Source: EIA Shale Oil Overview)

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