Hydraulic Fracturing as a Social-Ecological System: Robustness and Governance Implications of Development

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Over the past decade, natural gas development on the Utica and Marcellus shale has increased substantially. Despite major growth in the industry nationwide, the federal government does little to regulate fracking leaving it up to individual states to pass legislation. The Pennsylvania state government has limited the ways in which municipalities can regulate hydraulic fracturing both explicitly in the form of oil and gas regulations and implicitly in the form of constitutional restrictions on state preemption. Home of the first oil well (Rabe & Borick, 2013), little history of natural gas regulation and seen as a major player in the natural gas industry ("Department of Conservation and Natural Resources," 2018), Pennsylvania serves as an interesting case study when analyzing institutional restraints on the volatile nature of the natural gas social ecological system. Drawing on institutional theory and using a robustness framework this work aims to fill a gap in literature that neglects diminishing local government capacity within the Marcellus and Utica Shale natural gas resource economy. This paper examines the layered restrictions placed on localities by the Pennsylvania state legislature and the overall robustness of policies at state and local levels. We posit that the current state of governance is inadequate at the local level for communities are unable to limit negative externalities of the boom-bust nature of the natural gas industry.

Natural gas has become a prominent resource in the United States' energy portfolio as a result of low prices, domestic abundance, low rate of burning carbon dioxide emissions, federal push for energy independence and search of greener energy sources (Soeder & Kappel, 2009; Willow & Wylie, 2014). Increased natural gas production, accompanied with human and environmental health incidents, has called institutional regulations and formulation strategies into question.

Our goal is to further general understanding of current regulation strategies and their robustness to the volatile natural gas industry by examining the formation and governing structures, promoting or limiting development in the state of Pennsylvania.

We begin with an overview of the social-ecological system framework and a description of the resource, followed by a review of institutional theory. This framework coupled with institutional theory provides a robust analysis of current institutions at the federal and state level impacting/limiting local natural gas governing capacity within the Marcellus and Utica Shale region. Pennsylvania serves as the focus of this case study due its unique local-state governing structure, restrictive oil and gas policies and incorporation of the natural gas industry into local and state economies. We conclude with an analysis of the robustness of different aspects of the natural gas social-ecological system and by highlighting the potential fragility of the system.

Propositions

While state preemption of local policy making and restrictive policies limiting local governing capacity does not destroy the viability of the hydraulic fracturing social ecological system, it does decrease the overall robustness and thus increases system vulnerabilities given the cross-scale nature of the social-ecological system.

Social-Ecological System Robustness Framework

A social ecological system (SES) is an ecological system affected by and linked to one or more social systems, where an ecological system an interdependent network of organic units and/or organisms. Due to the complexities of the governance system surrounding this SES the robustness framework is applied to the natural gas development SES to aid in the understanding of current system fragilities.

Robustness, or the idea that a system can maintain invariable outputs despite variable inputs (John M. Anderies, Folke, Walker, & Ostrom, 2013), is applied to understand the sustainability and susceptibility of a resource system. A SES is robust enough if it prevents the ecological system from moving into a domain that is unable to support the human population, or one that avoids a transition that produces long-term human suffering (John M Anderies, Janssen, & Ostrom, 2004). An outline of the robustness framework is outlined in Figure 1.

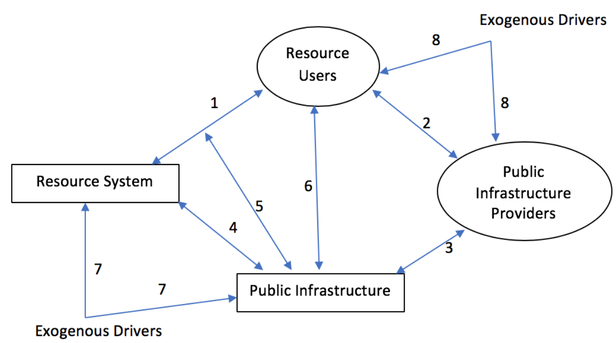

Figure 1 Robustness framework outlining interconnections of resource system components (J.M. Anderies & Janssen, 2013).

To address the robustness of a system the following questions are to be addressed: What is the system of concern? What are the desired system characteristics? At what point does the lack of robustness of a subsystem destroy that of the entire system?

The framework depicted in Figure 1 captures the interactions between actors, shown in ovals and infrastructure, shown in rectangles. The public infrastructure providers are those who control the resource (link 2). Hard and soft infrastructure created by the public infrastructure providers (link 3) regulates not only the resource user (link 6) and the resource system directly (link 4), but also the interactions between the user and the resource system (link 5) (J.M. Anderies & Janssen, 2013). Exogenous drivers, while not a part of the initial system structure, are identified due to variable levels of influence.

SES Scale Dynamics

There is a growing body of literature that examines the mismatch of environmental phenomena and governance. Environmental systems are typically not confined to jurisdictional boundaries or imposed legislative temporal scales, complicating governance strategies. As rigid governmental systems govern human-environmental systems, it is important to acknowledge the scale and level dynamics of SES.

The term scale will refer to spatial, temporal, quantitative and analytical dimensions and levels will refer to units located on the same scale that may or may not be positioned within a hierarchy (Gibson, Ostrom, & Ahn, 2000). Interactions may occur cross-scale and cross-level, complicating system dynamics; cross-scale refers to interactions across scales and cross-level refers to interactions among various levels within a particular scale. Cash et al. (2006) identify three common societal challenges of these dynamics. The first is the failure to acknowledge critical scales and levels within a system, the second is the consistent discrepancy between SES levels and scales, the third being the failure to recognize actor values and perceptions of scales. Ignorance is highlighted as the fundamental flaw in approaching human-environmental scale-level dynamics. This highlighted ignorance and mismatches between institutions and environmental phenomena cannot be sustainably managed through top-down or bottom-up policy approaches, for these approaches are, respectively, too insensitive to local opportunities and constraints and as well as local contribution to larger problems (Cash et al., 2006).

Hydraulic Fracturing as a SES

A robustness framework is used to outline the complex interactions restricting local governing capacity regarding the natural gas SES, for this complex system contains multiple layers of institutions impacting local rule setting which are heightened by volatility in the natural gas industry. These complex interactions are best captured in the robustness framework due to the dynamic interactions and evolution of variables outlined in this SES (J.M. Anderies & Janssen, 2013, p. 519). An overview of system components is shown within the robustness framework in Figure 2.

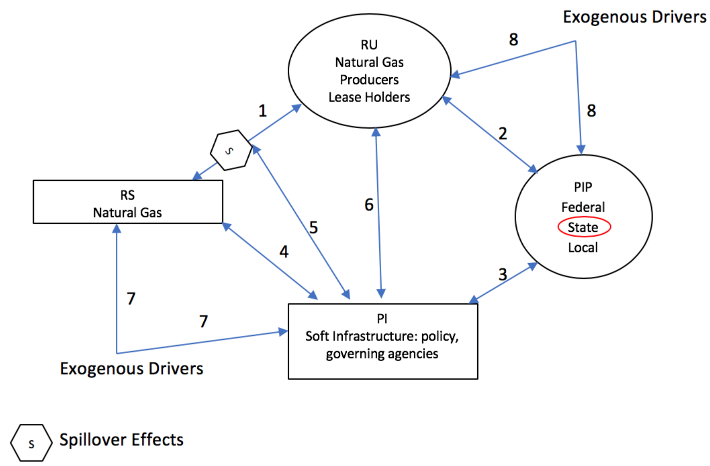

Figure 2 Natural gas resource system represented in the robustness framework.

The resource system is identified as natural gas reserves which interact with the resource users, natural gas producers and lease holders through the amount of natural gas extracted (link 2), this connection flows from the users to the system via extraction efforts. Spillover effects are identified as environmental and socio-economic concerns. The users interact with the public infrastructure providers through lobbying efforts (link 2), where the primary provider is identified as the state government which will be further explained in the following sections. The PIP interact with the soft human infrastructure through funding and forming legislation (link 3) that serve as the base for governing agencies including the PA Department of Environmental Protection (PA DEP), the Public Utility Commission (PUC), the Department of Conservation and Natural Resources (DNCR) and the Department of Oil and Gas. This soft human made infrastructure interacts with the resource system through monitoring and measurement efforts (link 4). Both link 5 and 6 represent regulations enacted by the public infrastructure. Exogenous drivers (link 7 and 8) include the volatile nature of the natural gas market and globalization.

Resource System

High volume hydraulic fracturing, or ‘fracking’, is an unconventional extraction process to access natural gas deposits located in tight underground shale formations. The major shale plays in the Appalachia region include the Marcellus and Utica Shales. These are shown in Figure 3 along with well presence in the region.

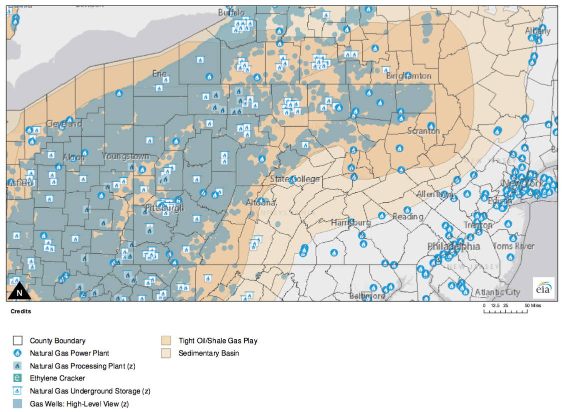

Figure 3 Natural gas shale plays in the Appalachia region. In addition to displaying natural gas availability, this map also shows well counts for the region (EIA, n.d.)

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The fracking extraction process dates back more than 50 years, however technological advancements in horizontal drilling have enabled the withdrawal of previously irretrievable deposits (Goho, 2012). Wells are drilled thousands of feet vertically into the ground, then horizontally in order to maximize natural gas capture. A mixture of water, chemicals and proppants are pumped at high quantities and pressures in order to create fissures hundreds of feet from the bore hole open to allow hydrocarbons to flow to the surface. Proppants are used to keep fissures open to allow for continual gas flow (EPA, 2018). Once the injection process is completed, fracking fluids resurface before the natural gas can flow. This flowback is injected underground or held in onsite storage tanks for disposal (EPA, 2018).

Substantial amounts of water are required during the drilling process, using up to 3 million gallons of water per treatment (Kondash, Lauer, & Vengosh, 2018) and can be fracked up to 18 times over the well's lifespan (Finewood & Stroup, 2012). The amount of water used per well increased 770% over the 2011-2016 time period and it is estimated that natural gas extraction efforts account for 15% of the world's total water consumption (Kondash et al., 2018). The steady increase in water use per well suggests that greater amounts of water will be needed per well as the industry continues to extract natural gas however this is influenced by the geology of the region which have “serious implication[s] for local communities, where increased drilling volume will lead to large instantaneous water demands” (Kondash et al., 2018). The United States Geological Survey highlights three main water concerns, 1) providing ample water supplies without impacting local water tables, 2) avoiding local degradation of small watersheds and streams from heavy equipment transportation on rural roads, 3) determining and establishing proper methods for safe disposal of large quantities of flowback (Soeder & Kappel, 2009). The fracking and disposal process not only introduce chemicals into the environment, potentially contaminating local groundwater but can also dislodge naturally occurring, underground chemicals (Kondash et al., 2018; Soeder & Kappel, 2009). The Environmental Protection Agency found that the fracking process has contributed to water contamination throughout all stages of the process, including during water withdrawal process, spills of fluids, injections of fluids directly into underground water reservoirs, inadequately treated fracking fluids and improper disposal methods despite pre-disposal treatment regulation (Soeder & Kappel, 2009). These can lead to secondary impacts including accidental explosions and spills during the extraction and transportation process (C. E. Davis, 2017)

In addition to environmental health concerns, a Pennsylvania study found that 75% of water wells within 1 kilometer of a fracking site were contaminated from deep shale formations (Osborn, Vengosh, Warner, & Jackson, 2011). Furthermore, municipal drinking water has experienced levels of contamination due to the inability to filter out toxic waste from industry flowback (Howarth & Ingraffea, 2011). Health concerns are amplified by undisclosed chemical use. Listed as proprietary chemicals, fracking corporations are not required to report the cocktail of chemicals used during the hydraulic fracturing process curtesy of the “Halliburton Loophole” which exempts the fracking industry from federal regulations including the Safe Drinking Water Act (Howarth & Ingraffea, 2011) despite known toxicity. Injected chemicals have the potential to pose acute and chronic hazards, in regard to human health, water and air quality (C. E. Davis, 2017; Swyngedouw, 2009).

Atmospheric concerns exist within this SES as well. An estimated a 3.9%-7.9% of methane is vented or leaked into the atmosphere over the lifetime of an unconventional gas well, compared to 1.7-6% of a conventional well; these statistics and the high rates carbon dioxide emissions during the burning process support the claim that over a 20-year time period, the greenhouse gas footprint of natural gas is greater than conventional oil or coal (Howarth & Ingraffea, 2011).

Resource System Volatility: Community Impacts

Boom-bust (BB) cycles and subsequent local impacts on quality of life and livelihoods have been studied by rural sociologists and economists alike (Jacobsen & Parker, 2016; Jacquet, 2009; Recker, Besser, Aigner, & Coates, 2009). The "Boomtown Impact Model" emerged from social and economic development trend research as a method for conceptualizing rapid rural community development (Jacquet, 2009), the growth is commonly attributed to an industrial process, presented in the form of mass resource extraction or the conversion of extracted resources into power (England & Albrecht, 1984). These localities undergo extreme rates of population growth as a result of rapid economic expansion (Jacquet, 2009). Boom counties experienced short-term economic benefits, accompanied by persistent long-term hardships presented in the form of depressed incomes and joblessness (Jacobsen & Parker, 2016) as a result of aforementioned economic shocks (Recker et al., 2009). Municipal vulnerability is exposed during uncontrolled growth and development, clearing a path towards "increased environmental, social, and economic risk" (Apple, 2014).

Boom Bust Cycles and Hydraulic Fracturing

Hydraulic fracturing BB literature examines responses to fluctuating fracking revenue and its impacts on local economic planning. BB cycles can severely damage these local, fracking dependent economies. During booms, when oil and gas companies heavily pursue mining, areas rich in oil and gas see their service sectors expand, employment increase, and local tax revenues grow. However, communities also grapple with increased pollution and crime, higher rents and housing prices, strained public services, and infrastructure inadequacies (Brasier et al., 2017; Mayer, Olson-Hazboun, & Malin, 2017) overwhelming small communities (Freilich &

Popowitz, 2012). When a boom ends, these areas are often left worse off than before; employment gains tend to disappear, and societal impacts persist (Jacobsen & Parker, 2016). The natural gas BB cycle is shown in Figure 4.

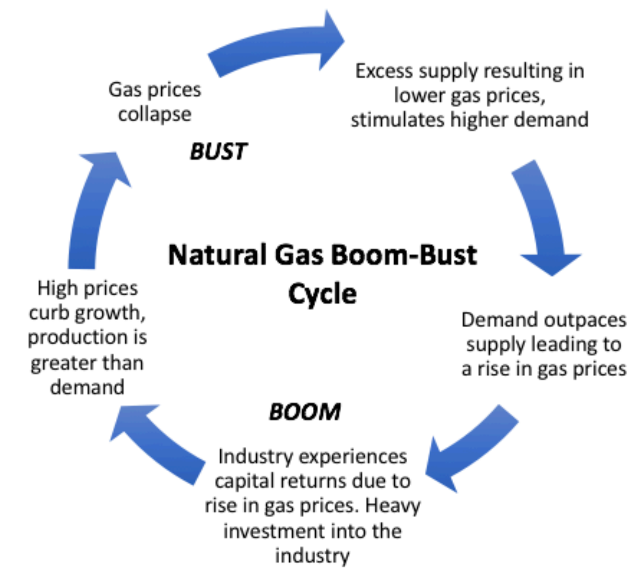

Figure 4 Boom-bust cycle of natural gas (Jacobsen & Parker, 2016; Jacquet, 2009; Mayer et al., 2017)

Increased industry interest is accredited to technological advancements, a newfound national interest in “cleaner” fuels, geopolitical concerns surrounding United States energy independence and national security (Goho, 2012) which generated initial industry interest. The increase of industry interest equates to a 37% increase in natural gas output from 2000-2016 (Mayer et al., 2017). An output that has supported hundreds of thousands of jobs throughout the United States since the initial natural gas boom. However, as these sectors jobs are contingent on BB cycles of hydraulic fracturing and therefore, employment has historically been variable. National oil and gas jobs peaked in 2014 at 678,000 jobs, this number has decreased to 540,900 for 2018 (Bureau of Labor Statistics, 2018). Fluctuating employment is used as an indicator for hydraulic fracturing development and subsequent state and local funding streams. United States oil and gas employment is shown in Figure 5, demonstrating the BB cycle shown in Figure 4, in terms of job availability.

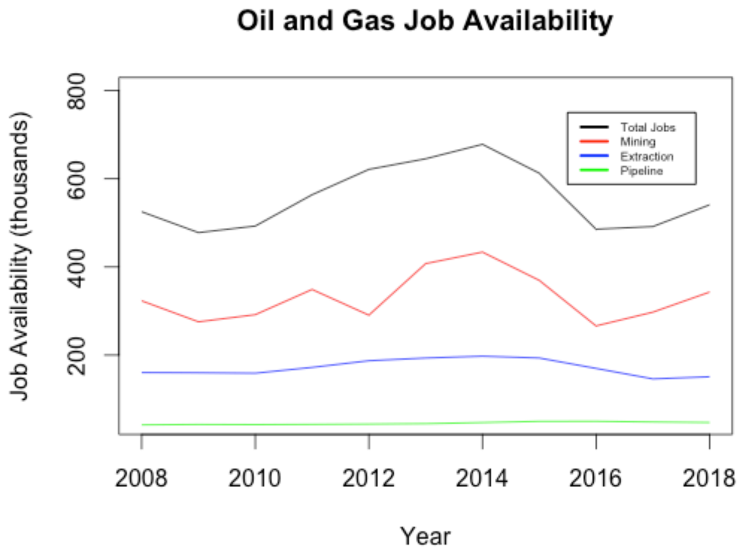

Figure 5 shows varying employment within the oil and gas industry. Mining represents all employees working in mining and logging for the oil and gas industry, pipeline represents jobs in the oil and gas pipeline transmission process and extraction represents all jobs available in the oil and gas extraction process (Bureau of Labor Statistics, 2018).

In addition to varying degrees of job availability, communities experience a lag-time between revenue influx and revitalization projects, which often fuels public discontent. Employment opportunities as promised by the natural gas industry to gain local buy-in are, more than not, ill-matched for long-term residents commonly lacking skillsets sought out by the industry. If only, falling short of expectations (Jacquet, 2009). Jacquet (2009) found that those best-suited for employment opportunities are commonly outsiders taking advantage of openings in the industry, leaving established residents to face the environmental and social burdens while receiving poor state derived compensation. Areas with greater experience in natural gas extraction such as Texas and Oklahoma have shown that primary work forces move from shale play to shale play, further limiting local job availability. Jobs are thus concentrated in trucking construction and retail which merely present part-time, short-term economic opportunities (Christopherson & Rightor, 2012).

Jarron Saint Onge (2007) found that while natural resource based economic revitalization may increase the average household income, they are accompanied or in connection with a rising cost of living. Thus, job-seeking migrants tend to disproportionately benefit from shifting economies. Benefits felt by short-term rural residents are typically contingent on resource availability. However, this relationship is not present in long-term residents. Rather, established community members are not privy to high social mobility given amenity-based population increases. In sum, influxes of new residents have the potential to lead to cultural clashes as well as aforementioned environmental concerns, traffic congestion and decreases in quality of life for long-term rural residents in these high amenity areas (Saint Onge, Hunter, & Boardman, 2007, p. 8). This culmination of socio-economic impacts makes resource dependent communities less attractive to new industries as there are higher housing costs and labor competition rampant in the area (Christopherson & Rightor, 2012, p. 16).

As the demand for energy grows and fracking becomes a more prevalent energy source its impacts are expected to increase exponentially, not only in areas with natural gas development but globally (Willow & Wylie, 2014). Political and economic decisions at the global, national and state level greatly impact extraction heavy localities and as direct impacts occur at the local and regional level the importance of institutions surrounding development become increasingly more important.

Institutional Analysis

Beginning in the mid-2000s', a booming natural gas market and decreased costs of fracking on formally marginal shale plays leading to the expansion of fracking across the United States. Fracking developed in many areas that had not had natural gas exploration, although many of these regions had experienced coal and oil production in prior decades. In response to rapid growth, states amended previous fracking regulations to align with governmental and industry interests.

Natural resources are managed under institutions also known as rules, norms and shared strategies, and organizations within a three-layered system; a system referring to private rights and the individual's right to lease land; regulatory overlays between state and local governments and respective accountabilities regarding environmental protection, health sanitation, infrastructure improvements, zoning, indirect and direct mitigation of fracking development; local law, influenced and/or restricted by state regulations (Apple, 2014). This matrix fundamentally alters relationships and powers of actors situated within the fracking development process.

Jointly, these structures reduce uncertainty by determining production and transaction costs, which in turn determines economic profitability. Possibilities of conflict arise when markets transcend community boundaries. Effective institutions would limit potential conflict by amplifying the benefits associated with cooperation and/or the costs of defection (North, 1991).

Federal Institutions

Analysts have found minimal evidence of federal guidance or standards when it comes to hydraulic fracturing governance (C. E. Davis, 2017; Osborn et al., 2011; Rabe & Borick, 2013). While chemicals used are typically regulated under the Safe Water Drinking Act, hydraulic fracturing is exempt from these and other EPA regulations under the Energy Policy Act of 2005. Other exemptions include the Resource Conservation and Recovery Act, fracking wastes are not regulated through the hazardous waste clause, and the Emergency Planning and Community Right-to-Know, where producers may voluntarily disclose chemicals used during the fracturing process but are not required to do so (C. E. Davis, 2017). Though other avenues for federal environmental regulation are present, fracking is excluded (Rabe & Borick, 2013). The lack of federal involvement leaves room for individual state governments to form their own policies which tend to place an emphasis on energy development rather than environmental protection (C. E. Davis, 2017).

Pennsylvania State Institutions

Pennsylvania has been the second largest producer of natural gas for the past four years. State records of natural gas production date back to 1960 and up until 2011 production remained relatively consistent, it was in 2011 when production doubled from previous years (Energy Information Administration, 2017). In 2012 PA updated their preexisting and outdated oil and gas regulations with the passing of the Act 13 or the Oil and Gas Act. This act is the primary piece of legislation that governs local government regulation capacity of natural gas development, however state preemption regulations also come into play when addressing hydraulic fracturing in the Commonwealth.

The majority of Eastern states operate under Dillion's rule, where municipalities are considered "creations of the state" (Goho, 2012). This restrictive form of local governance explicitly grants municipalities powers under the constitution, while municipalities operating under home-rule are able to operate in any area that is not explicitly granted to the state. Pennsylvania municipalities govern under Dillion's rule, it is upon a vote by the electorate in the form of a referendum that municipalities are able to establish Home Rule (Arnold & Holahan, 2014). As a source of state-local conflict, the state preemption debate has been amplified by third party interest groups who have lobbied against perceived burdensome ordinances within the three-layered system, attempting to incite state preemption to further vendettas (Hicks & Weissert, 2018).

The PA state legislature passed Act 13 Title 58: Oil and Gas Act with the intention to regulate oil and gas production within the Commonwealth. Regulations include bole hole length, proximity to residential areas, discharge procedures, well casing requirements and chemical injection reporting. The state collects impact fees to compensate for environmental degradation, permit fees for administrative purposes and fines for those who violate regulations established under Act 13. Not all money collected directly benefits localities with fracturing operations. Impact, administrative and permit fees, income taxes and fines are placed into the state's Unconventional Gas Fund. Impact fees, following state agency allotment, directly benefit counties, while other earnings remain at the state level (Oil and Gas Act, 2012). Unlike many other states, PA has placed the Public Utility Commission (PUC) with power of implementing key provisions of Act 13. Previously seen solely as a regulator of major utility placement and rate setting, the PUC is granted the newfound power of environmental protection law enforcement (Rabe & Borick, 2013). A member of the PUC commented on the agency's involvement, "Act 13 was a funding mechanism, it was the impact fee, and our job with that is simply as a cash register take the money in and then the distribute it" (Public Utility Commission, 2018).

PA's Act 13: Oil and Gas establishes an impact fee for environmental and local impact compensation. The fee structure is based on the year of the well and the average annual price of natural gas and begin the year that the well is "spud" or the year that drilling of unconventional gas begins. Fees slowly decrease as wells age and expires completely after 15 years. The PUC may adjust fee rates based on upward changes in the Consumer Price Index for urban areas in the tristate area, given the number of wells spud exceeds the previous year. All fees and fines collected from unconventional gas drilling operations by the PUC are placed into the State Treasury established Unconventional Gas Fund which is then allocated to counties with jurisdictional well. Specific dollar amounts are awarded first to state agencies and departments before the remaining 40% of the revenue is placed into the Marcellus Legacy Fund which is accessible to both counties with and without wells. (Oil and Gas Act, 2012).

Counties with hydraulic fracturing wells are allocated 36% of the locality disbursed impact fee revenue from both funds. Act 13 stipulates the manner by which Unconventional Gas Fund monies may be used. All county funding decisions are contingent on funding availability as determined by natural gas development and production which mirrors the volatility of the industry as a whole. Localities are required to submit fund use for approval to the Public Utility Commission (Oil and Gas Act, 2012).

However, if counties wish to receive disbursements from the Unconventional Gas Fund and/or the Marcellus Legacy Fund they are required to pass an ordinance establishing impact fees, those who do not pass an impact fee ordinance are prohibited from receiving funds. This serves as a mechanism used by state legislators to avoid blame by placing the responsibility on local leaders rather than state officials (Rabe & Borick, 2013). Funds may also be withheld if localities enact ordinances conflicting with detailed land-use provisions as stated in Act 13 (Oil and Gas Act, 2012). A stipulation that spurred an unusual linkage between state fiscal and regulatory power in attempt to limit local governing capacity (Rabe & Borick, 2013). Counties with or without impact fee ordinances are unable to pass regulations inhibiting oil and gas development; counties "May not impose conditions, requirements or limitations on the construction of oil and gas operations that are more stringent than conditions, requirements or limitations imposed on construction activities for other industrial uses within the geographic boundaries of the local government" (Oil and Gas Act, 2012). Additionally, the PUC wields the authority to deem counties as eligible or ineligible (Rabe & Borick, 2013).

Pennsylvania Municipal Institutions

Municipalities were concerned with their inability to regulate local fracking operations due to negative environmental externalities (C. Davis, 2014) and were able to overturn the state preemption zoning clause of Act 13. *Robinson Township v Commonwealth of Pennsylvania* affirmed the ability of local governments to restrict fracking from zones incompatible with comprehensive plans. At this time, the court ruled that Act 13 was unconstitutional in that the legislation grants power to the PA Department of Environmental Protection without "definitive standards or language" (*Robinson Township v Commonwealth of Pennsylvania*, 2012). Additionally, the court ruled that the state could not "make an unconstitutional action constitutional by imposing it as a state regulation" (Freilich & Popowitz, 2012, p. 553).

Analysis

Actors participating within this system complicate the policies regulating the fracking industry and the state royalties collected. Actors have influenced Pennsylvania legislation on a much deeper level, as identified by existing literature. Hudgins and Poole (2014) posit that political elites representing pro-fracking interests dominated the crafting of Pennsylvania's Act 13, going as far as claiming "the construction of the law illustrates the anti-democratic nature of the relationship between capital and the state on the one hand and society on the other, and further amplifies the utilitarian nature of the category of the individual in service to capital" (Hudgins & Poole, 2014, p. 310). The governmental advisory commission included a limited range of expertise. Of the 31 experts included in the commission, Governor Tom Corbett appointed one academic, previously funded by the drilling industry; ten governmental employees; 11 industry representatives, four of which resided outside of Pennsylvania; four environmental group members; and five civil society group members. Applied social scientists and public health officials were excluded from the commission (Hudgins & Poole, 2014; Rabe & Borick, 2013).

Following in depth interviews with private officials, it was revealed that during the process of congress led stakeholder consultation that not all associations were privy to the full proposed bill. A leading environmental group reported that they were shown only environmental provision proposals and not the entirety of the legislation; it was not until after the bill was quickly proposed and passed that parties were able to view additional sections of the legislation. It was the group's view that if the complete version was presented prior to its passing, the association would have advised differently for it did not support state preemption sections ("Pennsylvania Environmental Group," 2018).

During additional stakeholder interviews it became apparent that the public and municipal leaders were largely kept out of these decisions. A member of the DCNR team attributes this to a lack of knowledge and it was those who were located in shale plays with substantial development that accrued knowledge on fracking practices. Individuals in large population hubs with little to no prevalence of fracking operations, such as Pittsburg and Philadelphia were "out of the know" (Department of Conservation and Natural Resources, 2018; Department of Environmental Protection, 2018) because politically there was no reason for rural republicans of resource rich areas to converse with urban democrats with little resource development. It was not until natural gas development was well along the way, 2014-2015, that "to the public, all of the sudden fracking appeared, and it was a giant massive thing" (Department of Conservation and Natural Resources, 2018). It was around this rapid development that municipal input was received by sophisticated conservation districts, or sub-jurisdictions tasked with managing environmental issues within their respective county. These districts are charged overall promotion and protection of the safety and general welfare of constituents, which in the case of natural gas development includes permitting. Sophisticated districts were those that were capitalizing on gas development, their increased permitting activity led to a need for additional personnel and funding which was voiced to county commissioners and congressional representatives (Department of Conservation and Natural Resources, 2018). This was the only method by which local input was (indirectly) received.

However, not all stakeholders share this sentiment. Esteemed officials support current policies, claiming that “[PA] has the strongest set of regulations throughout the county” (PA Chamber of Business and Industry, 2018). However, with the restraints placed on municipalities regarding their governing capacity, this can arguably be seen as ignorance. The complexity of environmental system dynamics is both cross-scale and cross-level; Cross-scale complications include varying levels of authority within the governing system and cross-level complications include the dynamics between spatial and jurisdictional domains. By limiting local governing abilities the hydraulic fracturing SES is approached at a single level, top-down form of governance, one that does not allow for those experiencing externalities to manage outcomes (Cash et al., 2006; Rabe & Borick, 2013). Ignoring this aspect of the SES creates a range of management problems, for it is systems that consciously address dynamic elements that are more successful.

Discussion

Robustness is used as a framework within SES to assess the susceptibility to variable inputs within this resource system. The three questions poised are: What is the system of concern? At what point does the lack of robustness of a subsystem destroy that of the entire system? What are the desired system characteristics? The system of concern has been outlined, in this paper, as hydraulic fracturing in the context of local governing capacity. At this time, it is difficult to discern if the lack of robustness of the subsystem, identified as lack of local government control over negative externality mitigation, will destroy the entirety of the system. Up until this point, it has not. Instances of crime, increased costs of living, persistent financial hardships, traffic congestion, water and air pollution have continued to rise at the local level without hampering the growth of the natural gas industry or the United States energy economy. This SES continues to function, however is this at the behest of the state interests or its constituents? This then begs the question which basin is the most attractive? What characteristics are desired? For resource rich areas struggling to cope with rapid development that are both limited in the ways they can mitigate negative externalities and expand upon preexisting environmental protections it is difficult to argue that their desired basin is being used during the execution of Act 13.

It is easy to sacrifice local communities for the good of the whole system. Fracking proponents and industry representatives employ a neo-liberal cost analysis by analyzing the water cycle economically to normalize hydro-social impacts and support their claim that local social and ecological degradation can by outweighed by national and industry benefits (Finewood & Stroup, 2012). This view shifts ecological, cultural and non-economic values away from the public good, encouraging locals to sacrifice spatially fixed resources for the greater good (Finewood & Stroup, 2012). This is not to say that all communities are struggling under this increased development but rather to highlight the complexities of the natural gas SES and potential vulnerabilities introduced from constraints placed on municipalities within the policy formation process and enactment. While there is something to be said for uniformity in the industry from a state policy perspective, this should not negate the value of local knowledge and expertise.

As a member of the Oil and Gas Division stated, “It's hard to predict [the future of natural gas], so many things have happened here in PA, most people would not have predicted that we go from the state that produces a modest amount of hydrocarbons to the amount we produce now” (Department of Environmental Protection, 2018). With an uncertain future, the adequacy of current and future institutions is paramount. Current institutions, Dillion’s Rule and Act 13, act as a top down form of legislation, one that had and currently receives little input from local districts (Department of Conservation and Natural Resources, 2018), thus neglecting the cross-level aspects of this environmental system. Other methods of approaching the hydraulic fracturing SES as suggested by Cash et al. (2006) including institutional interplay, co-management or bridging organizations would be a more appropriate and sustainable form of political, environmental and economic management.

Conclusion

The purpose of this paper was to outline the complexities of natural gas development and highlight the layers of the current governing regime. Up until this point, local government officials have largely been left out of the policy formation process leading to vulnerabilities within the SES. Applying the robustness framework, an institution is robust if it can support the current population and prevent long-term suffering (John M Anderies et al., 2004); without the local ability to regulate the fracking industry within municipal limits, marginal funds disbursed for regional risks and given ample externalities associated with the industry, it is difficult to support the robustness of local governing capacities. Despite increased negative externalities associated with fracking at the local level, the lack of community robustness does not lead to an entire system collapse but does increase the fragility of the system. Hydraulic fracturing remains a hotly contested, inherently contentious issue in Pennsylvania. Neglecting municipal input and limiting governance adds fuel to this fire, generating more negative outcomes than positive at the local level.

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