Principled design: Analyzing Colorado's oil and gas Memorandums of Understanding (MOUs) using common-pool resource (CPR) theory's design principles (DPs)

Abstract

This paper analyzes 13 Memorandums of Understanding (MOUs) between local governments and oil and gas industry operators in Colorado, taking the first steps to better understand the design of these agreements. Specifically, this paper studies MOUs or Operator Agreements between 11 different local governments in Colorado and industry operators. Using the design principles (DPs) of common-pool resource (CPR) theory as a lens, this paper examines the structure of these MOUs. The paper finds that while generally the number of DPs present in the MOUs has increased over time, this has not always been the case. This suggests that MOU variation is more complex than simply the passage of time or institutional learning. Even if MOUs are becoming increasingly more robust, several questions remain. Are certain DPs more important than others? How enforceable are MOUs and how effective are they at increasing trust in either/both local governments and/or in industry? To fully understand the possible linkages between the presence of CPR theory's DPs in MOUs and their potential to increase trust and ameliorate conflict, however, requires further study.

Introduction

This paper is a purely descriptive piece that sets the stage for a larger body of research in the form of a doctoral dissertation and provides a foundation for the remaining portions of the dissertation. This dissertation will add to the knowledge base on local government regulation of the contentious oil and gas extraction method, hydraulic fracturing, by exploring Memorandums of Understanding (MOUs) signed between oil and gas companies and local governments in Colorado. As discord surrounding hydraulic fracturing has increased and MOUs have become a popular way to regulate the practice, it is necessary to understand more about these MOUs. Building off of this paper, which examines the design of these oil and gas MOUs and whether they comport with the theoretical principles of successful natural resource management, future research will examine MOU enforcement in terms of stringency, authority, and what enforcement challenges exist and what the relationship is, if any, between MOUs and trust namely, whether MOUs increase trust in either government and/or industry with respect to the practice of hydraulic fracturing.

The paper proceeds as follows. First it defines hydraulic fracturing and discusses its expansion in the United States, illuminating why the process of hydraulic fracturing is contentious. Next it overviews the literature on MOUs, provides background on Colorado's oil and gas MOUs and characterizes MOUs as voluntary, self-governing environmental agreements or institutions. It then discusses the Institutional Analysis and Development (IAD) Framework and its companion, common-pool resource (CPR) theory, as method for studying these MOUs and places oil and gas development in a CPR context. Next the paper offers a brief overview on previous literature that has applied CPR theory's design principles (DPs) and applies CPR theory's DPs to Colorado's MOUs. The paper then overviews the data, 13 MOUs across 11 local

governments and two shale plays, which includes both variation within and across local governments, and the methods for their in-depth examination. Next the paper shares the results and offers a discussion of the findings. The paper closes with a conclusion and directions for future research.

The expansion of hydraulic fracturing

The United States Energy Information Administration (USEIA) predicts significant growth in global energy demand and a corresponding 45 percent increase in global energy consumption from 2012-2040 (USEIA 2016). To meet rising energy demands, U.S. hydrocarbon production from shale resources has continued to grow,[1] primarily driven by an increase in horizontal drilling efficiency from a process known as high volume horizontal hydraulic fracturing (USEIA 2014). Hydraulic fracturing[2] involves injecting sand, water, and chemical additives under high levels of pressure thousands of feet below ground into oil and gas reservoirs and wells to extract hydrocarbons (i.e. oil and natural gas) (USGS 2019; COGCC 2019).

As the hydraulic fracturing market has increased, so has the contentiousness of the extraction method. Proponents of oil and gas development that uses hydraulic fracturing maintain that it creates jobs, reduces carbon emissions, boosts the economy, lowers the cost of energy, and reduces U.S. reliance on foreign oil (Helman 2013). Opponents, however, are concerned with many types of potential environmental and health hazards (DeSmogBlog 2010). Among these are possibilities of groundwater, drinking water, and soil contamination; release of

[1] PR Newswire (2016) predicts that the global hydraulic fracturing and services market will grow at a 9.3% compound annual growth rate by 2025.

[2] In this paper, as is widely done, the term hydraulic fracturing refers to the process of fracturing rock formations and includes the entire process, from pre-drilling activities—such as sub-surface lease negotiations—to the drilling itself, to post-drilling activities—such as transmitting oil and gas to consumers. Please note, oil and gas industry operators would object to this wide-ranging use of the term as actual hydraulic fracturing is a relatively minor portion of the process. Despite this, my use of use of the term denotes no bias against the oil and gas industry.

greenhouse gases, such as carbon dioxide and methane; increased water consumption; and potential increased seismic activity (DeSmogBlog 2010).

With the expansion of oil and gas wells across the nation, researchers have begun to speculate on the numbers of Americans potentially impacted by their proximity to wells. Some estimate that at least 15.3 million American people live within one mile of a well that that has been drilled since the year 2000 (Gold and McGinty 2013), while others estimate this number to be 17.6 million Americans living within 1,600 meters (~1 mile) of one or more confirmed active oil or gas wells (Czolowski et al. 2017). Considering the popularity of this extraction method, its potential for encroachment on urban and suburban areas, and many related environmental and public health concerns—the proximity of these wells to schools, homes, hospitals, and natural features, and the ability to regulate the practice—is of great interest to those living in and near communities with active oil and gas development.[3]

In many instances,[4] the public has sought local control over hydraulic fracturing[5] despite the fact that U.S. states typically have primary regulatory authority (UCS 2015). As the primary regulator, the state decides how much regulatory discretion to bestow upon the local level (UCS 2015). Many states have elected to retain their regulatory authority, which has led to regulatory conflict with local governments (Golten, Ward, and Mutz 2016; UCS 2015). Theoretically,

[3] The practice of hydraulic fracturing has become so controversial that many U.S. cities, counties, and states, as well as foreign nations—among them Wales, Scotland, France, Germany, and Bulgaria—have either issued moratoria or bans on the practice (Keep Tap Water Safe 2019).

[4] Keep Tap Water Safe (2019) keeps a running list hydraulic fracturing bans worldwide.

[5] In fact, Colorado citizens recently sought to pass Ballot Initiative 75, Colorado Local Control of Oil and Gas Development Amendment; this would have amended the state constitution to allow local governments the authority to regulate oil and gas development, to include banning the practice, within the confines of their town's geographic border (Ballotpedia 2016). Initiative 75, however, failed to qualify for the November 2016 ballot (Ballotpedia 2016). After proponents of Initiative 75 collected 107,232 signatures, more than the required 98,492 signatures, the Colorado Secretary of State's office rejected 1,380 signatures in the random five percent sample the office uses to confirm signature validity (Colorado Secretary of State 2016). With the rejection of those signatures, the projected number of valid signatures was 80.85 percent, falling short of the required 110 percent required to put the measure on the ballot (Colorado Secretary of State 2016).

MOUs may increase public trust in local governments while alleviating regulatory conflict between state and local governments. MOUs may also increase public trust in and reduce conflict with the industry; the public may view the industry's active participation in addressing the externalities associated with hydraulic fracturing as a reason to trust industry operators.

Case selection: Why study Colorado?

This paper emphasizes the potentially influential case of Colorado to empirically analyze oil and gas MOUs between local governments and industry. This case analysis represents a starting point for deductively testing theories surrounding natural resource management, institutional design, regulation enforcement, and trust. When no strong theory exists about the mechanism connecting independent to dependent variables, the case analysis generally follows an inductive pattern (Gerring and Cojocaru 2016). When, as is the case in this research, a theoretical expectation exists, the case analysis takes a more deductive approach to identify the mechanism (Gerring and Cojocaru 2016). Influential, diagnostic cases may assess the following: measurement error, scope conditions, causal heterogeneity, confounders, and causal mechanisms[6] (Seawright and Gerring 2008; Gerring and Cojocaru 2016), which is of particular interest to the larger body of research where this paper is situated.

Colorado resembles an influential, diagnostic, case for the following reasons. First, Colorado has been a front-runner in oil and gas development that uses hydraulic fracturing. It is the fifth-largest natural gas-producing state[7] (USEIA 2019) and is home to 11 of the nation's 100

[6] If a researcher wishes to examine the causal mechanism and selects the case based on the dependent variable, then the researcher "knows the value of the outcome [(Y)] for cases that are under consideration for intensive study, but not the values of X ["the presumed cause of theoretical interest"] or Z ["background factors of no theoretical interest"]" (Gerring and Cojocaru 2016, 395).

[7] According to the U.S. Energy Information Administration (USEIA), in 2017 Colorado ranked sixth in terms of marketed natural gas production, whereas Texas, Pennsylvania, Oklahoma, Louisiana, and Ohio ranked one through five, respectively (USEIA 2017).

largest natural gas fields (USEIA 2019).[8] Second, the practice of hydraulic fracturing in Colorado has been particularly contentious.[9] Colorado's robust economic growth (Mullis et al. 2016) and rapid population growth (Murphy 2016) has witnessed oil and gas development's encroachment on suburban and urban areas (Davis 2012; Golten, Ward, and Mutz 2016; Shaffer, Zilliox, and Smith 2017), which has, in turn, led to conflict between state and local governments and between citizens and industry. Third, Colorado is a bellwether state. It has more stringent regulations than many other oil and gas producing states (Davis 2012; Richardson, Krupnick, and Wiseman 2013)[10] and it was the first state to implement MOUs between local governments and industry operators.[11] Since beginning the practice in 2005, Colorado has signed 47 MOUs—representing 11 cities/towns or counties—yielding ample data for analysis (Intermountain Oil and Gas BMP Project 2019c). Although Colorado is, to the author's knowledge, the only state to implement this type of MOU, we can learn valuable lessons about this approach to governance, which may be applicable to similar states.

While some scholars have investigated the ability of MOUs to facilitate marine management in Canada (McCrimmon and Fanning 2010), India's governance of public sector undertakings/state-owned enterprises (Subramanian 2016), and relatedly, whether the existence

[8] The state's crude oil production has also quadrupled since 2010, partly due to the increased use of hydraulic fracturing (USEIA 2019a). The Colorado BLM (2017) estimates that ninety percent of 2017 wells drilled in Colorado were hydraulically fractured indicating that most new wells drilled in the state use hydraulic fracturing in their exploitation.

[9] The cities of Boulder (and Boulder County), Broomfield (City and County), Fort Collins, Longmont, and Lafayette have all sought to ban or enact moratoria against hydraulic fracturing (Antonacci 2016).

[10] Colorado was the first state to regulate oil and gas produced methane emissions and was an early adopter of the requirement to publicly disclose chemicals in hydraulic fracturing fluids (Heikkila et al. 2014; Rinfret, Cook, and Pautz 2014; Shaffer, Zilliox, and Smith 2017).

[11] Some states, including Colorado, have MOUs in place between state regulators and operators, interagency agreements, and intergovernmental agreements governing oil and gas development. For example, California's Department of Conservation, Division of Oil, Gas, and Geothermal Resources, has many different MOUs with other state and federal agencies (California Department of Conservation 2019). To the author's knowledge no state other than Colorado employs MOUs between local governments and industry operators to govern oil and gas development.

of an MOU in an Indian central public enterprise increases its financial performance (Gupta, Jain, and Yadav 2011), even fewer studies have assessed MOUs in an oil and gas context. Fortuitously, the research analyzing MOUs in this context has emphasized Colorado. Shaffer, Zilliox, and Smith (2017) and Zilliox and Smith (2017), for example, analyze how MOUs signed by local governments and industry operators in Colorado shape public opinion of energy production; (Zilliox 2016) discusses the effectiveness of MOUs as a policy strategy for mollifying stakeholders' competing interests; Golten, Ward, and Mutz (2016) study the role of MOUs in curbing state versus local regulatory conflict; and Zilliox and Smith (2017b) examine the effectiveness of these agreements in terms of inclusion of community concerns, community engagement, and enforceability.

Although these studies lend helpful insight into how MOUs fit within a larger political landscape, they do not specifically analyze several important questions regarding MOU design, enforcement, and potential to increase trust in either/both industry and/or local government. Regarding MOU design, previous literature has left the following questions underexplored: How are MOUs related to oil and gas development structured; how do their designs differ across local governments and over time; and how do their designs align with the theoretical principles of successful natural resource management? Regarding enforcement, there are gaps in the literature surrounding the following questions: Does an MOU's design support enforcement; which entity has enforcement authority; and what challenges exist for enforcement? Regarding trust, the following question remains: To what extent do MOUs increase trust in either/both industry and/or local governments?

Literature review

As a way to understand the questions related to MOU design and provide context for the for future research related to enforcement and trust, the literature review proceeds as follows. First, it briefly discusses what an MOU is and how it may have advantages over other forms of collaboration and defines and characterizes MOUs as voluntary, self-governing environmental agreements or institutions. It then offers background on Colorado's oil and gas MOUs. Next, it discusses the IAD Framework and its companion, CPR theory, and places oil and gas development in a CPR context, briefly discussing literature on the application of CPR theory's DPs. The literature review concludes with a discussion of how CPR theory's DPs apply to MOU design elements.

What are MOUs?

MOUs, simply put, are written agreements—which may or may not be legally binding[12]—that clarify collaboration between two or more entities (Colorado Nonprofit Association 2013). MOUs often seek to streamline processes and establish formal relationships (Imperial 2005; Payne 1998). Written agreements, such as MOUs, have many advantages. The process of creating and revising an MOU, for example, allows parties to set the tone of the agreement and to agree upon key issues (Colorado Nonprofit Association 2013). Written documents can support accountability and reduce conflict between parties as these documents can clearly define expectations, decision-making procedures, roles, and responsibilities (Colorado Nonprofit Association 2013). Written documents also can make future collaborative efforts less dependent on specific leaders and can lessen potential distrust that may accompany losing previously established personal relationships when there is staff turnover (Bardach 1998;

[12] This depends on the MOUs specific language.

Imperial 2005). With these benefits, MOUs can help build successful and sustainable collaborations (Colorado Nonprofit Association 2013).

At a more complex level, MOUs are a way to "institutionalize shared policies and norms" (Imperial 2005, 299). Adopting MOUs thus is "an institutional-level activity because it results in rules that govern subsequent actions at the operational or policy-making level" (Imperial 2005, 289). MOUs also, according to North (1986),[13] fit within the definition of an institution, further supporting this viewpoint. Considering MOUs through an institutional lens, it is understandable that they have become common practice in diverse governance contexts.

MOUs in a governance context

Governments, in fact, have used MOUs to address a wide variety of issues beyond oil and gas development. While an exhaustive list of MOUs and their specific governance contexts is beyond the scope of this paper, it is appropriate to highlight a few MOUs that are outside this setting. One example is when the City and Borough of Wrangell (CBW), Alaska, entered into an MOU with the Wrangell Cooperative Association, a tribe in the CBW, to set the collaborative framework for transportation infrastructure projects in CBW (USDOT 2019). Not only is this outside the environmental context, but it also offers evidence that local governments can establish MOUs with tribal governments.

Local governments, in Colorado and in other states, have also used MOUs to address environmental issues beyond oil and natural gas development. California's Tahoe Regional Planning Agency, for example, used MOUs to avoid duplicative efforts and to formally delegate some of its watershed permitting responsibilities to local governments (Imperial 2005). The Colorado Department of Public Health; the U.S. Environmental Protection Agency, Region 8;

[13] "Institutions are rules, enforcement characteristics of rules, and norms of behavior that structure repeated human interaction" (North 1986, 6).

and the U.S. Department of the Interior, National Park Service, Rocky Mountain Region, enacted an MOU to establish a collaborative relationship between the parties to address air quality issues in Rocky Mountain National Park; this MOU specifically mandated parties to coordinate and consult with local governments (CDPHE 2019, 2005). In the former case, a regional government entity established an MOU to work with the local level, and in the latter case, state offices of federal agencies worked together to engage local government. These MOU examples offer insight into the potential applicability of this paper to other topical areas of interest (e.g., beyond either oil and gas development or environmental issues), as well to other levels of governments.

MOUs as voluntary environmental programs/agreements

MOUs are also akin to voluntary environmental programs or agreements (VEPs or VEAs). VEPs are a form of self-governance of natural resources or of environmental externalities from industries and are often used in place of, supplemental to, or in the absence of existing command-and-control regulation (Mosier and Fisk 2013; Steelman and Rivera 2006; J. E. Rivera and deLeon 2008; Delmas and Terlaak 2001; Coglianese and Nash 2016; Carter, Scott, and Mahallati 2018; Koehler 2007). VEPs are institutions that can induce firms to "produce positive environmental externalities beyond what government regulations require" (Prakash and Potoski 2007, 773; van der Heijden 2012). Some VEP literature likens them to clubs, or institutions for allocating and producing goods that are neither fully public (i.e. non-excludable, non-rivalrous) nor fully private (i.e. excludable, rivalrous) (Buchanan 1965; Prakash and Potoski 2007). VEPs can thus generate "positive social externalities to club members," which can have attributes of common property resources (Prakash and Potoski 2007, 276-277).

Like oil and gas MOUs VEPs are a strategic industry or firm tool that, depending on the VEP design, could reduce, or increase—if program membership is particularly taxing—a firm's

regulatory burden (Prakash and Potoski 2007). If regulatory burdens are reduced and firm membership is feasible, it could potentially keep regulators from passing additional regulations or could reduce the stringency of existing regulations (Khanna et al. 2007). VEPs can also communicate firms' environmental stewardship to both the public and stakeholders (Delmas and Terlaak 2001; Prakash and Potoski 2007) as well as to others in industry (Prakash and Potoski 2007).

VEPs have been around for decades in the United States (Darnall and Sides 2008; Rivera and deLeon 2008) and typically fall into one of three types: public agreements, unilateral agreements, and negotiated agreements (McEvoy and Stranlund 2010; Morgenstern and Pizer 2007; Alberini and Segerson 2002; Koehler 2007). In public agreements, regulators set requirements and membership rewards for program participation and firms voluntarily decide to join; in unilateral agreements, industry or firms develop and implement the program without regulatory involvement, and in negotiated agreements, which are similar to Colorado's oil and gas MOUs, firms/industry and regulators jointly set environmental targets (McEvoy and Stranlund 2010).

Despite the popularity of VEPs, debate as to their effectiveness, defined as the ability to meet their environmental goals, continues (Darnall and Sides 2008). Contributing to this debate is the heterogeneity present in VEP design and structure (Rivera and deLeon 2008; Darnall and Sides 2008). VEPs range from weak designs—with no required standards, reporting, or oversight—to strong designs—with performance-based requirements and certification (Rivera and deLeon 2008; Darnall and Sides 2008). Each design type, of course, has tradeoffs (Darnall and Sides 2008; ten Brink 2002). While weak designs may increase participation and flexibility and lower implementation costs, they may be less effective (ten Brink 2002). Similarly, strong

designs may see lower participation rates, be more rigid, and have higher implementation costs, but they may prove to be more effective than those VEPs with weak designs (ten Brink 2002; Carter, Scott, and Mahallati 2018).

Regardless of design strength, the VEP effectiveness literature discusses the need to mitigate two collective action problems in order to increase effectiveness: attracting firm/industry participants and ensuring that those who join adhere to the agreed upon objectives (Matisoff 2015; Potoski and Prakash 2009; Darnall and Sides 2008). Without active participation, whereby participants abide by the agreement, VEPs are largely pointless. As such, the literature emphasizes both how VEP design can positively influence participation rates and how to avoid free riding and shirking, whereby participants gain VEP benefits without investing in its goal (Carter, Scott, and Mahallati 2018; Prakash and Potoski 2007; Koehler 2007; Delmas and Terlaak 2001). While subsidies or decreased regulation can incentivize participation, the literature has identified two main elements to guard against free riding and shirking: monitoring and enforcement mechanisms (Prakash and Potoski 2007; Carter, Scott, and Mahallati 2018; Koehler 2007; J. Rivera and de Leon 2004; van der Heijden 2012; Lyon and Maxwell 2007). VEP designs with public disclosure of audit information, program sponsor sanctioning, and third party monitoring further discourage shirking and free riding (Prakash and Potoski 2007; Darnall and Carmin 2005; Darnall and Sides 2008; van der Heijden 2012).

As Colorado's oil and gas MOUs are comparable to VEPs, the discussion of how VEP design can influence agreement effectiveness directly relates to the exploration of MOUs' structure and the implications for their ability to minimize externalities associated with oil and gas development that uses hydraulic fracturing. The following section offers background information on the Colorado oil and gas MOUs as a way to provide context for the analysis.

Background on Colorado's oil and gas MOUs

While an in-depth history of Colorado's oil and gas regulatory history is beyond the scope of this paper, Golten, Ward, and Mutz (2016) remark that the 1980s and 1990s were fraught with legal conflicts over the question of state versus local control. These conflicts have persisted until the landmark 2016 Colorado Supreme Court decision in *City of Longmont v. Colorado Oil & Gas Association*, which determined that state regulations preempt conflicting local regulations if they interfere with the state's interest in permitting wells to reach their "maximum efficient rate of production" (COGCC 2014, 2). At the same time, local ordinances may not forbid what state law allows, or allow what state law forbids (COGCC 2014; Golten, Ward, and Mutz 2016; Colorado Supreme Court 2016). While the ramifications of this decision remain unclear, the Court has clearly ruled that state regulations preempt local ordinances prohibiting either oil and gas development more generally, or development specifically using hydraulic fracturing (Golten, Ward, and Mutz 2016).

Considering the financial costs of lawsuits[14] and the possibility for decisions that are unfavorable, local governments have continued to think beyond the courts as a way to resolve conflict (Golten, Ward, and Mutz 2016). Beginning in 2005, for example, La Plata County implemented MOUs with several industry operators[15] following lawsuits and both regulatory and citizen-industry conflicts (Golten, Ward, and Mutz 2016; Intermountain Oil and Gas BMP

[14] For example, the City of Fort Collins spent about $191,000 on outside counsel (Marmaduke 2016) and the City of Longmont spent $192,028 on special counsel costs for their respective attempts to ban hydraulic fracturing within their city limits (Antonacci 2016). The Colorado Oil and Gas Association, an industry group, spent about $1 million on its legal costs in their cases against Longmont, Fort Collins, and Broomfield (Antonacci 2016).

[15] In 2005, the Board of County Commissioners of La Plata signed MOUs with BP American Production Company and Samson Resources Company and in 2006 with BP American Production Company, ConocoPhillips Company, Burlington Resources Oil and Gas Company Elm Ridge Exploration Company, Four Star Oil & Gas Company, Maralex Resources Inc., Petrogulf Corporation, and ETO Energy Inc. (Intermountain Oil and Gas BMP Project 2019b). These MOUs have continued into 2014 for La Plata County and many other counties have followed suit (Intermountain Oil and Gas BMP Project 2019a).

Project 2019b). Most frequently negotiated through an administrative, rather than a public regulatory process, MOUs between industry operators and local governments are legally enforceable obligations and skirt the issue of state preemption and the somewhat murky question of jurisdiction (Golten, Ward, and Mutz 2016; Wilson 2012). In Colorado, for example, local governments typically have local land use authority to govern the placement or allowance of industry, such as marijuana dispensaries. The 2016 Colorado Supreme Court decision, however, made it clear that local governments lack land use authority when it comes to disallowing (via bans or moratoria) hydraulically fractured wells; local governments, however, do retain some land use authority that allows them to address other land use impacts, such as truck traffic on local roads.

MOUs potentially represent a non-zero-sum game whereby both industry operators and local governments (to include concerned citizens) benefit—in a "win-win" scenario. The MOUs that La Plata County signed with industry operators, for example, guaranteed the county certain operating practices and road fees in exchange for the operators' avoidance of lengthy formal hearings associated with the county's land use permitting process (Intermountain Oil and Gas BMP Project 2019a). Thus, the MOUs became a way to address local citizen concerns in a site-specific manner—sometimes above and beyond state regulations—and to avoid costly litigation, while ensuring industry operators the receipt of timely permits and development opportunities (Golten, Ward, and Mutz 2016).

Considering that, since 2005, many different counties and industry operators have enacted MOUs, variation among them is perhaps expected. MOUs, for example, differ substantially from one jurisdiction to another—both in terms of the process local governments use to negotiate them and the level of their specificity (Intermountain Oil and Gas BMP Project

2019a). In some instances, several operators will sign an MOU that is more general in nature with little time spent negotiating terms, and at other times, a single operator will sign a highly site-specific MOU following contentious negotiations (Intermountain Oil and Gas BMP Project 2019a). At times, MOU negotiations have involved industry and regulatory groups, respectively, (e.g., the Colorado Oil and Gas Association) and the Colorado Oil and Gas Conservation Commission[16] (COGCC), while others have not (Intermountain Oil and Gas BMP Project 2019a). Sometimes MOU negotiations have solicited public input, through public information sessions, city council and COGCC meetings, or have informally engaged the community and other stakeholders; at other times, the MOU negotiation process has largely excluded the public (Intermountain Oil and Gas BMP Project 2019a). Thus, MOUs can be heterogeneous.

While MOUs can be dissimilar from one another, they frequently have common elements in terms of their components. Generally, most MOUs introduce the reason for the MOU and define the parties to the agreement (Intermountain Oil and Gas BMP Project 2019a). While not universal, many MOUs also include the following administrative provisions: whether the agreement will apply to its successors or assigns, the timeframe for the agreement, definitions of terms, and information on default, force majeure (unforeseeable circumstances), waiver of rights, and how to end an agreement (Intermountain Oil and Gas BMP Project 2019a). MOUs also have common, though not universal, substantive provisions, such as: best management practices (BMPs),[17] in what context the MOU applies (e.g., for a specific well or for future development), fee and enforcement provisions, and information on operator and community incentives for enacting the agreement (Intermountain Oil and Gas BMP Project 2019a). Although the

[16] The COGCC is the Colorado regulator of oil and gas.
[17] BMPs themselves vary both in terms of where they appear in the MOU, if present, and what they include (Intermountain Oil and Gas BMP Project 2019a).

Intermountain Oil and Gas BMP Project (2016) has begun to differentiate these MOUs, categorizing their similarities and differences, they have not specifically studied whether an MOU's design elements increase of reduce trust in either/both local government and/or industry, whether their designs align with the theoretical principles of successful natural resource management, or whether and how they are enforceable.

Oil and gas development in a CPR context

To analyze MOUs' design elements, this paper draws on the IAD Framework and its companion, CPR theory. The IAD Framework is an overarching framework for studying the "ways in which institutions operate and change over time" (McGinnis 2011, 169). The IAD and CPR theory also provide insights on how institutional design can be robust for governing natural resources, especially though voluntary community-based agreements (Blomquist and deLeon 2011; McGinnis 2011; Heikkila, Schlager, and Davis 2011). While the broader IAD Framework is relevant, this paper emphasizes CPR theory because it provides insights on the types of design features of self-governing institutions that are known to be associated with successful governance of common-pool resources.

CPR theory is a valid tool for evaluating the design elements of an MOU between local government and industry for two main reasons. First, CPR theory has well-documented, empirically tested criteria for evaluating the robustness of self-governing institutions[18] e.g., MOUs (Carter and Weible 2014; Ostrom and Ostrom 1977; Ostrom 1990). Ostrom (1990), for example, studied scenarios in which communities created enduring and robust CPRs by

[18] MOUs themselves would qualify as an institution under Crawford and Ostrom's (1995, 582) definition: "Institutions are enduring regularities of human action in situations structured by rules, norms, and shared strategies, as well as by the physical world. The rules, norms, and shared strategies are constituted and reconstituted by human interaction in frequently occurring or repetitive situations." As previously mentioned, MOUs also qualify under North's (1986, 6) definition: "Institutions are rules, enforcement characteristics of rules, and norms of behavior that structure repeated human interaction."

developing their own self-regulation methods—without substantial government intrusion—which led to long-term, sustainable use of the resource. In this case, MOUs provide an example of a "self-governing" (e.g., between industry and local governments) institutional arrangement, rather than a self-governing institutional arrangement among the oil and gas producers. Second, while not a "pure" CPR, oil and gas development in Colorado shares similar characteristics to problems that arise with the governance of CPRs.

In the absence of property rights to the minerals, oil and gas reserves would fit the classic definition of a CPR: a resource where (1) the exclusion of users is either impossible or difficult and (2) the consumption of one user takes away from the consumption of another user (Ostrom and Ostrom 1977; Quilligan 2019). In Colorado, like all other states in the United States, mineral rights to oil and gas reserves are privately owned, which then makes the resource excludable. In other words, the institutions governing a CPR can change the characteristics of the resources as a "commons." However, many states, including Colorado, split the ownership (and leasing) of surface lands (landowners/leasers) from subsurface lands (mineral rights owners/leasers) (Wilson 2012). The rights of subsurface owners (e.g., those with mineral rights) and leasers trump the rights of surface owners (e.g., homeowners) and leasers, meaning that surface owners cannot prevent the development of minerals underlying their property (Wilson 2012).

This split property rights regime can create adversarial relationships between surface owners and mineral rights owners. If, for example, a surface owner wishes to use their land for a purpose other than oil and gas extraction (e.g., agricultural production), then this means that the mineral rights owner will detract from the consumption of the surface owner. Thus, many farmers and ranchers are opposed to hydraulic fracturing as oil and gas leaks and spills may

damage crops and kill livestock, and farmers must compete with oil and gas companies for water rights (Jaffe 2014; Finley 2012; Healy 2012).

MOUs also strive to address problems typical of commons governance e.g., the externalities caused by resource extraction. These negative externalities, briefly discussed in the paper's introduction, relate to environmental and health hazards, such as possible contamination of groundwater, drinking water, and soil and the potential for generating earthquakes (DeSmogBlog 2010). These externalities may extend beyond the property (or mineral rights) owner's overlying oil and gas wells. Thus, in the case of oil and gas development, there are characteristic impacts on surface owners, as well as other production externalities, that are similar to other CPR governance issues e.g., water (Herzog and Ingold 2019). To address these externalities, regulatory or top-down institutional arrangements can be (and have been) used. Yet, communities and the industry can also work together through collective action, as in the case of MOUs, to manage these challenges. Examining MOUs through the lens of CPR theory therefore potentially allows for the identification of design elements that will prove most effective in successfully addressing these externalities.

Literature examining natural gas development that uses hydraulic fracturing through a CPR lens, while limited, is not absent. Some research has examined the ability of two institutions, well-spacing requirements and integration contracts, to minimize environmental externalities, and has compared these externalities to non-point source pollution (Holahan and Arnold 2013). Others have framed hydraulic fracturing as a CPR problem to examine the rise in opposition to compulsory or "forced" pooling[19] (Farrer, Holahan, and Shvetsova 2013, 2017).

[19] Colorado law permits forced or "statutory" pooling (COGCC 2014). With forced pooling oil and gas companies can apply to the Colorado Oil and Gas Conservation Commission (COGCC), the state regulatory body, for an order to pool resources located within a drilling area, regardless of whether they have the mineral owner's consent, thereby allowing development to move forward (Sura 2019). Colorado House Bill 1336, "Additional Protections

Similarly, some literature has analyzed various applications of CPR theory's DPs and have examined the importance of individual DPs. Cox, Arnold, and Tomás (2010, 2), for example conducted a meta review of 91 studies that have applied the DPs, identifying the DPs' primary role as explaining "under what conditions trust and reciprocity can be built and maintained to sustain collective action." While they found differences in the level of support for the DPs, the lack of support they found was abstract rather than empirical (Cox, Arnold, and Tomás 2010). Overall, they characterize the DPs as being sound foundation for future research (Cox, Arnold, and Tomás 2010).

Recently the *International Journal of the Commons* published a special issue, where Schlager (2016) who wrote the editorial introduction to the issue specifically identified the Cox, Arnold, and Tomás (2010) meta review as the starting point to examine how DP patterns relate to diverse CPR settings. Included in the special issue is an article that analyzes both the co-occurrence of the DPs and the combinations of DPs that lead to social and ecological success (Baggio et al. 2016). Ultimately, they find that the importance of the DPs depends on the human made and natural infrastructure (i.e. equipment, canals) e.g., monitoring is more important when the infrastructure is static rather than mobile, and that the congruence between rules and local conditions and the proportionality between extraction and investment are key to a CPR's success. Despite the meta review and special issues consideration of the DPs, they have not emphasized MOUs' specific DPs. Thus, there is a gap in the literature.

Forced Pooling Order," intended to offer greater protections against forced pooling, passed the Colorado house in April 2017, but the Senate Committee on State, Veterans, & Military Affairs, postponed it indefinitely (BillTrack50 2019). Since then, Senate Bill 18-230 passed in June 2018; it clarifies that drilling may apply to more than one well and provides limited immunity from nonconsenting mineral owners and modifying the conditions for entering forced pooling (Colorado General Assembly 2018).

CPR theory's DPs and their application to MOU design elements

Although local governments and industry have enacted MOUs to manage the externalities of the oil and gas production process, to mitigate conflict, and to promote development, it is unclear which MOU design elements, if any, will be most effective at mitigating citizen-industry conflict and promoting sustainable use of the reserves, or whether all design elements must be present to witness the sustainable management of the resource. As both oil and gas industry development and related MOUs fit well in a CPR context, this paper uses CPR theory's design principles (DPs) as a way to evaluate the robustness of MOUs' design elements and thus their potential ability to sustainably govern oil and gas development that uses hydraulic fracturing.

This paper emphasizes six of the eight DPs. The first DP, "clearly defined boundaries" and the seventh CPR principle, "minimal recognition of rights to organize," do not vary in the Colorado context as all communities within the state have the authority to enter into MOUs and, as legal documents, all MOUs clearly specify both the parties to the agreement and the resource boundaries. Therefore, this paper does not examine the first or seventh DP. Appendix A overviews and briefly defines the eight DPs that empirical evidence has shown to produce long-enduring CPR institutions (Ostrom 1990, 90).

Groups that structure institutional arrangements based on these DPs are likely to be more robust and to survive over time (Ostrom 2008). CPR users follow operational rules, or "agreed-upon and enforced prescriptions that require, forbid, or permit specific actions for more than a single individual" (Schlager and Ostrom 1992, 250) and they collectively participate in shaping the rules for participation and action, the most important of which are access and withdrawal (Schlager and Ostrom 1992). Similarly, if "enough of the design principles are in use,"

institutions may solve their immediate CPR problem, but will not endure "unless further institutional development occurs and the arrangements come closer to meeting the full set of design principles" (Ostrom 1990, 181). These DPs work together in a variety of ways to mitigate conflict and to promote the sustainable management of the CPR.

What follows is a brief discussion of each of the six DPs analyzed in this paper, and how they relate to MOUs.

DP #2, "congruence between appropriation and provision rules and local conditions," equates to a "proportional equivalence" between costs and benefits. For MOUs, this principle equates to clear industry operation guidelines specific to the local setting, with funds for their implementation.

DP #3, Ostrom's (2008) "collective-choice arrangements," allows affected users to have a voice in crafting or changing rules. In MOUs this principle translates to "opportunities for relevant actors to participate in collective choice arrangements," which translates to the ability to define and/or change the rules. Not only does this principle allow users to create an agreement that considers the local context, it also helps to maintain the agreements as environments change over time (Ostrom 2008). In the MOU context, this involves the participation of all relevant stakeholders in the form of community engagement/notification.

DP #4, "monitoring," gives stakeholders the ability to go beyond blindly trusting each other and hoping for reciprocity. MOUs may require/allow operator-level/local-level monitoring. In some instances, MOUs may require monitoring by local government actors or neutral third parties who are independent of both the COGCC and the oil and gas companies. Some members of the public believe that the COGCC does not operate independently of the oil and gas industry e.g., that the COGCC suffers from regulatory capture, given its dual mandate to both promote

and regulate oil and gas development (Johnson 2013). Independent monitoring may further increase the public's level of trust and confidence in the practice of hydraulic fracturing.

DP #5, "graduated sanctions," establishes a clear penalty system for breaking the rules, but given its graduated nature, is forgiving if a stakeholder unintentionally violates the agreement (Ostrom 2008). For MOUs, this principle relates to an enforcement mechanism and equates to the existence of both a default mechanism and a clear process for responding to defaults. In addition to identifying whether an MOU has and enforcement mechanism and what it might look like, future research will also consider the stringency of the enforcement mechanism.

DP #6, "conflict resolution mechanisms," necessitates "rapid, low-cost, local arenas to resolve conflict" (Ostrom 2008, 9). In an MOU, this is a dispute resolution mechanism.

DP #8, "nested enterprises," whereby governance occurs in nested layers, makes particular sense from a conflict mitigation perspective (Ostrom 2008). As the state government in Colorado has regulatory authority over oil and gas development and MOUs are taking place at the local level, it is particularly important to design MOUs that fit within the confines of the state's broader legal framework. If, for example, the COGCC views a component of the MOU to be in violation of the law, then this will likely increase, not reduce conflict. This DP is manifested as linked or nested governance in an MOU.

Data and methods

Ideally this paper would examine the population of 47 MOUs, as a way to identify the presence of CPR theory's DPs both spatially and temporally, however, this is beyond the paper's scope at this time. Instead, this paper takes a first step by analyzing 13 different MOUs across 11 different local governments and two different shale plays, the Denver-Julesburg (D-J) Basin and the San Juan Basin. This paper examines MOUs from the following local governments: La Plata

County (2005 and 2014), Longmont (2012), Town of Erie (2012 and 2015), Arapahoe County (2013), Fort Collins (2013), City and County of Broomfield (2013), Hudson (2014), Elbert County (2014), Adams County (2015), Town of Timnath (2015), and Brighton (2017). This sample is representative of the local governments that have enacted oil and gas MOUs. Coding a representative sample of MOUs lends insight into the variation across MOUs over time. Table 1 below gives an overview of the 13 MOUs coded and provides information on the county and shale basin that each local government represents.

Table 1: MOUs Coded by County and Shale Play

Parties to MOU	Year	County of Local Government	Shale Play
La Plata County & BP	2005	La Plata	San Juan Basin
Longmont & TOP	2012	Boulder	Denver-Julesburg Basin
Town of Erie and Encana	2012	Boulder & Weld	Denver-Julesburg Basin
Arapahoe County & "Operator"	2013	Arapahoe	Denver-Julesburg Basin
Fort Collins & Prospect Energy	2013	Larimer	Denver-Julesburg Basin
City and County of Broomfield and Sovereign	2013	Broomfield	Denver-Julesburg Basin
Hudson & Great Western	2014	Weld	Denver-Julesburg Basin
La Plata County & XTO Energy	2014	La Plata	San Juan Basin
Elbert County & Agave	2014	Elbert	Denver-Julesburg Basin
Adams County and Great Western	2015	Adams	Denver-Julesburg Basin
Town of Timnath and Peterson Energy	2015	Larimer	Denver-Julesburg Basin
Town of Erie and Encana	2015	Boulder & Weld	Denver-Julesburg Basin
Brighton and Petro	2017	Adams	Denver-Julesburg Basin

At the same time, the author coded two Town of Erie and two La Plata County MOUs to assess the variation within local governments over time. Details on the variation within governments and across MOUs appears below.

Variation within local governments

Although the La Plata County signed the first MOUs in 2005, the 2012 and 2015 MOUs between the Town of Erie (Erie) and Encana are particularly interesting for a variety of reasons. First, given that Erie implemented these MOUs with the same operator, Encana Oil and Gas, it

offers an excellent opportunity for conducting a comparison over time. Second, the Town of Erie offers an interesting case study as it spans Boulder and Weld counties, which traditionally have very different political positions and divergent outlooks on oil and gas development (Zilliox 2016). Weld County has a long history with oil and gas development and is majority Republican, while Boulder County has little experience with oil and gas development and is majority Democratic (Zilliox 2016).

Third, the 2012 Erie MOU, while certainly not the first MOU negotiated with an oil and gas operator, was the first of its kind in many ways (Dunnahoe 2013; Aguilar 2012). It was, for example, the first MOU to establish a relationship at the company, rather than at the individual well level, shifting the MOU negotiation process from a "well-by-well basis" to a "company-by-company basis" (Aguilar 2012, 1).

Fourth, while the first MOUs in La Plata County in 2005 included a series of best management practices (BMPs) for a specific well location, they did not include among them noise, light, and dust mitigation plans (as seen in Appendix A).[20,21] The 2012 Erie MOU was the first MOU to include these among their BMPs. Fifth, the 2015 Erie MOU greatly expanded the BMPs of the 2012 MOU. The 2012 Erie MOU, for example, specified 11 BMPs, while the 2015 MOU specified 39 (Intermountain Oil and Gas BMP Project 2019c). Thus, comparing these two

[20] The author selected and MOU from each local government in Colorado that had signed an MOU and selected MOUs based on the level of completeness. Many of the MOUs that the Intermountain Oil and Gas BMP project database has are in various stages of completion. The Arapahoe County MOU that the author coded, for example, is a generic operator agreement and is thus missing the name of the operator, the date, and signatures. Since writing this paper, however, the author has acquired all MOUs that the county signed and the generic agreement coded in this paper is nearly identical to the others that the county passed. Other copies of MOUs analyzed, specifically Adams County, Timnath, and Erie's 2015 MOU, are missing complete signatures from all parties, but are otherwise complete.

[21] While Erie's 2012 MOU specified that Encana had to submit "a plan for noise, light, and dust mitigation, to the extent feasible," this was the only mention of these appropriation rules in the document (Town of Erie 2012, 6). Thus, the coding scheme for the paper did not find this substantive enough to warrant coding it in the affirmative.

Erie MOUs may offer relevant insight into the robustness of these MOUs and the possibility for mitigating citizen-industry and regulatory conflict.

While comparing the 2005 and 2014 La Plata County MOUs to the two Erie MOUs is also an interesting exercise for studying variation within local governments, the La Plata County MOUs are, unfortunately, with two different operators. This somewhat limits the comparative power within La Plata County. Interestingly, the number of DPs represented in the La Plata MOUs declined over time.

Variation across MOUs

While a detailed comparison of each individual MOU in relation to the others coded is beyond the scope of this paper, the City of Brighton's 2017 MOU with Petro Operating Company, LLC is worth further discussion for two main reasons. First, the 2017 Brighton MOU, compared to the 2015 Erie MOU expands the number of BMPs and addresses 102 different BMPs (Intermountain Oil and Gas BMP Project 2019c). Second, the 2017 Brighton MOU provides an interesting opportunity to examine whether municipalities have implemented any structural changes to the MOUs following the 2016 Colorado Supreme Court decision. Now that the Colorado Supreme Court has ruled that municipalities are unable to pass bans or five-year moratoria on oil and gas development that uses hydraulic fracturing (*The Denver Post* Editorial Board 2016), it is possible that municipalities, however unintentional, may include higher numbers of CPR theory's DPs in their MOUs as a way to strengthen their ability to mitigate conflict.

Document coding: Translating traditional CPR DPs to an MOU context

In order to determine how many CPR DPs (of the seven studied) are present in the 13 different MOUs, the paper presents a document coding scheme that translates six of the eight

traditional CPR DPs to an MOU context. As previously mentioned, DP #7, "minimal rights to organize" does not vary across MOUs. In addition, the paper does not report findings for DP #1, "clearly defined boundaries" as this also does not vary across MOUs (draft agreements, however, may not contain this information). What follows is a brief account of how to identify traditional DPs in oil and gas MOUs.

Some CPR scholars split DP #2, "congruence between appropriation and provision rules and local conditions," into appropriation versus provision rules, and this adjustment makes sense in the MOU context; thus, this chapter splits DP #2 into 2.1, provision rules (for appropriation) and 2.2 (a-n), appropriation rules tailored to the local setting. In the MOUs, provision principles pertain to occasions where operators pay for costs associated with implementation, such as costs associated with monitoring, or those associated with mitigating the development's impact This must be a substantive effort to provide rules for appropriation. An example would be an MOU that requires developers to pay road impact fees or repair fees, or costs associated with monitoring, such as water quality/supply monitoring. Appropriation rules equate to clear industry operation guidelines specific to the local setting that guide how the resource is extracted or produced. This paper codes for the following appropriation rules (a-n): air quality/methane emissions, noise, water quality, water supply, road/traffic, setbacks, dust, chemicals, wildlife, floodplain requirements, visual impacts/landscape requirements, pits and waste disposal, containment berms, and flow lines.

DP #3 "collective-choice arrangements," or "opportunities for relevant actors to participate in collective choice arrangements," in the MOU context, has, to some extent already been completed through the permitting process; the Oil and Local Gas Assessment (OLGA), one of the two permits oil and gas operators must obtain from the COGCC prior to drilling, for

example, requires a 20-day public comment period, during which citizens may make comments and local governments may consult and request extensions to the public comment period to 30 or 40 days (COGCC 2019a). Thus, this DP pertains to forms of community engagement that allows the public to assist in defining or changing the rules. What follows are examples of community engagement: the ability/requirement for meetings with the public, surface owners, or representatives of local government; notification of impending development, via posted signs, mailed notices, or community web pages; and the ability for the community to have a voice or dialogue, such as allowing public comment, or posting contact information for 24/7 noise complaints. This is a softer interpretation of the DP.

As MOUs can contain information on the ability for and regularity of local-level monitoring (DP 4.1 and 4.2, respectively) and the requirement for operator-level monitoring (DP 4.3) at specific intervals (DP 4.4), this paper splits DP #4 into these four categories. Required operator-level monitoring/inspections can relate to a variety of things e.g., monitoring or air and water quality and soil testing, testing pipelines and flow lines, and monitoring of storage facilities, etc. The ability to conduct local-level monitoring/inspections can also relate to a variety of things e.g., roads; facilities; and air, water, soil monitoring, etc. This includes the stated ability of the operator and local government to meet as necessary to monitor and discuss issues related to development. MOUs that specify a time frame for either local-level or operator-level monitoring e.g., monthly, yearly, at beginning and ending of operations, etc., qualifies as regular monitoring.

While DP #5, "graduated sanctions," generally refers to an explicit mechanism for sanctioning violators, as the COGCC is the state regulator of oil and gas development in Colorado, in an MOU context this translates to default processes or an enforcement mechanism.

Default mechanisms are processes put in place by the negotiators to address appropriators' (oil and gas companies) or officials accountable to the appropriators' (local governments) violations of the operational rules. The paper splits this DP into 5.1, a specified default mechanism or process, and 5.2, a clear indication of how to respond to defaults. If an MOU mentions a mechanism for default or breach of agreements, then this is sufficient evidence of a default process. If an MOU outlines a clear method for responding to defaults e.g., time frames for curing defaults, then this counts as a default response. Future research efforts will also evaluate the stringency level of the default process/enforcement mechanism as well as the party responsible for enforcing MOU provisions, if any.

For MOUs, DP #6, "conflict resolution mechanisms," translates to dispute resolution mechanisms (DP 6.1) and whether the dispute resolution mechanism is low cost (DP 6.2). Low cost mechanisms equate to negotiation, arbitration, facilitation, and mediation. Law suits are not low-cost measures. The City and County of Broomfield and Sovereign Operating Company's (2013, 12-13) "Oil and Gas Operator Agreement" states for example, "If either Party believes that mediation would be advantageous in connection with such meeting, or if a resolution of the matter cannot be achieved at the meeting, both parties agree to make a reasonable effort to work through and with a mutually acceptable mediator to attempt to resolve the dispute."

In MOUs DP #8, "nested enterprises," equates to nested governance. If an MOU mentions the COGCC, city/county ordinances, federal and state laws, this is evidence of nested governance. The City and County of Broomfield and Sovereign Operating Company's (2013, A-27) "Oil and Gas Operator Agreement" states for example, "The Operator agrees to comply with applicable State of Colorado, Department of Natural Resources and other applicable State

regulations concerning the source of water used in drilling and completion operations." After coding many MOUs, however, it became clear that this DP does not vary.

Table 2: Coding Strategy for CPR Theory's Design Principles (DPs) in MOUs

DP #1: Clearly defined boundaries: Individuals or households who have rights to withdraw resource units from the CPR must be clearly defined, as must be the boundaries of the CPR itself.		
DP (name)	**DP (#)**	**Evidence of DP in MOU**
Clearly defined social/group boundaries	1.1	MOU explicitly specifies the parties to the agreement. **Note: All final MOUs will specify this; thus, it will not vary.**
Clearly defined resource/physical boundaries	1.2	MOU explicitly specifies where the MOU applies. **Note: All final MOUs will specify this; thus, it will not vary.**
DP #2: Congruence between appropriation and provision rules and local conditions: Appropriation rules restricting time, place, technology, and/or quantity of resource units are related to local conditions and to provision rules requiring labor, material, and/or money.		
DP (name)	**DP (#)**	**Evidence of DP in MOU**
Congruence between appropriation and provision rules	2.1	MOU requires operators to fund costs/impacts associated with appropriation.
Congruence between rules/levels of restrictions and local conditions	2.2	As many MOUs offer best management practices that are specific to the local conditions, this design principle splits the appropriation rules into specific areas as a way to assess how well the MOU covers issues that may impact the surrounding area.
Air quality/methane emissions	2.2a	MOU includes substantive rules pertaining to air quality (mitigating air pollution) or methane emissions.
Noise	2.2b	MOU includes substantive noise rules.
Water quality	2.2c	MOU includes water quality rules; this includes rules on spills, containment berms, well casing requirements to protect groudwater; recycling/reusing wastewater to minimize the volume of waste produced; responsible products programs that limit the types of chemicals/fluids that a company uses to lessen environmental impacts; and water quality monitoring plans.
Water supply	2.2d	MOU includes water supply rules; this pertains to any specific rules regarding where an operator sources its water, water sources in close proximity to wellsites, etc.
Road/Traffic	2.2e	MOU includes road/traffic rules; this includes any requirements for access/private roads and public roads; rules related to either/both road construction, road use/maintenance/upkeep, weight/chain restrictions, and road permits, traffic studies, submission of proposed routes and traffic volume during development, and traffic management plans, etc.
Setbacks	2.2f	MOU includes setbacks rules e.g., rules associated with the minimum distance a well or anything associated with development (waste disposal pits, pipelines, flowlines, etc.) must be from occupied buildings, open spaces, or waterways.
Dust	2.2g	MOU includes substantive dust rules to mitigate/suppress dust generated in association with the development. This includes dust control plans that require local government approval of the material used for dust suppression as a condition for an access permit.
Chemicals	2.2h	MOU includes rules on chemical storage to include the prohibition of storing chemicals, any specifications on the design of chemical storage facilities, requirement for information on chemicals being stored, or the need for designated storage for chemicals.
Wildlife	2.2i	MOU substantive rules pertaining to wildlife.
Floodplain requirements	2.2j	MOU includes floodplain rules, such as the prohibition or limitation of development activities in a floodplain or compliance with specific local government ordinances that pertain to floodplains.
Visual impacts/landscape requirements	2.2k	MOU includes rules to reduce visual impacts e.g., requirements for lighting, weed control, fencing, paint color, etc., or any landscape requirements, such as revegetation.
Pits and waste disposal	2.2l	MOU includes rules for pits or any waste disposal. Evidence of this is the requirement for a closed-loop or modified closed-loop systems; waste management and the disposal/removal of waste, to include produced water and pipelines for waste removal.
Containment berms	2.2m	MOU includes rules for containment berms, their use and/or requirements for their composition/structure.
Flow lines	2.2n	MOU includes substantive rules for flow lines , which transport oil and gas from well sites; this includes rules for flow lines setbacks and locations of flow lines, construction and operation provisions, the need to record locations with the local government, etc.
DP #3: Collective-choice arrangements: Most individuals affected by the operational rules can participate in modifying the operational rules.		
DP (name)	**DP (#)**	**Evidence of DP in MOU**
Collective choice arrangements	3	MOUs include forms of community engagement between operators and public e.g., public meetings or meetings with surface owners; information provided to community e.g., 24/7 contact information on noise complaints ; notification of commencing operations, to include signs and mailed notices; and opportunities for community to have a voice, such as the ability to comment at public meetings.**(This is a softer interpretation of the DP.)**
DP #4: Monitoring: Monitors, who actively audit CPR conditions and appropriator behavior, are accountable to the appropriators or are the appropriators.		
DP (name)	**DP (#)**	**Evidence of DP in MOU**
Local level monitoring enabled	4.1	MOU mentions or enables local government monitoring and/or inspections related to oil and gas development. This could relate to roads; facilities; and air, water, soil monitoring, etc. This includes the stated ability of the operator and local government to meet as necessary to monitor and discuss issues related to development.
Regular local level monitoring conducted	4.2	MOU specifies that the local governments will conduct monitoring/inspections related to oil and gas development with any regularity e.g., monthly, quarterly, yearly, at beginning and ending of operations, etc.
Operator level monitoring required	4.3	MOU requires operator-level monitoring/inspections. These inspections could relate to a variety of things e.g., monitoring of air and water quality and soil testing, testing pipelines and flow lines, monitoring of storage facilities, etc.
Regular operator level monitoring conducted	4.4	MOU specifies that the operator must conduct regular monitoring e.g., monthly, yearly, at beginning and ending of operations, etc.
DP #5: Graduated sanctions: Appropriators who violate operational rules are likely to be assessed graduated sanctions (depending on the seriousness and context of the offense) by other appropriators, by officials accountable to these appropriators, or both.		
DP (name)	**DP (#)**	**Evidence of DP in MOU**
Default processes	5.1	MOU has explicit mechanism for default processes. **(This is a softer interpretation of the DP.)**
Default response	5.2	MOU's default processes for responding to the default are clearly specified e.g., the MOU sets up a detailed plan for responding to the default.
DP #6 Conflict-resolution mechanisms: Appropriators and their officials have rapid access to low-cost local arenas to resolve conflicts among appropriators or between appropriators and officials.		
DP (name)	**DP (#)**	**Evidence of DP in MOU**
Dispute resolution	6.1	MOU specifies how disputes get resolved e.g., a dispute resolution mechanism.
Dispute resolution costs	6.2	The MOU contains a dispute resolution mechanism that is low cost e.g., mediation, negotiation, facilitation (lawsuits are not low cost).
DP #7 Minimal recognition of rights to organize: The rights of appropriators to devise their own institutions are not challenged by external governmental authorities.		
As the state already gives local governments the right to organize, all MOUs will have this DP. Therefore, given the lack of variation, this study does not examine this DP.		
DP #8 Nested enterprises: Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises. (For CPRs that are part of larger systems.)		
DP (name)	**DP (#)**	**Evidence of DP in MOU**
Nested enterprises	8	MOU contains specific language that mentions state/local government (city/county) rules/laws e.g., COGCC rules, city ordinances, etc. **Note: After coding 13 MOUs it is clear that this DP does not vary.**

Results and discussion

This paper carefully considers the following 13 MOUs: La Plata County (2005 and 2014), Longmont (2012), Town of Erie (2012 and 2015), Arapahoe County (2013), Fort Collins (2013), City and County of Broomfield (2013), Hudson (2014), Elbert County (2014), Adams County (2015), Town of Timnath (2015), and Brighton (2017). To assess the potential effectiveness of the MOUs, the author conducts document coding to identify the presence of CPR theory's DPs. Table 3 details the findings of the coding for DPs 2.1 (note: this excludes appropriation rules in 2.2 a-n), 3, 4, 5, 6, and 8. As previously mentioned, the paper splits DP #4 into four parts, DP #5 into two parts, and DP #6 into two parts; thus, the coding scheme's findings in Table 3 consider 11 DPs.

Table 3: CPR Theory's Design Principles (DPs) in Colorado's Oil and Gas MOUs

Name of MOU/ Operator Agreement (and Year)	2.1: Operator pays for implementation costs/adverse impacts	3: Operators interact with community	4.1: Allows local-level monitoring	4.2: Regular interval of local-level monitoring	4.3: Requires operator-level monitoring	4.4: Regular operator-level monitoring	5.1: Specifies default mechanism	5.2: Clearly specifies how to respond to defaults	6.1: Dispute resolution	6.2: Low-cost dispute resolution	8: Nested governance	Percentage of design principles present by MOU
La Plata County & BP (2005)	✓				✓	✓			✓	✓	✓	55%
Longmont & TOP (2012)	✓		✓		✓	✓	✓		✓	✓	✓	73%
Erie and Encana (2012)		✓					✓	✓			✓	36%
Arapahoe County & "Operator" (2013)	✓	✓	✓	✓	✓	✓	✓	✓			✓	82%
Fort Collins & Prospect Energy (2013)	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	91%
City and County of Broomfield and Sovereign (2013)	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	91%
Hudson & Great Western (2014)	✓						✓	✓			✓	36%
La Plata County & XTO Energy (2014)	✓				✓				✓	✓	✓	45%
Elbert County & Agave (2014)		✓	✓	✓	✓	✓	✓	✓			✓	73%
Adams County and Great Western (2015)	✓	✓	✓	✓	✓	✓	✓	✓			✓	82%
Timnath and Peterson Energy (2015)	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	91%
Erie and Encana (2015)	✓	✓	✓		✓	✓			✓	✓	✓	73%
Brighton and Petro (2017)	✓	✓	✓		✓	✓	✓	✓			✓	73%
	85%	69%	69%	23%	85%	77%	77%	69%	54%	54%	100%	
Percentage of individual design principles present across MOUs (Note: Does not include appropriation rules)												

Of the 13 MOUs examined, 77 percent (10/13) exhibited at least 50 percent of the coded DPs. Fort Collins, Bromfield, and Timnath all had 91 percent (10/11) of the DPs, the highest in the sample coded. The 2012 Erie MOU and the 2014 Hudson MOU had the fewest DPs present, 4/11 or 36 percent. DP #8, nested governance, was present in all MOUs. As oil and gas MOUs are already embedded in multiple levels of government, from the local level to the federal level, it is unsurprising that they would all exhibit this. For this reason, future coding of these MOUs need not consider this DP.

The cases of Fort Collins and Longmont are particularly interesting given the Colorado Supreme Court's 2016 ruling against these cities for trying to ban or have a moratorium on hydraulic fracturing. While Fort Collins' 2013 MOU had 91 percent of the DPs, Longmont's 2012 MOU only had 73 percent. While Fort Collins and Longmont passed these MOUs long before the Supreme Court ruling, Brighton's 2017 MOU passed after the ruling only had 73 percent of the DPs represented. This may indicate that the ruling did not impact MOU design. To better understand whether this is the case, however, requires coding more than one MOU enacted after the ruling. As MOUs might take a year or more to develop, it will be interesting to see whether future MOUs exhibit more representation of the DPs and thus are more institutionally robust.

While the presence of the DPs appears to have increased over time, this has not always been the case, especially when considering variation within local governments. Erie's 2015 MOU increased the number of DPs present to 73 percent or 8/11 DPs (compared to its 2012 MOU), but La Plata County actually had a higher number of DPs in its 2005 MOU (55 percent or 6/11) compared to its 2014 MOU, which had 5/11 or 45 percent. This suggests that MOU

variation is more complex than simply the passage of time or the presence of institutional learning.

This paper examines the following 14 different appropriation rules: air quality/methane emissions, noise, water quality, water supply, road/traffic, setbacks, dust, chemicals, wildlife, floodplain requirements, visual impacts/landscape requirements, pits and waste disposal, containment berms, and flow lines. Table 4 presents the presence of these appropriation rules across MOUs.

Table 4: CPR Theory's Appropriation Rules in Colorado's Oil and Gas MOUs

Name of MOU/ Operator Agreement (and Year)	2.2a: Air quality/ methane	2.2b: Noise	2.2c: Water quality	2.2d: Water supply	2.2e: Road/ traffic	2.2f: Setbacks	2.2g: Dust	2.2h: Chemical storage	2.2i: Wildlife	2.2j: Floodplain	2.2k: Visual/ landscape	2.2l: Pits and waste disposal	2.2m: Containment berms	2.2n: Flow lines	Percentage of appropriation rules present by MOU
La Plata County & BP (2005)	✓		✓		✓	✓						✓			36%
Longmont & TOP (2012)		✓	✓		✓	✓	✓			✓	✓	✓		✓	64%
Erie and Encana (2012)	✓		✓	✓	✓	✓						✓	✓		50%
Arapahoe County & "Operator" (2013)		✓	✓	✓	✓	✓	✓			✓	✓	✓	✓		71%
Fort Collins & Prospect Energy (2013)	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	93%
City and County of Broomfield and Sovereign (2013)	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	93%
Hudson & Great Western (2014)			✓		✓			✓				✓			29%
La Plata County & XTO Energy (2014)	✓		✓	✓	✓	✓	✓					✓			50%
Elbert County & Agave (2014)	✓		✓	✓	✓	✓	✓			✓	✓	✓	✓		71%
Adams County and Great Western (2015)	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		86%
Timnath and Peterson Energy (2015)	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	93%
Erie and Encana (2015)	✓	✓	✓		✓	✓	✓				✓	✓	✓		64%
Brighton and Petro (2017)	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	86%
	77%	62%	100%	69%	92%	92%	77%	38%	8%	62%	69%	100%	69%	38%	
	Percentage of individual design principles present across MOUs														

In terms of the appropriation rules studied, eighty-five percent (11/13) MOUs contained at least 50 percent of the 14 appropriation rules considered. The Fort Collins, Timnath, and

Broomfield MOUs all had 93 percent (13/14) appropriation rules. Hudson's MOU had the fewest number of appropriation rules at 29 percent or 13/14, and La Plata County's 2005 MOU had the next lowest at 36 percent or 5/14. All MOUs had appropriation rules for pits and waste disposal and water quality. Although the fact that all MOUs had these appropriation rules is interesting, it is not surprising. Perhaps one of the largest concerns opponents of hydraulic fracturing have relates to water quality issues, and waste disposal directly links to water quality, especially where homeowners are reliant on well water as their source of drinking water.

Ninety-two percent of all MOUs also had road/traffic and setbacks appropriation rules. The finding on road/traffic rules and setbacks is somewhat expected. Setbacks rules can make a difference in terms of whether the industry locates a well in someone's residential backyard. The abundance of road/traffic rules is also understandable given Colorado's booming population growth, which has already begun to increase traffic on roadways; adding heavy, industrial trucks only increases these issues. Adams County's 2015 MOU is the only that included wildlife rules, which is interesting considering that many MOUs specifically mention wildlife protected as one of the rationales for creating the MOU. Rules for chemical storage and flow lines were not well-represented across the MOUs; they were present in only 38 percent or 5/13 MOUs. This is particularly interesting given the COGCC's recent rule making session on flow lines, which suggests that there have been issues with flow lines in the past.

Conclusion and next steps

This paper takes a first step in examining MOUs between local governments and oil and gas industry operators using CPR theory's DPs with a broader research goal of understanding how the design of these MOUs, including the stringency of enforcement, relate to enforcement in practice—to include enforcement challenges, and trust. It analyzes the following 13 MOUs: La

Plata County (2005 and 2014), Longmont (2012), Town of Erie (2012 and 2015), Arapahoe County (2013), Fort Collins (2013), City and County of Broomfield (2013), Hudson (2014), Elbert County (2014), Adams County (2015), Town of Timnath (2015), and Brighton (2017) for evidence of six CPR theory DPs.

Specifically, the paper considers the following DPs: 2, congruence between appropriation and provision rules (split into 2.1 for provision rules and 2.2 a-n for specific appropriation rules i.e., air quality/methane emissions, noise, water quality, water supply, road/traffic, setbacks, dust, chemicals, wildlife, floodplain requirements, visual impacts/landscape requirements, pits and waste disposal, containment berms, and flow lines); 3, collective choice rules, which equates to community engagement; 4, monitoring (split into four parts, ability for local-level monitoring, the requirement of operator-level monitoring, and the regularity of the interval for each); 5, graduated sanction, which pertains to default in MOUs (split into two parts, default processes and default responses); 6, conflict resolution mechanisms, which relate to dispute resolution in MOUs (split into two parts, dispute resolution and the cost of dispute resolution); and 8, nested enterprises, which is nested governance in MOUs.

Strong evidence of the DPs exists in the 13 MOUs examined. Seventy-seven percent (10/13), for example, exhibited at least 50 percent of the 11 coded DPs and 85 percent (11/13) of the MOUs contained at least 50 percent of the 14 appropriation rules considered and the presence of these DPs appears to increase, for the most part, over time. While local governments are not likely making a conscious effort to increase the numbers of DPs represented, perhaps these numbers bode well for the management of oil and gas reserves in Colorado. Theoretically, institutions that design property right based on CPR's DPs are likely to be more robust and to survive over time (Ostrom 2008). The DPs may work in concert to mitigate conflict.

The case of oil and gas as a CPR is an interesting one as its management and use directly impacts additional CPRs, such as airsheds, watersheds, and open spaces. Given rapid population growth, the demand for the preservation of open space, especially considering its multiple uses, could be a flashpoint for conflicts should oil and gas infiltrate these areas. Boulder County is currently facing this dilemma following the submission of a comprehensive drilling plan in areas that involve open space (del Castillo 2017). For this reason, effectively managing the oil and gas CPR is critical, not only as a potential method for mitigating conflict, but also for environmental protection.

To fully understand the possible linkages between CPR theory's DPs presence in MOUs and their potential to ameliorate conflict, however, requires further study. A next step in this research would be to examine the population of oil and gas MOUs in Colorado and assess them for their presence of CPR theory's DPs. Further research should identify potential causes for variation among MOUs e.g., intensity of conflict; demographic, political, and geographic factors. Researchers should also develop a composite score for each DP to better compare the DPs present in the MOUs with more traditional understanding of the DPs and conduct interviews with stakeholders involved in the MOU process. A final step in this broader research agenda involves operationalizing trust, while controlling for potential confounding factors, to determine whether these MOUs are actually playing a role in trust and whether individual design principles are more effective at promoting trust than others. Clearly these MOUs offer a potential avenue for effectively managing oil and gas development in Colorado and subsequently they may offer a potential path for reducing conflict over the contentious issue of oil and gas development that uses hydraulic fracturing.

Works cited

(UCS), Union of Concerned Scientists. 2015. "Managing the Risks of Unconventional Oil and Gas Development What Local Communities Can Learn from Others' Experiences." Cambridge, MA. https://www.ucsusa.org/sites/default/files/attach/2015/07/ucs-managing-risks-unconventional-oil-gas-development-2015.pdf.

Aguilar, John. 2012. "Erie's Oil and Gas Agreements Could Serve as Statewide Model." *Boulder Daily Camera*, September 6.

Alberini, Anna, and Kathleen Segerson. 2002. "Assessing Voluntary Programs to Improve Environmental Quality." *Environmental and Resource Economics* 22 (1/2). Kluwer Academic Publishers: 157–84. doi:10.1023/A:1015519116167.

Antonacci, Karen. 2016. "Colorado Supreme Court Strikes Down Longmont's Voter-Approved Fracking Ban." *Longmont Times-Call*, May 2. http://www.timescall.com/longmont-local-news/ci_29839751/colo-supreme-court-strikes-down-longmont-fracking-ban.

Baggio, Jacopo Alessandro, Allain J. Barnett, Irene Perez-Ibarra, Brady Ute, Elicia Ratajczyk, Nathan Rollins, Cathy Rubiños, et al. 2016. "Explaining Success and Failure in the Commons: The Configural Nature of Ostrom's Institutional Design Principles." *International Journal of the Commons* 10 (2): 417. doi:10.18352/ijc.634.

Ballotpedia. 2016. "Colorado Local Control of Oil and Gas Development Amendment." https://ballotpedia.org/Colorado_Local_Control_of_Oil_and_Gas_Development_Amendment_(2016).

Bardach, Eugene. 1998. *Getting Agencies to Work Together: The Practice and Theory of Managerial Craftsmanship*. Washington, D.C.: Brookings Institution Press.

BillTrack50. 2019. “CO - HB1336.” Accessed February 23. https://www.billtrack50.com/BillDetail/870496.

Blomquist, William, and Peter deLeon. 2011. “The Design and Promise of the Institutional Analysis and Development Framework.” *Policy Studies Journal* 39 (1): 1–6. doi:10.1111/j.1541-0072.2011.00402.x.

Brink, Patrick ten. 2002. “Prologue.” In *Voluntary Environmental Agreements: Process, Practice and Future Use*, edited by Patrick ten Brink, 14–28. New York: Routledge.

Buchanan, James M. 1965. “An Economic Theory of Clubs.” *Economica* 32 (125): 1. doi:10.2307/2552442.

California Department of Conservation. 2019. “Memoranda of Understanding/Agreement.” Accessed February 22. https://www.conservation.ca.gov/dog/for_operators/Pages/mou_moa.aspx.

Carter, David P., and Christopher M. Weible. 2014. “Assessing Rule Compliance and Robustness in Recreational Resource Management.” *Journal of Environmental Policy & Planning* 16 (1). Routledge: 117–39. doi:10.1080/1523908X.2013.821943.

Carter, David P, Tyler A Scott, and Nadia Mahallati. 2018. “Balancing Barriers to Entry and Administrative Burden in Voluntary Regulation.” *Perspectives on Public Management and Governance* 1 (3). Oxford University Press: 207–21. doi:10.1093/ppmgov/gvx005.

City and County of Broomfield and Sovereign Operating Company, LLC and its Affiliates. 2013. “Oil and Gas Operator Agreement.”

COGCC. 2014. “Appendix Part V. Oil and Gas Conservation Act. Title 34, Article 60 (As Amended).” Denver: Colorado Oil and Gas Conservation Commission (COGCC). http://cogcc.state.co.us/documents/reg/Rules/LATEST/AppendixV.pdf.

Coglianese, Cary, and Jennifer Nash. 2016. "Motivating Without Mandates: The Role of Voluntary Programs in Environmental Governance." Philadelphia. http://scholarship.law.upenn.edu/faculty_scholarshiphttp://scholarship.law.upenn.edu/faculty_scholarship/1647.

Colorado Bureau of Land Management (BLM). 2017. "BLM Rescinds Rule on Hydraulic Fracturing." https://www.blm.gov/press-release/blm-rescinds-rule-hydraulic-fracturing.

Colorado Department of Public Health and Environment (CDPHE). 2019. "Rocky Mountain National Park Initiative." Accessed February 23. https://www.colorado.gov/pacific/cdphe/rocky-mountain-national-park-initiative.

———. 2005. "Memorandum of Understanding for Interagency Collaboration to Address Air Quality Issues Affecting Rocky Mountain National Park." https://www.colorado.gov/pacific/sites/default/files/AP_PO_Memorandum-of-Understanding-for-Interagency-Collaboration_1.pdf.

Colorado General Assembly. 2018. "Modify Laws Drilling Units Pooling Orders SB18-230." https://leg.colorado.gov/bills/sb18-230.

Colorado Nonprofit Association. 2013. "Collaboration Toolkit Creating an MOU." http://anschutzfamilyfoundation.org/wp-content/uploads/2016/04/MOU-toolkit-MAIN.pdf.

Colorado Oil and Gas Conservation Commission (COGCC). 2019a. "Environmental Unit. Oil and Gas Location Assessment Permit." Accessed February 23. https://cogcc.state.co.us/documents/about/TF_Summaries/GovTaskForceSummary_Environmental_OGLA.pdf.

———. 2019b. "Frequently Asked Questions About Hydraulic Fracturing." Accessed February 22. https://cogcc.state.co.us/Announcements/Hot_Topics/Hydraulic_Fracturing/Frequent_Questions_about_Hydraulic Fracturing.pdf.

Colorado Secretary of State. 2016. "Measures Aimed at Oil-and-Gas Fail to Make the Ballot." https://content.govdelivery.com/accounts/COSOS/bulletins/160232c.

Colorado Supreme Court. 2016. "No. 15SC667. City of Longmont v. Colo. Oil and Gas Ass'n—Preemption—Inalienable Rights Provision." https://www.courts.state.co.us/userfiles/file/Court_Probation/Supreme_Court/Opinions/2015/15SC667.pdf.

Cox, Michael, Gwen Arnold, and Sergio Villamayor Tomás. 2010. "A Review of Design Principles for Community-Based Natural Resource Management." *Ecology & Soceity* 15 (4). http://web.a.ebscohost.com.aurarialibrary.idm.oclc.org/ehost/pdfviewer/pdfviewer?vid=1&sid=93e11741-2c7a-4f47-8a5b-59c781705297%40sdc-v-sessmgr02.

Crawford, Sue E.S. S., and Elinor Ostrom. 1995. "A Grammar of Institutions." *American Political Science Review* 89 (03). Cambridge University Press: 582–600. doi:10.2307/2082975.

Czolowski, Eliza D., Renee L. Santoro, Tanja Srebotnjak, and Seth B. C. Shonkoff. 2017. "Toward Consistent Methodology to Quantify Populations in Proximity to Oil and Gas Development: A National Spatial Analysis and Review." *Environmental Health Perspectives* 125 (8). National Institute of Environmental Health Science: 086004. doi:10.1289/EHP1535.

Darnall, Nicole, and Joann Carmin. 2005. "Greener and Cleaner? The Signaling Accuracy of U.S. Voluntary Environmental Programs." *Policy Sciences* 38: 71–90. doi:10.1007/s11077-005-6591-9.

Darnall, Nicole, and Stephen Sides. 2008. "Assessing the Performance of Voluntary Environmental Programs: Does Certification Matter?" *The Policy Studies Journal* 36 (1): 95–117. https://s3.amazonaws.com/academia.edu.documents/3463597/VEP_meta-analysis.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1542603501&Signature=tDVijscyqIfWsR267vQ9v7QhXOM%3D&response-content-disposition=inline%3B filename%3DAssessing_the_performance_of_.

Davis, Charles. 2012. "The Politics of 'Fracking': Regulating Natural Gas Drilling Practices in Colorado and Texas." *Review of Policy Research* 29 (2). John Wiley & Sons, Ltd (10.1111): 177–91. doi:10.1111/j.1541-1338.2011.00547.x.

Delmas, Magali A., and Ann K. Terlaak. 2001. "A Framework for Analyzing Environmental Voluntary Agreements." *California Management Review* 43 (3): 44–63. http://users.uom.gr/~esartz/teaching/genvecon/CALMANREVIEW.pdf.

DeSmogBlog. 2010. "Fracking the Future. How Unconventional Gas Threatens Our Water, Health and Climate." Vancouver, BC. https://www.desmogblog.com/fracking-the-future/desmog-fracking-the-future.pdf.

Dunnahoe, Tayvis. 2013. "Colorado Communities Collaborate with Operators." *Oil & Gas Journal*. https://www.ogj.com/articles/uogr/print/volume-1/issue-4/colorado-communities-collaborate-with-operators.html.

Farrer, Benjamin, Robert Holahan, and Olga Shvetsova. 2017. "Accounting for Heterogeneous Private Risks in the Provision of Collective Goods: Controversial Compulsory Contracting Institutions in Horizontal Hydrofracturing." *Journal of Economic Behavior & Organization* 133 (January): 138–50. doi:10.1016/j.jebo.2016.11.008.

Farrer, Benjamin, Robert Holahan, and Olga V. Shvetsova. 2013. "Technological Change, Institutional Stickiness and Changing Political Coalitions: The Shift to Horizontal Hydraulic Fracturing." Philadelphia: Paper presented at the 2013 American Political Science Association Annual Meeting. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2301195.

Finley, Bruce. 2012. "Colorado Farms Planning for Dry Spell Losing Auction Bids for Water to Fracking Projects – The Denver Post." *The Denver Post*, March 31. https://www.denverpost.com/2012/03/31/colorado-farms-planning-for-dry-spell-losing-auction-bids-for-water-to-fracking-projects-2/.

Gerring, John, and Lee Cojocaru. 2016. "Selecting Cases for Intensive Analysis." *Sociological Methods & Research* 45 (3). SAGE PublicationsSage CA: Los Angeles, CA: 392–423. doi:10.1177/0049124116631692.

Gold, Russell, and Tom McGinty. 2013. "Energy Boom Puts Wells in America's Backyards." *The Wall Street Journal*, October. https://www.wsj.com/articles/energy-boom-puts-wells-in-america8217s-backyards-1382756256?tesla=y.

Golten, Ryan, Taber Ward, and Kathryn Mutz. 2016. "Stakeholder Assessment Colorado Oil & Gas Development Insights from the Field Toward an Understanding of Industry-Community MOUs Intermountain Oil and Gas BMP Project." Boulder. http://www.oilandgasbmps.org/docs/CO189_MOU_Stakeholder_Assessment_2016.pdf.

Gupta, Seema, P.K. Jain, and Surendra S. Yadav. 2011. "Impact of MoU on Financial Performance of Public Sector Enterprises in India." *Journal of Advances in Management Research* 8 (2). Emerald Group Publishing Limited: 263–84. doi:10.1108/09727981111175984.

Healy, Jack. 2012. "For Farms in the West, Oil Wells Are Thirsty Rivals." *The New York Times*, September 5. https://www.nytimes.com/2012/09/06/us/struggle-for-water-in-colorado-with-rise-in-fracking.html.

Heijden, Jeroen van der. 2012. "Voluntary Environmental Governance Arrangements." *Environmental Politics* 21 (3): 486–509. doi:10.1080/09644016.2012.671576.

Heikkila, Tanya, Jonathan J. Pierce, Samuel Gallaher, Jennifer Kagan, Deserai A. Crow, and Christopher M. Weible. 2014. "Understanding a Period of Policy Change: The Case of Hydraulic Fracturing Disclosure Policy in Colorado." *Review of Policy Research* 31 (2): 65–87. doi:10.1111/ropr.12058.

Heikkila, Tanya, Edella Schlager, and Mark W. Davis. 2011. "The Role of Cross-Scale Institutional Linkages in Common Pool Resource Management: Assessing Interstate River Compacts*." *Policy Studies Journal* 39 (1): 121–45. doi:10.1111/j.1541-0072.2010.00399.x.

Helman, Christopher. 2013. "President Obama Gets It. Fracking Is Awesome." *Forbes*. https://www.forbes.com/sites/christopherhelman/2013/02/12/president-obama-gets-it-fracking-is-awesome/.

Herzog, Laura M., and Karin Ingold. 2019. "Threats to Common-Pool Resources and the Importance of Forums: On the Emergence of Cooperation in CPR Problem Settings." *Policy Studies Journal* 47 (1). John Wiley & Sons, Ltd (10.1111): 77–113. doi:10.1111/psj.12308.

Holahan, Robert, and Gwen Arnold. 2013. "An Institutional Theory of Hydraulic Fracturing Policy." *Ecological Economics* 94: 127–34. doi:10.1016/j.ecolecon.2013.07.001.

Imperial, Mark T. 2005. "Using Collaboration as a Governance Strategy." *Administration & Society* 37 (3). Sage PublicationsSage CA: Thousand Oaks, CA: 281–320. doi:10.1177/0095399705276111.

Intermountain Oil and Gas BMP Project. 2019a. "Anatomy of an MOU." Boulder. Accessed February 23. http://www.oilandgasbmps.org/resources/MOU-anatomy.php.

———. 2019b. "Bibliography Search." Boulder, CO: University of Colorado Boulder. Accessed February 23. http://www.oilandgasbmps.org/bibliosearch.php.

———. 2019c. "Database of Memorandum of MOUs." Accessed February 22. http://www.oilandgasbmps.org/resources/MOU-databases.php.

———. 2016. "Elements Comparison Table, CO Oil and Gas MOUs." Boulder. https://docs.google.com/spreadsheets/d/1e-VcuSd4xvFa6vxHnLslhRl8aVBdZAvSbbX9Qejz10w/edit#gid=1503432545.

Jaffe, Mark. 2014. "When Drought Occurs, Fracking and Farming Collide." *The Denver Post*, February 7. https://www.denverpost.com/2014/02/07/when-drought-occurs-fracking-and-farming-collide/.

Johnson, Kate. 2013. "Fox Shouldn't Be Guarding Henhouse." *Longmont Times-Call*, March 28.

Keep Tap Water Safe. 2019. "List of Bans Worldwide." Accessed February 22. https://keeptapwatersafe.org/global-bans-on-fracking/.

Khanna, Madhu, Patricia Koss, Cody Jones, and David Ervin. 2007. "Motivations for Voluntary Environmental Management." *Policy Studies Journal* 35 (4). John Wiley & Sons, Ltd (10.1111): 751–72. doi:10.1111/j.1541-0072.2007.00246.x.

Koehler, Dinah A. 2007. "The Effectiveness of Voluntary Environmental Programs-A Policy at a Crossroads?" *Policy Studies Journal* 35 (4). John Wiley & Sons, Ltd (10.1111): 689–722. doi:10.1111/j.1541-0072.2007.00244.x.

Lyon, Thomas P, and John W Maxwell. 2007. "Environmental Public Voluntary Programs Reconsidered." *The Policy Studies Journal,* 35 (4): 723–50. http://webuser.bus.umich.edu/tplyon/PDF/Published Papers/Lyon Maxwell PSJ.pdf.

Matisoff, Daniel. 2015. "Sources of Specification Errors in the Assessment of Voluntary Environmental Programs: Understanding Program Impacts." *Policy Sciences* 48 (1): 109–26. doi:10.1007/s11077-014-9204-7.

McCrimmon, Donald, and Lucia Fanning. 2010. "Using Memoranda of Understanding to Facilitate Marine Management in Canada." *Marine Policy* 34 (6). Pergamon: 1335–40. doi:10.1016/J.MARPOL.2010.06.006.

McEvoy, David M., and John K. Stranlund. 2010. "Costly Enforcement of Voluntary Environmental Agreements." *Environmental and Resource Economics* 47 (1). Springer Netherlands: 45–63. doi:10.1007/s10640-010-9364-7.

McGinnis, Michael D. 2011. "An Introduction to IAD and the Language of the Ostrom Workshop: A Simple Guide to a Complex Framework." *Policy Studies Journal* 39 (1). John Wiley & Sons, Ltd (10.1111): 169–83. doi:10.1111/j.1541-0072.2010.00401.x.

Morgenstern, Richard D., and William A. Pizer. 2007. "Introduction: The Challenge of Evaluating Voluntary Programs." In *Reality Check The Nature and Performance of Voluntary Environmental Programs in the United States, Europe, and Japan*, edited by Richard D. Morgenstern and William A. Pizer, 15–28. Washington, D.C.: Resources for the Future. doi:10.4324/9781936331123-6.

Mosier, Samantha, and Jonathan Fisk. 2013. "Can Local Voluntary Environmental Programs 'Work'? An Examination of Fort Collins' (Colorado) Climate Wise Program." *Environmental Management* 51 (5). Springer-Verlag: 969–87. doi:10.1007/s00267-013-0022-z.

Mullis, Natalie, Marc Carey, Larson Silbaugh, Louis Pino, Greg Sobetski, Kate Watkins, and Debbie Grunlien. 2016. "Focus Colorado: Economic and Revenue Forecast." Denver. http://www2.cde.state.co.us/artemis/gaserials/ga417internet/ga417201606internet.pdf.

Murphy, Joe. 2016. "Chart: Colorado Is the Second-Fastest Growing State in the U.S." *The Denver Post*, July 7. https://www.denverpost.com/2016/07/07/colorado-second-population-growth-2015/.

Newswire, PR. 2016. "Global Hydraulic Fracturing & Services Market Analysis & Trends 2016-2025 - Market Is Poised to Grow at a CAGR of Around 9.3% to Reach Approximately $112 Billion." *PR Newswire*. https://www.prnewswire.com/news-releases/global-hydraulic-fracturing--services-market-analysis--trends-2016-2025---market-is-poised-to-grow-at-a-cagr-of-around-93-to-reach-approximately-112-billion-300240581.html.

North, Douglass C. 1986. *Institutions and Economic Growth: An Historical Introduction*. Ithaca, NY: Cornell University.

Ostrom, Elinor. 1990. *Governing the Commons. The Evolution of Institutions for Collective Action*. Cambridge, England: Cambridge University Press.

———. 2008. "The Challenge of Common-Pool Resources." *Environment: Science and Policy for Sustainable Development* 50 (4): 8–21. doi:10.3200/ENVT.50.4.8-21.

Ostrom, Vincent, and Elinor Ostrom. 1977. “Public Goods and Public Choices.” In *Alternatives for Delivering Public Services: Toward Improved Performance*, 7–49. Boulder, CO: Westview Press.

Payne, Scott M. 1998. *Strategies for Accelerating Cleanup at Toxic Waste Sites: Fast-Tracking Environmental Actions and Decision Making*. Boca Raton: Lewis Publishers. https://trove.nla.gov.au/work/23928753?selectedversion=NBD13422800.

Potoski, Matthew, and Aseem Prakash. 2009. *Voluntary Programs: A Club Theory Perspective*. Cambridge, MA: The MIT Press.

Prakash, Aseem, and Matthew Potoski. 2007. “Collective Action through Voluntary Environmental Programs: A Club Theory Perspective.” *Policy Studies Journal* 35 (4): 773–92. doi:10.1111/j.1541-0072.2007.00247.x.

Quilligan, James B. 2019. “The Wealth of the Commons. A World Beyond Market & State: Why Distinguish Common Goods from Public Goods?” Accessed February 27. http://wealthofthecommons.org/essay/why-distinguish-common-goods-public-goods.

Richardson, Nathan, Alan Krupnick, and Hannah Wiseman. 2013. “The State of State Shale Gas Regulation.” Washington, D.C. https://www.rff.org/documents/524/RFF-Rpt-StateofStateRegs_Report.pdf.

Rinfret, Sara, Jeffrey J. Cook, and Michelle C. Pautz. 2014. “Understanding State Rulemaking Processes: Developing Fracking Rules in Colorado, New York, and Ohio.” *Review of Policy Research* 31 (2). John Wiley & Sons, Ltd (10.1111): 88–104. doi:10.1111/ropr.12060.

Rivera, Jorge E., and Peter deLeon. 2008. “Voluntary Environmental Programs: Are Carrots without Sticks Enough?” *Policy Studies Journal* 36 (1). John Wiley & Sons, Ltd: 61–63. doi:10.1111/j.1541-0072.2007.00253.x.

Rivera, Jorge, and Peter de Leon. 2004. "Is Greener Whiter? Voluntary Environmental Performance of Western Ski Areas." *The Policy Studies Journal* 32 (3): 417–37. doi:10.1111/j.1541-0072.2004.00073.x.

Schlager, Edella. 2016. "Introducing the Importance of Context, Scale, and Interdependencies in Understanding and Applying Ostrom's Design Principles for Successful Governance of the Commons." *International Journal of the Commons* 10 (2). International Association for the Study of the Commons: 405–16. doi:10.18352/ijc.767.

Schlager, Edella, and Elinor Ostrom. 1992. "Property-Rights Regimes and Natural Resources: A Conceptual Analysis." *Source: Land Economics*. Vol. 68. http://econ.ucsb.edu/~tedb/Courses/Ec100C/Readings/OstromSchlager.pdf.

Shaffer, Austin, Skylar Zilliox, and Jessica Smith. 2017. "Memoranda of Understanding and the Social Licence to Operate in Colorado 's Unconventional Energy Industry: A Study of Citizen Complaints." *Journal of Energy and Natural Resources Law* 35 (1): 69–85. doi:http://dx.doi.org/10.1080/02646811.2016.1216696.

Steelman, Toddi A., and Jorge Rivera. 2006. "Voluntary Environmental Programs in the United States. Whose Interests Are Served?" *Organization & Environment* 19 (4). Sage PublicationsSage CA: Thousand Oaks, CA: 505–26. doi:10.1177/1086026606296393.

Subramanian, S. 2016. "A Comparison of Corporate Governance Practices in State-Owned Enterprises and Their Private Sector Peers in India." *IIM Kozhikode Society & Management Review* 5 (2). SAGE PublicationsSage India: New Delhi, India: 200–216. doi:10.1177/2277975215617268.

Sura, Matt. 2019. "Colorado Landowner's Guide to Oil and Gas." Boulder: University of Colorado at Boulder. Accessed February 23. doi:10.1021/es304119a.

The Denver Post Editorial Board. 2016. "Colorado Supreme Court Gets It Right on Fracking," May 2.

Town of Erie. 2012. "Resolution No. 12-74." Erie, Colorado.

U.S. Department of Transportation (USDOT). 2019. "Tribe and Local Government Collaborate to Improve Transportation Corridors in Wrangell, Alaska." Accessed February 23. https://www.fhwa.dot.gov/planning/processes/tribal/case_studies/wrangell.pdf.

U.S. Energy Information Administration (USEIA). 2014. "Growth in U.S. Hydrocarbon Production from Shale Resources Driven by Drilling Efficiency." https://www.eia.gov/todayinenergy/detail.php?id=15351.

———. 2016. "International Energy Outlook 2016." Washington, DC. https://www.eia.gov/outlooks/ieo/pdf/0484(2016).pdf.

———. 2017. "Rankings: Natural Gas Marketed Production, 2017." https://www.eia.gov/state/rankings/#/series/47.

———. 2019a. "Colorado - State Energy Profile Analysis." https://www.eia.gov/state/analysis.php?sid=CO.

———. 2019b. "Colorado - State Energy Profile Overview." https://www.eia.gov/state/?sid=CO.

U.S. Geological Survey (USGS). 2019. "What Is Hydraulic Fracturing?" Accessed February 22. doi:10.1785/0220150067.

Wilson, Geoff. 2012. "State and Local Regulation of Oil & Gas Operations in Colorado." *Knowledge Now.*, no. August. Denver, CO: 1–3. https://www.cml.org/Issues/Oil-and-Gas/State-and-Local-Regulation-of-Oil-and-Gas-Operations-in-Colorado/.

Zilliox, Skylar. 2016. “Regulating Relationships: Memorandums of Understanding and Unconventional Energy Development in Suburban Colorado.” Colorado School of Mines. https://mountainscholar.org/bitstream/handle/11124/170241/Zilliox_mines_0052N_11024.pdf?sequence=1.

Zilliox, Skylar, and Jessica M. Smith. 2017a. “Supraregulatory Agreements and Unconventional Energy Development: Learning from Citizen Concerns, Enforceability and Participation in Colorado.” *The Extractive Industries and Society* 4 (1). Elsevier: 69–77. doi:10.1016/J.EXIS.2016.11.008.

———. 2017b. “Memorandums of Understanding and Public Trust in Local Government for Colorado’s Unconventional Energy Industry.” *Energy Policy* 107 (August). Elsevier: 72–81. doi:10.1016/J.ENPOL.2017.04.032.

APPENDIX A: Design principles illustrated by long-enduring CPR institutions[22]

1. Clearly defined boundaries	Individuals or households who have rights to withdraw resource units from the CPR must be clearly defined, as must the boundaries of the CPR itself.
2. Congruence between appropriation and provision rules and local conditions	Appropriation rules restricting time, place, technology, and/or quantity of resource units are related to local conditions and to provision rules requiring labor, material, and/or money.
3. Collective-choice arrangements	Most individuals affected by the operational rules can participate in modifying the operational rules.
4. Monitoring	Monitors, who actively audit CPR conditions and appropriator behavior, are accountable to the appropriators or are the appropriators
5. Graduated sanctions	Appropriators who violate operational rules are likely to be assessed graduated sanction (depending on the seriousness and context of the offense) by other appropriators, by officials accountable to these appropriators, or both.
6. Conflict-resolution mechanisms	Appropriators and their officials have rapid access to low-cost local arenas to resolve conflicts among appropriators or between appropriators and officials.
7. Minimal recognition of rights to organize[23]	The rights of appropriators to devise their own institutions are not challenged by external governmental authorities.
For CPRs that are part of larger systems:	
8. Nested enterprises	Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nester enterprises.

[22] Reproduced from (Ostrom 1990, 90).

[23] Due to the regulatory nature of oil and gas development in Colorado e.g., the ability of local governments in Colorado to enter into agreements, this paper does not consider this DP.

APPENDIX B: Brief example of MOU coding

The Town of Erie and Encana Oil and Gas signed an MOU on August 28th, 2012.

Resolution NO. 12-74, "A resolution authorizing the Town of Erie, Colorado, to enter into a memorandum of understanding with Encana Oil & Gas (USA) INC.; authorizing and directing the appropriate town officers to sign said memorandum of understanding; and, setting forth details in relation thereto."

- Evidence of DP 1.1, clearly defined social/group boundaries
    - "This Memorandum of Understanding (this "MOU") is made and entered into this day of 2012 by and between the Town of Erie, a Colorado municipal corporation ("Erie"), whose address is 645 Holbrook Street, P.O. Box 750, Erie, Colorado 80516, and Encana Oil & Gas (USA) Inc., a Delaware corporation ("Encana"), whose address is 370 1ih Street, Suite 1700, Denver, Colorado 80202. Encana and Erie may be referred to individually as a "Party" or collectively as the "Parties" (Town of Erie 2012, 1).
- Evidence of DP 1.2, clearly defined resource boundaries
    - "Encana is the owner of oil and gas leasehold and mineral interests within Erie's town limits. Encana currently operates oil and gas wells within Erie's town limits and has the right to develop its current and future oil and gas leasehold and mineral interests by drilling additional wells within Erie's town limits" (Town of Erie 2012, 1).

- Evidence of DP 2.2a, air quality rules
    - "Utilize a high-low pressure vessel (HLP) and vapor recovery unit (VRU) for new wells drilled. Encana may remove the VRU system at such time Encana determines that the VRU system is no longer necessary due to reduced emission recoveries and/or efficiencies, but no earlier than one (1) year after the new well is drilled" (Town of Erie 2012, 6).
- Evidence of DP 5.1 and 5.2, default processes and default response
    - "Default. If a Party defaults in the performance under this MOU, the defaulting Party shall have thirty (30) days to cure the default after receipt of written notice of such default from the non-defaulting Party, provided the defaulting Party shall be entitled to a longer cure period if the default cannot reasonably be cured within thirty (30) days and the defaulting Party commences the cure within such thirty (30) day period and diligently pursues its completion. If the defaulting Party fails to cure the default within the applicable cure period, then the non- defaulting Party shall have the right to immediately terminate this MOU upon written notice to the defaulting Party" (Town of Erie 2012, 4).