Landscape and Urban Planning xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Comment

Modeling and predicting natural gas fracking pad landscapes require a multidisciplinary approach: A commentary☆

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HIGHLIGHTS

- Long-reach horizontal well ('frac') pads have proliferated across western Pennsylvania.
- Key factors include legal status of site & economics of leasing it for well development.
- Landscape variables should be analyzed using data for all Pennsylvania frac pad sites.
- Geological variables (depth, thickness, organic richness, maturity) should be analyzed.
- Explicit evaluation of variable uncertainty (value and positional accuracy) is needed.

ARTICLE INFO

Article history:
Received 12 February 2016
Received in revised form 31 January 2017
Accepted 15 February 2017
Available online xxx

Keywords:
Unconventional wells
'Frac' well pads
Marcellus shale
Pennsylvania

ABSTRACT

Modeling the proliferation of hydrocarbon wells across a landscape using logistic regression against landscape variables is a novel approach with significant potential to inform regional planning. However, any modeling study should incorporate the most relevant controlling variables, and as much data as possible about both the phenomenon and the controlling variables. Accurate and precise spatial correspondence between causes and the effect is a prerequisite for drawing conclusions from such an analysis. The analysis by Meng is an important step toward modeling hydrocarbon well proliferation as a landscape process, but a more fundamental understanding and more robust accounting of the factors that influence pad locations is required for a useful treatment of the subject. Although geology is one of the factors to be accounted, as Klein and Manda observe, regulatory and economic circumstances are more proximate drivers of pad-site selection.

1. Introduction

The recent, rapid proliferation of pads for drilling long-reach horizontal wells ('frac' pads) across the landscape of western Pennsylvania underlain by the Marcellus shale has resulted in profound (if localized) changes in the character and functioning of the landscape. Thus, it is timely to ask what factors control the location of these wells? The first factor will, of course, be the presence of hydrocarbons at depth, in 'commercial' quantities (although what is commercial changes rapidly with changes in energy prices). But many other factors influence the viability of drilling at a particular site.

Meng (2014) took a novel and useful approach of modeling the spatial propagation of frac pad sites in the same way as an invasion of insect or plant pests, using landscape variables to predict the probability of future invasion. The use of logistic regression appears to be a suitable way to approach the question, and Meng appears to have implemented it well. However, as pointed out by Klein and Manda (2015), Meng (2014) did not include subsurface geological attributes as variables to consider in such an analysis. Both Meng (2014) and Klein and Manda (2015) have overlooked even more important regulatory and economic factors that not only govern the spatial distribution and propagation of frac pad sites, but which themselves evolve over time.

The data and concepts that have been enlisted in the discussion so far are acceptable to bring the issue to light, but are not adequate to investigate the phenomenon in a comprehensive manner. In this perspective, we review the factors influencing frac pad siting, and

☆ This is an invited and peer-reviewed commentary. While no further commentary will be accepted, research papers on this topic are welcome. Any inquiries should be directed to the handling Co-Editor-in-Chief Wei-Ning Xiang at wnxiang@tongji.edu.cn.

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http://dx.doi.org/10.1016/j.landurbplan.2017.02.010

point to data sources and analyses that could provide a solid basis for a more rigorous analysis of frac pad location on the landscape.

2. Factors affecting frac pad location

2.1. Legal and economic viability

Given that a region is generally prospective for hydrocarbons, the most important factors to determine if a pad occupies a given position is whether the position is legally permissible, and if so, if it can be leased at a price that allows an acceptable return on investment.

Pennsylvania state regulations, for example, require setback from bodies of water or drinking water sources, and also restrict new wells from infringing on the drainage area of existing wells (see Pennsylvania Code Chapters 78 and 79 for a full description of restrictions: http://www.pacode.com/secure/data/025/chapter78/chap78toc.html and http://www.pacode.com/secure/data/025/chapter79/chap79toc.html). These regulations are constantly evolving: Chapter 78, Subchapter A, for example, has been amended 9 times from the authorization of the initial act in 1987 through October of 2016 (*cf.* § 78.1 "Source" in Chapter 78). As experience with the technology evolves, the regulatory framework evolves, too.

The US Clean Water Act Section 404 requires a permit for any activity that would result in fill within wetlands (see https://www.epa.gov/cwa-404/section-404-permit-program), and some states have additional restrictions based on water quality, flood management, or ecological concerns (e.g., Washington State's regulations protecting isolated wetlands, see http://www.ecy.wa.gov/programs/sea/wetlands/isolated.html, and California's regulations protecting water bodies, see https://www.wildlife.ca.gov/conservation/lsa).

Areas with bad geology are unlikely to be economically attractive under any scenario, but areas with good geology may not be drilled immediately if the price asked for a lease is too high. What constitutes "too high" is always evaluated with respect to the price that can be obtained for the gas, and the cost of support services to develop it (support services include building roads, trucking supplies, drilling and completing the well, wireline logging, and the fracking itself). On the other hand, once a lease has been signed, if it is about to expire because the operator has not drilled a well within the lease term, the operator may drill a sub-economic well to avoid a complete loss on the investment.

When prices are high, the cost of service is also high; when prices are high, there tends to be sub-rational competition that drives lease-price requests and service costs higher than the prices justify. On the other hand, when prices are low, there tends to be sub-rational survival behavior. The point about this complexity and volatility is that the potential for a given site to host a pad is time dependent; assessing only pads that initiate during a specific time period (for example 2010–2011, at the height of competition for leases) only captures the desirability of sites under that specific set of economic drivers, and at the state of geologic knowledge at that time.

2.2. Geologic and technical variables

Although the geology that governs the attractiveness of a given location for drilling does not change, our understanding of the geology does change (sometimes significantly and rapidly) as additional wells are drilled. The evaluation of geologic attractiveness will vary among operators, even based on the same information.

Statutory restrictions keep companies from drilling close to each other (Pennsylvania Code Chapter 79 http://www.pacode.com/secure/data/025/chapter79/chap79toc.html). As a practical matter, horizontal drilling means that there is a minimum distance between pad sites: once a pad is established, the center of neighboring pads will be at least twice the lateral length away (typically 2–3 km) so that the lateral segments of the wells will not run into each other or drain the same volume of rock, therefore no pad will occupy the intervening landscape.

2.3. Landscape variables

Meng (2014) considered landscape variables that are relevant to the extent they drive regulation and economics: forest vs brush vs cropland determines how much vegetation removal will cost, or how much compensation the landowner requires for taking a resource out of production; local topography influences how much earthmoving is required to level the site (however, a singular "slope" value from one pixel of a 30 m DEM doesn't capture this effect); distance from roads influences transportation costs (but distance from population is perhaps more important); distance to water features influences the cost to obtain frac water, but may even determine whether a site is legally permissible (too close is excluded).

3. Questionable conclusions

Three of the conclusions of Meng (2014) appear counterintuitive:

1. *That open water has the <u>lowest</u> probability of hosting a frac pad.* In fact, the probability that a frac pad is located in open water should be zero, because it is barred by statute. There is no chance this could happen. If the data or analysis suggest the probability is >0, it indicates a problem, such as the scale of data used may be too coarse to analyze this variable.
2. *That wetlands have the highest probability of hosting a frac pad, all other things being equal.* There are significant regulatory and economic reasons why wetlands are both legally and practically unlikely to host pads. Meng's conclusion seems more likely an artifact of poor registration between pad locations and land-cover data layer, or a case of misclassification in the land-cover data layer, than a true phenomenon.
3. *That elevation is an important landscape variable to predict frac pad location.* There is no *a priori* reason that elevation by itself should influence any factor that controls well-siting decisions. Elevation may be a proxy for some underlying geological variable, like depth to target, or co-vary with some other economic factor like transportation cost, but elevation doesn't really change by enough across the study area to impact drilling economics based on depth to target. This seems more likely a fortuitous correlation due to a restricted range of elevation among wells that are not otherwise representative of the whole population.

A more thorough analysis (such as proposed below) could test Meng's (2014) approach more rigorously.

4. Recommendations for future research

This topic could be more usefully addressed by future work incorporating a much larger data set of Pennsylvania frac pad sites publicly available from the Pennsylvania Department of Environmental Protection (PA DEP); quantitative data sets of geological variables like depth, thickness, organic richness, and maturity that are available from the PA DEP, the United States Geological Survey (USGS), and the scholarly geological literature; and explicit evaluation of variable uncertainty, including both value and positional