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Research article

Transport of hydraulic fracturing waste from Pennsylvania wells: A county-level analysis of road use and associated road repair costs

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ABSTRACT

Pennsylvania's rapid unconventional oil and gas (UOG) development—from a single well in 2004 to more than 6700 wells in 2013—has dramatically increased UOG waste transport by heavy trucks. This study quantified the amount of UOG waste and the distance it traveled between wells and disposal facilities on each type of road in each county between July 2010 and December 2013. In addition, the study estimated the associated financial costs to each county's road infrastructure over that period. We found that UOG wells produced a median wastewater volume of 1294 m^3 and a median of 89,267 kg of solid waste. The median number of waste-transport truck trips per well was 122. UOG wells existed in 38 Pennsylvania counties, but we estimated trucks transporting well waste traveled through 132 counties, including counties in West Virginia, Ohio, and New York. Median travel distance varied by disposal type, from 106 km to centralized treatment facilities up to 237 km to injection wells. Local roads experienced the greatest amount of truck traffic and associated costs ($1.1–6.5 M) and interstates, the least ($0.3–1.6 M). Counties with oil and gas development experienced the most truck traffic and incurred the highest associated roadway costs. However, many counties outside the active development area also incurred roadway repair costs, highlighting the extension of UOG development's spatial footprint beyond the active development area. An online data visualization tool is available here: www.nicholasinstitute.duke.edu/transportation-of-hydraulic-fracturing-waste.

1. Introduction

The United States has increased production of natural gas from shale by nearly 600%, from 1.99 trillion cubic feet (TCF) in 2007 to 11.9 TCF in 2013 (EIA, 2015a). The Commonwealth of Pennsylvania has been a major contributor to this trend, increasing production of shale gas from 0 trillion cubic feet (TCF) in 2007 to 3.05 TCF in 2013 (EIA, 2015b). The reason behind the increased production in Pennsylvania is that the state is underlain by several unconventional sources of oil and gas, including the Marcellus and Utica plays. The Marcellus play, extends from New York through Pennsylvania and into Maryland, Ohio, Virginia, and West Virginia and has an estimated 369 TCF of natural gas and 0.4 billion barrels (bbls) of shale oil that are technically recoverable (EIA, 2013). The Utica play has a similar geographic range and has an estimated 111 TCF of natural gas and 2.5 billion bbls of shale oil that are technically recoverable (EIA, 2013). The combined potential resources of the Marcellus and Utica plays suggest continued development of unconventional oil and gas (UOG) resources in Pennsylvania.

The shale gas revolution began in Pennsylvania with completion of the state's first UOG well in 2004 and by the end of 2013, more than 6700 UOG wells had been drilled in the state (PADEP, 2014), predominately in the Marcellus play. The rapid expansion of UOG development has increased jobs, revenue, and sales activity for local businesses (Herzenberg et al., 2014). At the same time, it has strained pre-existing road infrastructure by dramatically increasing heavy truck traffic to transport drilling and fracturing materials to the wellhead and disposal facilities. Because roads are designed on the basis of projected frequency and weight of traffic, the effects of UOG traffic vary.

Little peer-reviewed information exists on road repair costs associated with the transport of UOG waste on different road types, especially at a local scale. The goal of this study was to quantify those costs at the county level.

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1.1. UOG waste and disposal

UOG-generated waste falls into two broad categories: solid wastes and wastewater. Solid wastes are predominantly drill cuttings generated during well construction, but they can also include drilling muds and proppants (such as sand) that return to the surface after a well has been fractured. Solid wastes can contain naturally occurring radioactive materials (NORMs), and both are disposed of predominantly at approved landfills (NYSDEC, 2015). Portions of these solid wastes are transported across state lines and drainage basins (Maloney and Yoxtheimer, 2012).

Wastewater is composed of drilling fluids, flowback, and produced water that can contain chemicals, halogens, radionuclides, heavy metals, and salts (Olmstead et al., 2013; Warner et al., 2013). Wastewater disposal presents a unique challenge for Pennsylvania. The state's geology limits injection of wastewater into underground injection wells, requiring wastewater transport to Ohio or West Virginia injection wells (Lutz et al., 2013; MSAC, 2011). Historically, wastewater was also trucked to industrial treatment facilities and publically owned treatment works (POTWs). However, POTWs stopped accepting wastewater in April 2011 since they could not provide adequate treatment (Olmstead et al., 2013; Warner et al., 2013). Some UOG wastewater now goes to centralized waste treatment (CWT) facilities, which have been developed to meet Pennsylvania's limits on high total dissolved solid discharges into surface waters (Gilmore et al., 2013, Chapter 95 of the Pennsylvania Administrative Code, 2010). The majority of wastewater (60–90%) is recycled for reuse (Bluefield Research, 2014; Gannett Fleming Freight Solutions, 2011), such as fracturing of new wells.

1.2. Impact of heavy truck trips on roads

The impact of UOG traffic on roads varies with road type, because roads are designed and constructed to different specifications on the basis of projected traffic frequency and weight. Interstate highways are constructed to withstand higher volumes of traffic, including heavy truck traffic (defined as 4 or more axles), and heavier loads than local roads. Therefore, local roads are more susceptible to deterioration as a result of increased heavy truck traffic. However, reconstruction costs are higher for interstates (~$3.2 million (M) for one lane mile) than for local roads ($2.6 M for one lane mile) (Abramzon et al., 2014; Giessen et al., 2009). Thus, total financial costs to roads from heavy truck traffic must reflect both the frequency of travel on different road types and the associated reconstruction costs.

Increasing heavy truck traffic by UOG development has increased the expected rate of road deterioration (Abramzon et al., 2014; Quiroga et al., 2012; Gannett Fleming Freight Solutions, 2011). Quiroga et al. (2012) estimated that 1 year of truck traffic associated with development of 100 new wells would reduce the design life of a typical rural road in Texas by 40%. In North Dakota, UOG-related truck traffic on roads was projected to cost $907 M over 20 years (Tolliver and Dybling, 2010). In Pennsylvania, each new well was estimated to result in road repair costs of $13,000 to $23,000 over its lifetime, assuming all trucks traveled an average one-way distance of 20 miles (625–1148 truck trips) (Abramzon et al., 2014). Local roads will likely experience the greatest damage from UOG development due to their proximity to wells and their design for relatively light loads and traffic. Larger roads should perform better, though the addition of thousands of extra truck trips will increase their rate of deterioration.

Several studies have looked at the movement of UOG waste in Pennsylvania to its disposal location. Maloney and Yoxtheimer (2012) focused on the amount and type of waste transported between river basins and states. Lutz et al. (2013) focused on the shift in the amount of waste disposed of by different methods from 2001 to 2011. Building on these two studies, Rahm et al. (2013) found that from 2008 to 2011 wastewater reuse increased, POTW use decreased, and the average distance traveled by wastewater for treatment decreased (by more than 30%). Focusing on wells located in the Susquehanna River Basin, Gilmore et al. (2013) estimated the reduction in transportation mileage and greenhouse gas emissions that could be achieved by waste disposal at the closest possible destination. Abramzon et al. (2014) undertook a study of the hypothetical costs for road repair per well assuming a 20-mile, one-way travel distance. Our study builds on these contributions by exploring the potential county-level road repair costs of UOG waste transport.

In Pennsylvania, local government entities (counties, cities, boroughs, and townships) are responsible for the repair and maintenance costs for 124,766 km (77,526 mi) of highway, or 64% of roads (PATAC, 2011), carrying 23% of the state's traffic. The Pennsylvania Department of Transportation is responsible for the majority of remaining roads (PATAC, 2011).

To understand the potential road impacts of UOG waste transport at the county level, we estimated the number of truck trips and the total distance traveled by disposal method and road type in each county. Using published values for road repair, we then estimated the county-level cost of road maintenance due to heavy truck traffic from UOG waste disposal between July 2010 and December 2013. Our estimates of road use for UOG waste disposal and of associated road repair costs are the first that we know of at a county scale—a scale beneficial for local governments to assess and respond to UOG impacts on transportation infrastructure.

2. Methods

2.1. Data

We obtained statewide waste reports from the Pennsylvania Department of Environmental Protection (PADEP) Oil and Gas Electronic Reporting website from July 2010 through December 2013 (PADEP, 2014). Pennsylvania tracks waste origination, type, quantity, and disposal destination at 6-month intervals. The data, which are reported by well operators in accordance with Pennsylvania law, are the best publicly available data.

During evaluation of this dataset, we found incomplete and misreported information. For example, 18 waste facilities ($n = 208$) provided no spatial location; we used facility addresses to obtain their latitude and longitude. Some facilities had multiple types of disposal methods reported (e.g., centralized treatment and publically owned treatment works); we researched the correct disposal type. Some records also had erroneous waste units. We adjusted units when an error was clearly evident (for example 0.1 *bbls* of fracture sand sent to a landfill was changed to 0.1 *tons*).

2.2. Analysis

To identify the likely route between a well and its waste disposal site, we used TIGER street shapefiles (TIGER, 2012) to build a network in the Network Analyst extension of ArcGIS Desktop v10.1. We calculated the route with the shortest distance between a well and its disposal location using Network Analyst's Closest Facility tool. We created a model in ArcGIS to loop through each route and to summarize road mileage by road class for each county that intersected the route (Fig. SI1). Road classes are an attribute of the street data layer and reflect Census Feature Class codes A1 to A6 (Table 1).

The quantity of waste transported from the well to the disposal location was summarized for each route. We assumed a truck could