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The water-energy-food nexus of unconventional oil and gas extraction in the Vaca Muerta Play, Argentina

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ABSTRACT

Vaca Muerta is the major region in South America where horizontal drilling and hydraulic fracturing techniques are used to extract unconventional shale oil and gas. Despite the growing interest in the Vaca Muerta resources, there is only a limited understanding of the impacts that their extraction could have on local water resources. This study uses a water balance model to investigate the hydrological implication of unconventional oil and gas extraction in this region. We find that, with current rates of extraction, water scarcity is observed for four months a year. We also find that water consumption per fractured well increased 2.5 times in the period 2012–2016 and produced water from unconventional shale formation sharply increased from roughly zero to $1.15 \times 10^6\ m^3\ y^{-1}$ in the 2009–2017 period. Our projections estimate that in this region future water consumption for unconventional oil and gas extraction will increase 2.2 times in the 2017–2024 period reaching $7.40 \times 10^6\ m^3\ y^{-1}$. The consequent exacerbation of current water scarcity will likely lead to competition with irrigated agriculture, the greatest water consumer in this semiarid region. Produced water recycling, domestic wastewater reuse, brackish groundwater use, and waterless unconventional oil and gas extraction technologies are some of the strategies that could be adopted to meet future additional water demand. Our results estimate the likely range of water consumption and production from hydraulic fracturing operations in the Vaca Muerta region under current and future conditions. These results could be used to make informed decisions for the sustainable water management in this semiarid region of Argentina.

1. Introduction

Many countries are transitioning from reliance on conventional to unconventional fossil fuels (Farrell and Brandt, 2006). This transition has been driven by increasing global energy demand (International Energy Agency, 2017), continuing reliance on fossil fuels (International Energy Agency, 2017), technological innovations in the oil industry that have reduced marginal production costs (Brandt et al., 2018), high oil and natural gas prices (Brandt et al., 2018), and depletion of conventional oil sources (Bentley, 2002; Sorrell et al., 2010; Höök and Tang, 2013). For example, Canada is producing unconventional oil mainly from oil sands (Rosa et al., 2017), the United States are producing record amount of oil and natural gas from their unconventional shale oil and gas deposits (U.S. Energy Information Administration, 2018b), Estonia is retorting oil shale (Raukas and Punning, 2009), Mexico and China are increasing their efforts in unconventional shale oil and gas extraction (Castro-Alvarez et al., 2017; Masnadi et al., 2018), and Venezuela is mining heavy oil (Rosa et al., 2017).

Argentina is also undergoing a transition from conventional to unconventional fossil fuels extraction. Argentina was once the largest oil and natural gas exporter in South America (U.S. Energy Information Administration, 2018a), however, an increase in domestic energy demand and a decline in conventional oil and natural gas production made Argentina a net natural gas and oil importer since 2010 and 2013, respectively (BP, 2017).

In 2014, to prevent a further supply-demand energy imbalance, Argentina implemented a hydrocarbon reform to revive the energy sector and increase investments in mining its unconventional oil and gas (UOG) resources (U.S. Energy Information Administration, 2018a). Argentina has a world-class UOG shale endowment in the Vaca Muerta Play in the Neuquén Basin (Kuuskraa et al., 2013). The formation has 20 billion barrels of technically recoverable oil and 16 trillion cubic meters of technically recoverable natural gas (Kuuskraa et al., 2013). The presence of promising geological

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resources combined with existing natural gas infrastructures make Vaca Muerta an important region for the next shale boom (Mauter et al., 2014). Indeed, Vaca Muerta is at the preliminary stages of development and it is one of the major regions outside North America that is producing UOG using horizontal drilling and hydraulic fracturing (Suarez and Pichon, 2016).

As the use of hydraulic fracturing – the water demanding technology generally used to extract UOG from low permeability rocks – has become increasingly widespread, significant research has been conducted to determine its water consumption in the United States (Nicot and Scanlon, 2012; Clark et al., 2013; Gallegos et al., 2015; Chen et al., 2016; Jiang et al., 2014; Jackson et al., 2014), Mexico (Galdeano et al., 2017), and China (Guo et al., 2016). Previous studies have shown that water shortages are not an obstacle to UOG extraction in the United States (Nicot and Scanlon, 2012; Jiang et al., 2014; Scanlon et al., 2014). Indeed, water consumption for UOG extraction is dwarfed by the volumes consumed in agriculture (Rosa et al., 2018a). Moreover, fracking companies in the United States are willing to pay a premium price for the small amount of water (relative to agriculture) they use (Rosa et al., 2018a). However, it has been estimated that large areas underlain by global UOG shale deposits are affected by water stress where irrigation is critical for crop production (Rosa et al., 2018a). In these areas, including the Vaca Muerta Play, it is not clear if physical water scarcity can be a constraint on hydraulic fracturing and/or create competition for water allocation in important irrigated agricultural areas between food and energy systems. This type of competition constitutes the core of the ongoing water-energy-food nexus debate (D'Odorico et al., 2018; Lant et al., 2018).

Despite the growing interest in the Vaca Muerta UOG resources, there is only a limited understanding of the pressure that their extraction through hydraulic fracturing could place on local water resources in the course of the year. It remains unclear if water consumption of UOG extraction would compete with the irrigation sector and induce or exacerbate local monthly water scarcity, posing environmental, financial, reputational, and regulatory risks on both the hydrocarbon industry and local communities (Rosa et al., 2018a). This limited understanding of the potential impacts of UOG development on the local water balance thus prevents the implementation of a sustainable water management plan in the Vaca Muerta. It is therefore necessary to assess how renewable water availability varies along the year and assess if UOG extraction could lead to an inadequate management of local water resources as well as intensify the competition for water between irrigated agriculture and hydraulic fracturing in the Vaca Muerta Play.

Here we first assess current and projected water consumption and production from hydraulic fracturing activities in the Vaca Muerta Play. We assess the impacts of UOG extraction on the local water balance using a hydrologic approach that links the water consumption of UOG with local monthly renewable blue water availability, blue water consumption from agriculture, municipal uses, UOG extraction, and the industrial sector. We then explore the potential impacts hydraulic fracturing might have on regional water users and how future water demand could be sustainably met in the region while avoiding water shortages. We conclude discussing current water management plans, opportunities, and challenges from the development of OUG in the Vaca Muerta.

2. Material and methods

2.1. Vaca Muerta Play

The Neuquén Basin includes the Vaca Muerta and the underlying Los Molles sedimentary geologic formations located in Argentina's Patagonia Region (Fig. 1). The Vaca Muerta formation is the primary source rock for hydrocarbons in the Neuquén Basin. It covers four different Argentinian provinces and it has an estimated prospective area of 30,000 km^2 and an average depth greater than 2400 m (Kuuskraa et al., 2013). The Basin is bordered on the west by the Andes Mountains and on the north and south by the Rio Colorado, Rio Neuquén, and Rio Limay. The Basin has a pluvio-nival regime, with most of the precipitation coming from the eastern Andes (Forni et al., 2018). The Rio Limay and Rio Neuquén have six hydropower plants with a total installed capacity of 5000 MW, representing 15% of Argentina's electricity supply (Forni et al., 2018). The Neuquén Basin has both freshwater and brackish or saline aquifers at depths ranging between 0 and 600 m (Magali et al., 2016).

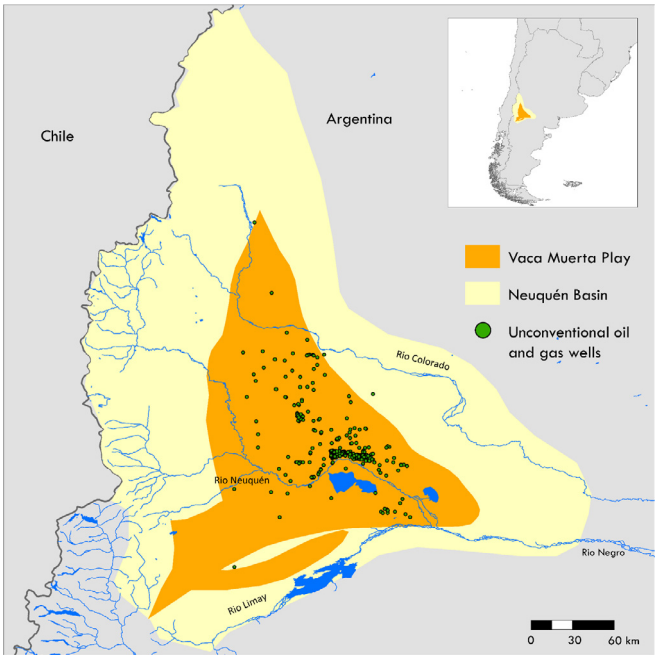

Fig. 1. The Vaca Muerta Play in the Neuquén Basin in Argentina. The map shows major rivers, four artificial reservoirs in the footprint of the Vaca Muerta shale play, and the distribution of UOG wells. In the 2010–2017 period, 760 wells were drilled to extract UOG from the Vaca Muerta shale formation (Ministerio de Energia y Mineria, 2018).

The region is already producing oil and gas from conventional and tight sandstones and it is emerging as the premier UOG development in South America. The climate is semiarid with mean annual precipitation of 178 mm (Mauter et al., 2014). In the Neuquén province, most croplands are irrigated and in year 2010 its population accounted for 551,000 people (INDEC, 2010). The region is an important agricultural area with an intensive production of fruits with 10 million hectares of irrigated lands (Mauter et al., 2014).

2.2. Assessing water consumption from UOG extraction

The water consumption of UOG extraction (WC_{UOG}) was calculated following Rosa et al. (2018a), as:

$$WC_{UOG}\left(\frac{m^3}{month}\right) = (W - F \cdot R) \cdot n \quad (1)$$

where, W is the water injected into one well using hydraulic fracturing technology; F is the produced water per well; R is the recycled fraction of the produced water (e.g., flowback and formation water); n is the average number of wells drilled and