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The future of natural gas infrastructure development in the United states

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HIGHLIGHTS

- Inter-state natural gas infrastructure investment across socioeconomic context.
- Existing pipeline capacity is insufficient to satisfy future demand for natural gas.
- Geographic distribution of investments within the U.S. is heterogeneous.
- Risks of under-utilization of pipeline capacity in a low-carbon future economy.

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ABSTRACT

Changes in the natural gas market have spawned the need for pipeline infrastructure planning. Previous studies have analyzed natural gas infrastructure development largely independent of the interactions of the natural gas sector with the broader economy. However, natural gas infrastructure development is strongly influenced by broader domestic and international socioeconomic conditions. We couple a global Human-Earth system model with state-level detail in the United States (GCAM-USA) that provides the broader socioeconomic context for natural gas supply and demand with a natural gas infrastructure investment model (NANGAM) to examine inter-state natural gas pipeline infrastructure development in the U.S. under a range of socioeconomic scenarios. Here we show that existing pipeline infrastructure in the U.S. is insufficient to satisfy the increasing demand for natural gas and investments in pipeline capacity will be required. However, the geographic distribution of investments within the U.S. is heterogeneous and depends on the capacity of existing infrastructure as well as the magnitude of increase in demand. Our results also illustrate the risks of under-utilization of pipeline capacity, in particular, under a scenario characterized by long-term systemic transitions toward a low-carbon economy. More broadly, our study highlights the value of integrated approaches to facilitate informed decision-making.

1. Introduction

Natural gas is gaining increasing importance in global energy markets primarily because of competitive prices driven by the shale gas boom. Indeed, in the U.S. natural gas surpassed coal to become the leading source of electricity generation in 2016, the most important sector consuming natural gas in the U.S.[1] In addition, U.S. pipeline and liquefied natural gas (LNG) exports have increased significantly over the last five years and are expected to continue to increase through the mid-century.[2] For example, pipeline natural gas exports to Mexico in 2016 were roughly four times the exports in 2010. Furthermore, LNG is projected to dominate U.S. natural gas exports,[3] increasing total U.S. liquefaction capacity by roughly ten times between 2016 and 2019 [1]. In this context, the U.S. is expected to become a net exporter of natural

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[1] Electricity explained. Electricity in the United States. Available at: https://www.eia.gov/energyexplained/index.cfm?page=electricity_in_the_united_states.

[2] Today in Energy: U.S. natural gas exports to Mexico continue to grow. Available at: https://www.eia.gov/todayinenergy/detail.php?id=28932.

[3] The top importers of U.S. LNG (Bcf in 2016) were Chile (29.4), Mexico (27.5), China, (17.2), India (16.9) and Argentina (16.7). See https://www.eia.gov/todayinenergy/detail.php?id=30052 and https://www.eia.gov/dnav/ng/ng_move_expc_s1_m.htm.

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Table 1
Summary of previous literature on natural gas infrastructure planning.

Author	Regional/ Geographic scope	Sectoral scope	Key insights
U.S. Department of Energy [9]	U.S.	Natural gas sector only. Demand is modeled from power sector only	Increased demand for natural gas in the power sector will lead to pipeline capacity additions. However, these additions will occur at a slower pace than historical expansion of pipelines
Liu et al., Zhang et al., and Barati et al. [13–15]	Not explicit (These studies consider sample networks such as the IEEE bus test networks)	These studies assess power sector unit commitment with natural gas transportation constraints. Supply from natural gas sector is not modeled explicitly	Combined coordination of the power sector and network operators of both the power and gas transportation network is required to avoid shortages and congestions, and for planning of new transportation infrastructure
Oliver at al, Brown et al., and M. Oliver [16–18]	U.S.	Natural gas sector only. Demand for natural gas is not modeled from individual sectors, but rather, in an aggregate manner	Lack of pipeline capacity results in network congestion and increased transportation costs. The increased prices could be managed by increased storage or additional pipeline capacity
Dieckhöner et al., Egging et al., Holz et al., [19–22]	Europe	Natural gas sector only. Demand for natural gas is not modeled from individual sectors, but rather, in an aggregate manner	The European natural gas market shows high integration. However, network congestions and need for new pipeline capacity was observed in Germany, Denmark and eastern Europe. Europe will also depend on exports from Africa and Caspian region, leading to added import pipeline capacity
Zhang et al. [23]	China	Natural gas sector only. Demand for natural gas is not modeled from individual sectors, but rather, in an aggregate manner at the provincial level	Scenarios with high imports in China show a substantial pipeline infrastructure expansions in the south-western regions. Pipeline imports replace LNG imports when international prices increase
Egging et al. [24]	World gas model	Natural gas supply sector only. Demand for natural gas is modeled by sector	Share of LNG and pipeline change over time and region. The European region will require new pipeline import capacity due to proximity to major gas suppliers. LNG will play a major role in the Asian market
Feijoo et al. [12]	North America (U.S., Canada, and Mexico)	Natural gas sector only. Demand for natural gas is not explicitly modeled from individual sectors, but rather, in an aggregated manner at the sub-national and regional level	Increased Mexican natural gas demand from the power sector results in higher U.S. pipeline exports. Exports to Mexico are possible under a shift of flows in the U.S. and pipeline capacity expansions in both the U.S. and Mexico

gas in 2017 and a net exporter of total energy by 2020[4]. Another example of increased importance of natural gas is the Chinese energy market. Natural gas production in China has grown rapidly in the last decade, increasing by 500% between 2000 and 2016 (27.2 bcm in 2000 to 136.9 bcm in 2016). However, as in many other countries (e.g., Mexico), the growth in demand (which increased about 850% over the same period) has surpassed supply capacity. The gap between Chinese natural gas demand and supply has been projected to continue to increase, reaching a gap ranging between 225 and 807 bcm in 2050 [2]. The increasing importance of natural gas in energy markets worldwide underline the need for adequate natural gas infrastructure and planning (e.g., see [3–8]) to not only proactively utilize this resource, but also protect from adverse implications for energy security. Indeed, the development of natural gas infrastructure has seen an expansion in the recent years. For example, in the U.S., recently completed or upcoming pipelines (e.g. the Rover pipeline and the Atlantic Coast Pipeline Project) connect newly emerging supply hubs such as the Middle Atlantic region (due to the increased supply from the Marcellus and Utica shale basins) to the rest of the U.S. In addition, new pipelines (e.g. Atlantic Coast Pipeline and the Valley Crossing Pipeline, Appendix A, Sections A1 and A2) also connect the West South Central region to Mexico to facilitate increased exports.

The increasing importance of natural gas and the emerging boom in investments in pipeline capacity raise several important questions such as: *Is the existing pipeline infrastructure in the sufficient to satisfy the increasing demand for natural gas in the future? What is the plausible range of the magnitude of future investments in pipeline capacity? How are these investments regionally distributed? Are there conditions under which the pipelines are underutilized?*

Answering these questions requires us to understand how future infrastructure development will be determined by broader domestic and international socioeconomic conditions. For example, the character of technology deployment in demand sectors such as the electric power sector, demographics, and economic growth patterns within the U.S. could shift natural gas demand centers resulting in shifts in infrastructure investment patterns compared to observed historical trends [9]. Likewise, changes in the energy and environmental policy landscapes in Mexico and Canada could affect U.S. pipeline and LNG exports, and thus U.S. energy security. Such interactions underscore the need for an integrated approach to study future natural gas infrastructure development—one that captures the complex *regional and sub-national* factors that affect investments in infrastructure while maintaining consistency with the broader *national* and *global* processes, and conditions.

We answer the above questions in the context of the U.S. We couple a global multi-sector Human-Earth system model with state level detail in the U.S. (GCAM-USA) [10] and a natural gas sector infrastructure investment model with updated data on the newest pipelines in North America (NANGAM) [11,12]. Using this coupled framework, we explore five socioeconomic scenarios of the future that vary across domestic and international natural gas demand patterns. The first scenario, labeled *Reference*, represents a counterfactual scenario to compare other scenarios against. The remaining scenarios are constructed as sensitivity cases of the *Reference* scenario representing high, low, and regionally variegated domestic demand (*High domestic demand*, *Low domestic demand* and *Heterogeneous domestic demand* scenarios respectively) and high international demand (*High international demand*) for natural gas.

Our study makes two important methodological contributions to the literature. First, although a number of previous studies examine future natural gas infrastructure development both in the U.S. and rest of the world [9,12–27] (see Table 1 and Appendix A3 for a literature review summary), they do not consider the broader socioeconomic context. GCAM-USA includes state-level representations of the supply and demand of natural gas along with interactions of the natural gas sector

[4] EIA's AEO2017 projects the United States to be a net energy exporter in most cases. Available at: https://www.eia.gov/todayinenergy/detail.php?id=29433.