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Disclosing water-energy-economics nexus in shale gas development

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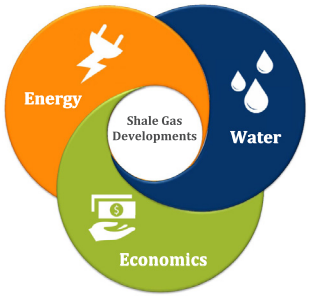
HIGHLIGHTS

- A critical review of shale gas reserves distribution and development is presented.
- An optimization-based system analysis in used to assess shale gas development.
- Water-energy-economics nexus in shale gas developments is explored.
- Synergies between water management and shale gas supply chain design are revealed.

GRAPHICAL ABSTRACT



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ABSTRACT

Shale gas has gained importance in the energy landscape in recent decades. However, its development has raised environmental concerns, especially, those associated with water management. Thus, the assessment of water management aspects, which inevitably impact the economic aspects, is crucial in evaluating the merits of any project exploiting this energy source. This paper provides a review of the economic and environmental implications of shale gas development around the world. Furthermore, to demonstrate the interplay between the various technical, environmental and economic factors in concrete terms, we report on a specific set of case studies conducted using an integrated decision-support tool that has been implemented to model and optimize shale gas development projects. The case study results confirm that the gas breakeven price decreases with expansion in scale of the shale gas development, i.e. increasing the number of well-pads in the system. However, scale also increases the options for water re-use and recycle in drilling and fracturing operations, which can result in lower freshwater withdrawal intensity. Moreover, under water scarcity scenarios, the choice of well-pad designs that are inherently less water intensive was found to be more cost-effective than water re-use or/and recycle strategies at reducing net freshwater demand. Similar trends were observed when the impact of wastewater quality, i.e. total dissolved solids concentration, on the optimal development strategy of shale gas plays was investigated. The results of these case studies reveal that greater efforts are needed at characterizing freshwater availability and wastewater quality for the evaluation of both the economic and environmental aspects of shale gas development.

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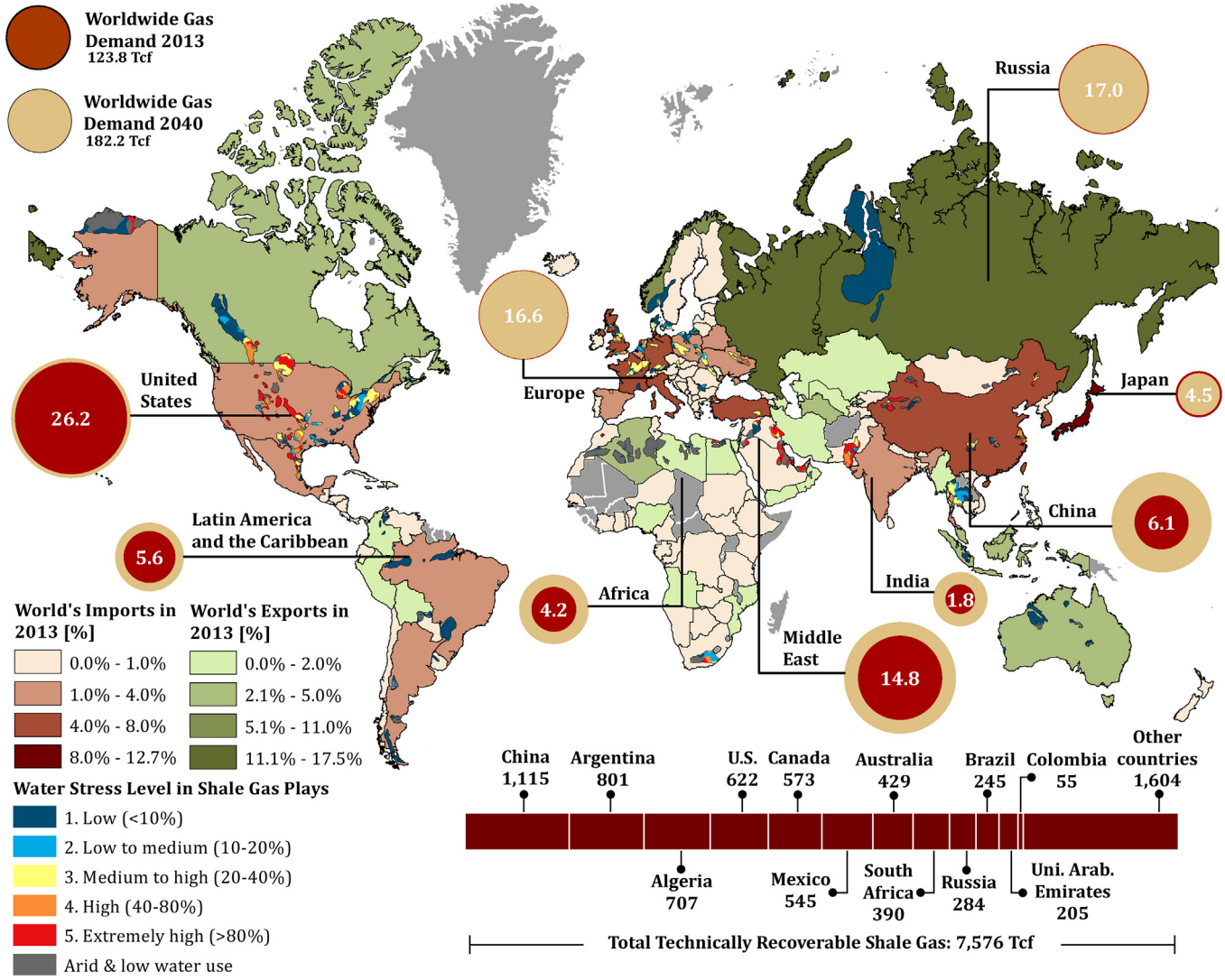

Fig. 1. Global gas demand and supply [21,28], shale gas reserves [34], and water stress [35,36]. Numbers inside the bubbles indicate the natural gas demand in 2013.

1. Introduction

The depletion of conventional fossil fuel reserves together with the growing demand for primary energy have spurred the development of new energy sources, with shale gas and shale oil among the unconventional fuels receiving most attention. Even though the development of these unconventional fossil fuels has brought new business opportunities for the energy sector, their exploitation relies on the implementation of more sophisticated and costly production techniques, specifically, horizontal drilling and hydraulic fracturing, which make their economics especially susceptible to volatile prices in the spot market. Additionally, the implementation of artificial stimulation techniques, used in hydraulic fracturing operations, has raised concerns regarding potential negative environmental impacts, especially the depletion and possible degradation of fresh water resources. Thus, a rigorous quantification of the trade-offs associated with the development of shale gas plays is essential for evaluating the economics of these unconventional fossil fuel projects as well as for formulating policies and regulations for their adequate exploitation and development [1].

In particular, shale gas development has drawn the attention of countries around the world, stimulated by its observed impacts in the United States not only on the economy but also on the increasing burden on water resources required for fracturing operations [2,3]. Accordingly, this increasing interest has resulted in numerous research studies addressing different aspects regarding the exploitation of shale gas resources. Some researchers have focused on the geological characterization, including prospectivity assessment [4–6] and productivity evaluation based on the identification of the naturally-fracture networks [7]. Reservoir modeling and simulation techniques have been implemented to investigate the productivity of shale gas plays by integrating petrophysical and geomechanical characterization along with different artificial stimulation strategies [8,9]. Moreover, the economic assessment of shale gas plays has also drawn the attention of the research community. Simulation-based and data driven tools have been reported for the preliminary evaluation of shale gas development [10,11]. Furthermore, given the complexity of the decision-making problem, optimization models have been developed and implemented for the tactical and strategic planning of shale gas fields and supply chains [12–17]. In addition to modeling, simulation, and economic evaluation of shale gas resources, the assessment of environmental impacts, in terms of CO_2 emissions, associated with the development of shale gas resources, has also been subject of extensive research [18–20]. Wastewater management is another crucial aspect, which is being considered in the development of shale gas plays. However, despite the extensive studies reported to date on shale gas issues, the integration of water management within the design and planning of shale gas supply