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Estimating the required underground natural gas storage capacity in Brazil from the gas industry characteristics of countries with gas storage facilities

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ABSTRACT

The Brazilian energy sector has undergone significant changes in recent decades. In particular, consumption and production of natural gas have intensified, and more infrastructures for its transport and importation have been built. In addition, recent discoveries (such as the huge natural gas volumes located in offshore fields) and new research into unconventional deposits indicate a rise in Brazil's proven natural gas reserves in the near future. However, Brazil lacks the geological or underground storage facilities to support its rapidly expanding gas industry, as well as important tools for meeting fluctuating demand and production and improving supply security. To assess the required storage capacity for Brazil, it is useful to analyze the international experience, clarifying the development of several aspects of the gas industry in gas storing nations. To this end, we investigated the relationships between storage and various characteristics of the gas sector by linear regression analysis. The research, conducted on all 38 countries with operational underground natural gas storage, evaluated the extent to which storage capacity is affected by proven reserves, production, consumption, infrastructure, total gas imports and exports, and the use of natural gas as a percentage of total national energy consumption. A very strong relationship emerged between underground natural gas working storage capacity and gas consumption (R^2 = 0.8825) and gas infrastructure (R^2 = 0.9130). Another important relationship was identified between storage and gas production volume (R^2 = 0.8239). The remaining aspects did not significantly affect the development of gas storage activity. We estimated the deviations between the values calculated by the linear regression equations and those reported in the technical literature. The errors varied from 89.1%, when all 38 countries were involved, to 31.4%, considering the 13 nations with the highest working gas storage capacities. The average deviation was significantly higher for the 12 nations with little storage capacity (as high as 288%); excluding these 12 countries, the average error reduced to 37.4%. Thus, the equations obtained by the correlations more accurately predicted the outcome in countries with higher storage capacity. The large deviations for countries such as Argentina, China, and Sweden are discussed. Finally, the required storage for the Brazilian gas sector was determined at two intervals: (i) 0.34–9.22 billion m^3, based on the error of 89.1%, and (ii) 1.98–6.70 billion m^3, based on the deviation of 37.4%. It is important to mention that high errors were expected, since gas storage depends on factors such as geology and demand seasonality, which were not considered in this work, but which could be analyzed in future researches.

1. Introduction

Underground or geological storage of natural gas is well developed in many countries. Among its several roles is to match different flows of production and demand and to improve supply security. Underground natural gas storage (UGS) sites are established in more than 30 countries, and are especially well developed

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in the United States (USA), Russia, Ukraine, Germany, Canada, France, and Italy (CEDIGAZ, 2011; Confort, 2006). The characteristics of the natural gas sector in gas storing nations can be investigated to determine relationships between developments in gas storage capacity and one (or several) industrial aspects, such as volumes of proven reserves, annual production, and annual consumption. The presented methodology could be used to estimate gas storage needs in countries lacking storage sites, such as Brazil.

The Brazilian gas sector is undergoing significant changes. Throughout the past two decades, Brazil's consumption and production of natural gas have grown by 11% and 8.4% per annum, respectively. Since 1998, the total length of gas pipelines, excluding low pressure distribution pipelines, expanded from 4600 to 11,700 km (exceeding 7% per annum). During the same period, the Brazilian gross domestic product increased approximately 3% each year. Finally, the proven volume of natural gas in Brazil increased from 181 (1991) to 459 billion m^3 (2012), indicating an annual growth of 4.5% (ANP, 2013; BP, 2013; WB, 2013). Recent studies suggest that known Brazilian reserves will increase even more steeply in future. According to the U.S. Energy Information Administration (EIA), the recent discovery of the Brazilian pre-salt mines may increase Brazil's volume of proven natural gas reserves by 50% (EIA, 2013b). The EIA also reported on shale gas in Brazil, stating that such unconventional gas categories could push Brazil's gas reserves toward 6400 billion m^3 (EIA, 2011). Considering these variations in consumption, production, infrastructure, and reserves, it is pertinent to question the importance of storage in Brazil under various scenarios; supposing, for example, that annual consumption stops growing and proven reserves rapidly increase. To answer this question, we should analyze the international experience of storage activity.

The main purpose of this work is to investigate whether relationships exist between gas storage capacity and the development of related activities in all countries with storage sites, according to the CEDIGAZ (2011), GIE (2013), and NGA (2012). From the obtained correlations, we estimate an appropriate level of geological storage in Brazil, compatible with the characteristics of the Brazilian gas industry.

In this study, the geological storage capacities, (billion m^3 or bcm) of all countries with UGS sites, were plotted against a number of activities related to the gas sector. Capacities were collected primarily from 2012 to 2013 data. The following gas sector characteristics were analyzed: (i) proven reserves in 2012 (bcm), (ii) production in 2012 (bcm), (iii) consumption in 2012 (bcm), (iv) infrastructure in 2013, measured in km of transport or transmission natural gas pipelines, (v) total gas imports in 2012 (bcm), (vi) total gas exports in 2012 (bcm), and (vii) natural gas consumption in 2012, as a percentage of total national energy consumption (%). Relationships between the variables (working gas capacity vs. proven reserves, working gas capacity vs. production, working gas capacity vs. consumption, and other combinations) were identified as strongly, moderately, or weakly correlated variables by evaluating their coefficients of determination (R^2) (Zentgraf, 2007).

Having obtained the coefficients of determination (R^2) of each relationship, the working gas capacity of each country was estimated from the most correlated relationships. To verify the accuracy of the methodology, the deviations between the estimated and reported storage capacities were determined for each case. Finally, the methodology was applied to estimate the storage requirements of Brazil (in terms of working gas capacity), based on its natural gas industry characteristics.

1.1. Objective

This study proposes a methodology for estimating the required volume of geological or underground natural gas storage in Brazil, accounting for the characteristics of the Brazilian natural gas industry. To meet this objective, the international experience of gas storage is analyzed from 2012 to 2013 data of all countries with UGS facilities.

1.2. General aspects of underground natural gas storage

Throughout the past century, underground (or geological) natural gas storage sites have been developed to meet the usually continuous gas supply, conveyed through long pipelines, and demands that may fluctuate with season, weather, and economic climate. Thus, controlling the volume of available gas is a distinct advantage (Tek, 1996). Underground gas storage facilities can be used for: (i) supplying gas during uncommon demand peaks, (ii) storing gas during the summer to be delivered during the winter, especially in temperate countries (seasonal demand), and (iii) assuring gas supply during operational, economical, or political problems that may interrupt the pipeline's gas flow (emergency situations). These objectives depend on national climate, gas production, reserves, and consumption profiles, which differ among countries. Stored resources are also tapped by less conventional services created by storage unbundling and the new market conditions of some nations. For example, some countries have taken measures to (i) ensure liquidity at market centers to restrain price volatility and maintain orderly gas markets, (ii) gain profits by storing the gas during low-price periods and selling it during periods of higher value, and (iii) reliably supply the gas at the lowest cost to ratepayers by maintaining specific levels of storage inventory (EIA, 1995; FERC, 2004). Currently, most of the natural gas is stored underground in depleted or exhausted oil or gas fields, aquifers, and salt domes or caves. Each of these storage types has unique physical properties (porosity, permeability, and retention capability) and economic characteristics (site preparation and maintenance costs, deliverability rates, and cycling capability) that govern its suitability to particular applications. Less used gas storage sites include abandoned mines and lined rock caves (EIA, 1995; FERC, 2004).

Among the most important characteristics of a storage site is its volume of deliverable natural gas, that is, its working (or top) gas storage capacity. The working gas is the volume of natural gas that can be effectively withdrawn. Importantly, most of the available data on storage capacity refer to the working gas capacity. Underground storages also contain cushion gas, whose main function is to retain suitable pressure for efficient withdrawal. In depleted reservoirs, a percentage of the cushion gas may be the remaining native natural gas once commercial production has terminated. When developing an underground natural gas site, additional gas is usually injected and combined with the existing volume of gas to maintain suitable pressures for the required withdrawal rates.

Underground natural gas storage is more developed in nations that pioneered the scheme or whose natural gas industry was already matured. These countries usually impose strict regulations on the location, construction, and operation of UGS facilities, and on commercial activities and access to the storage sites. Such countries include the United States of America (USA), Canada, Russia, Germany, France, and Italy (Confort, 2006; Confort and Mothé, 2009).

2. Methodology

The aspects of national gas sectors analyzed in this study are taken mainly from the BP Statistical Review of World Energy Report (BP, 2013) and from the CIA's The World Factbook (CIA, 2013).[1]

[1] The following sources were also considered: ABARE (2005, 2006), CIA (2012a), CSB (2013), Ćurčić (2011), NEB (2012), PHMSA (2012), and SEAI (2012).