Groundwater and Hydrocarbon Production in Brazil

Débora dos Santos Carvalho, José Aquiles Grimoni, and Miguel Morales Udaeta

***Abstract*—Resources are limited and new forms of exploitation of energy resources, such as hydraulic fracturing, tend to enter the country. This study analyses the nexus water-energy regarding to the exploitation of oil and gas from the continent by the hydraulic fracking. The research will be of a theoretical and bibliographic genre, of an applied nature, with the objective of proposing a mixed qualitative-quantitative approach to the issues of increasing energy security and increasing water security. It aims also about the shale gas extraction in Brazil and its challenges. As result of this discussion is that the unconventional sources of obtain energy can impact the hydro security specially the groundwater.**

***Index Terms*—Energetic security, fracking, hydro-security, groundwater, water-energy-nexus.**

I. INTRODUCTION

The water and energy nexus touches on a latent issue that can impact the quality and quantity of groundwater is the exploration of hydrocarbons on the continent and not on the high seas, as has been done.

A new source of fossil fuel is changing the energy landscape of some countries and promises to be the beginning of a new era in the world energy landscape: natural gas extracted from shale (shale gas, in English). Shale is a clayey rock of sedimentary origin; shale is a metamorphic rock, therefore of another origin. However, there is a long and mistaken Brazilian tradition, including among Petrobras technicians, of calling shale (shale) schist, hence there is a lot of talk about shale gas [1].

The rocks that generated the oil are located on the continent, after differences in pressure, over time, the oil was transported to the basins where it is found, in greater quantity, in the high seas, however, it can still be found petroleum, in liquid or gaseous state, in its source rocks.

The term shale gas could not be applied in Brazil, because in Brazil there is no expressive appearance of shale. What else exists in Brazil is another rock called Folhelho. All of Brazil's large oil and natural gas reserves originate from folhelho. The most scientifically appropriate term would be folhelho gas. However, it is very difficult to reverse the use of this terminology, since now the term shale gas represents not only the source rock, but also infers that an unconventional extraction technique was used, ie hydraulic fracturing. And hydraulic fracturing is used for gas extraction in both shale and folhelho.

Any rock that contains organic matter produces both gas and oil, once inserted in the necessary conditions of temperature and pressure. The most common types of reservoirs are shales due to their formation environment being favorable to the preservation of organic matter [2].

Shale gas, which constitute unconventional hydrocarbon extractions, enter a scenario where conventional sources of hydrocarbons are running out. Brazil has realized the importance of "diversification of energy sources' over the last few decades. Starting from an importing tradition and always with a strong "nationalist-developmentalist' vocation", the country improved its Energy Security in the most critical moments of the "era of oil conflicts"; overcoming "external oil dependence from the consumer's perspective"; and reaps as an additional fruit the possibility of reversing its position in International Oil Relations, reaching the status of an emerging exporting country [3], p. 33.

The Fig. 1 illustrates the main sedimentary domains in Brazil. The sedimentary domains contain water and energy reserves.

Fig. 1. Main sedimentary (green) and crystalline (yellow) domains. Source: Petrobras [4]

According to [5], Hydrocarbon gases are stored in source rock fractures:

1) Foliation is a property that rocks show that is manifested by the ease of fracturing along more or less parallel planes. This property results, in many cases, from an alignment of minerals that have a predominant cleavage in a given direction. Shale is a type of foliation. In this case, this is caused by the presence of a large amount of micas that are oriented in the rock. Lineation is a property of rocks to present lines, traces, which result from the alignment of prismatic minerals (in many cases).
2) The term "sedimentary shale" should not be used, keeping the word schist to characterize rocks from

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metamorphic environments. In older books (and unfortunately in some school textbooks) the term "clay shale" appears as a sedimentary rock. It is a clay that has a foliation (in principle, parallel to the stratification). This foliation results from the existence of an alignment of leaf minerals (usually micas) which, during the sedimentation process, are oriented in exactly the same way as a set of leaves are oriented when they fall to the ground.

3) Slate is a fine-grained, foliated metamorphic rock, usually dark in color. Phyllite is similar to slate, although the foliation is not so perfect, and may have different colors. Shale is a metamorphic rock that has schistosity (when micas are visible to the naked eye, the rock is called micaschist).
   Shale is a term not often used in Portuguese and that gives rise to confusion. Sometimes it appears associated with fine-grained sedimentary rocks with foliation and sometimes with fine-grained metamorphic rocks.
4) Gneisses are coarse-grained metamorphic rocks (with a high degree of metamorphism) that are characterized by the existence of distinct mineralogy bands. Orthogneisses are gneisses that result from the metamorphism of igneous rocks (granitic rocks) while paragneisses result from the metamorphism of sedimentary rocks (sandstones in most cases). In summary: For fine-grained detrital rocks from sedimentary environments, it will be better to use terms such as claystone and siltstone (according to the size of the sediments). These rocks may or may not be foliated (if so, the Anglo-Saxon literature uses the term shale for these rocks). For fine-grained metamorphic rocks, terms such as slate, phyllite and mica schist are used. If the rocks present coarse grain and banding, the term gneiss is used [5].

II. Water Resources Versus Energy Resources in Hydraulic Fracturing

Sedimentary basins are indicators of aquifers superimposed or underlain by hydrocarbon-generating rocks. The exploitation of these energy resources in these regions rich in water resources generates many challenges and controversies.

The main concern is with groundwater safety, because hydraulic fractionation can contaminate water intended for consumption or irrigation purposes [6].

According to [3], as shown in Table I. Comparison of volume of water consumed by MMBTU of energy produced by the company 'Chesapeake Energy' in 2009 below, which compares the production of shale gas of the company "Chesapeake Energy" in 2009, second largest producer of natural gas in the US, with the consumption of water from other energy resources, shale gas generates more energy (in Million British Thermal Unit - MMBTU) per liter of water.

TABLE I: Comparison of Volume of Water Consumed by MMBTU of Energy Produced by the Company 'Chesapeake Energy' in 2009

Energetics resources	Volume of water consumed by MMBTU of energy produced
Shale Gas	(3,18 - 12,61) Litros
Gas Natural Conventional	(3,79 - 11,36) Litros
Coal (powdered transport)	(7,57 - 30,28) Litros
Coal (paste transport)	(49,2 - 121,13) Litros
Nuclear (ready to use uranium in power plant)	(30,28 - 53) Litros
Conventional oil	(30,28 - 35,71) Litros
Synthetic - Carbonated Carbon	(41,64 - 98,42) Litros
Shale Oil from Oil	(83,28 - 212) Litros
Oil from tar sands	(102 - 257,4) Litros

Source: Mantell (2009)[1] apud [3]

In addition to the hydraulic fracturing process to obtain hydrocarbons putting groundwater sources at risk, it also makes intensive use of water resources.

Water expenditure in hydraulic fracturing for unconventional gas exploration can reach values greater than 3.7 million liters in wells subject to multiple fractures. Therefore, its application in arid areas may cause scarcity in the region [2].

However, despite producing more energy per liter of water used for energy production, this volume of water comes from systems that are much more complex and with more substantial impacts than that energy resource extracted from high evil, even with larger volumes of water resources.

In addition to the water resources required by hydraulic fracturing, energy resources are also used, given the need to produce high hydraulic pressures, so that pre-existing fractures are widened and new fractures open and deepen in the source rocks, so that the gas (and/or oil) are washed to the surface and captured. A range of products are used in auxiliary extraction wells, which also pose a real risk to soil and groundwater.

After the tests carried out in order to determine if the well can withstand the hydraulic pressures that will be used, a hydrochloric acid solution is applied to eliminate residues left during cementation. Then fluids are inserted, which can be based on water, oil, and acid. In the case of shale, water-based fluid is used, mainly due to its low cost, high performance and ease of handling [2].

In addition to liquids, physical agents are introduced underground in order to maintain the width of the fractures for gas flow. After the opening of the fractures and with the end of the pumping of the fluid, the weight of the rocks exerted on the cracks will lead to a closing and an eventual drop in the gas production. To prevent this from happening, a granular substance called proppant is applied to the water. Its composition varies, and the most used are resin-treated sands and ceramic proppants according to CACHAY (2004)[2] apud 2.

Nevertheless, the relevant fact is that, according to [7], fracturing fluid contains more than 600 chemicals to release natural gas.

The frac fluid used can be treated at stations in order to be reused in different wells. However, this is not the process that companies often do. Generally, it is deposited in subsoil areas that can hold the fluid and that are far from aquifers, so that there is no risk of contamination [2].

Secondary energy sources are obtained from primary energy sources through a transformation process. Some examples are gasoline that comes from petroleum and

[1] Mantell, M. E.; Engineer, P. C. E. 2009. Deep shale natural gas: abundant, affordable, and surprisingly water efficient.
[2] Cachay, L.R.S. Dec, 2004. Flow of Support Particles in Oil Wells Stimulated by Hydraulic Fracturing.

electricity that can be transformed from one of the aforementioned primary energy sources. [8]

The Fig. 2- Hydraulic fracturing detail illustrates in detail the operations involved in hydraulic fracturing. The figure shows the well, which can reach up to 3000 meters deep, crossing water bodies. Cracks or fractures in these wells can lead to leakage of the full range of materials used in hydraulic fracturing into the soil and groundwater.

At the end of the deep well, fractures appear that will facilitate the flow of gases into the well.

Contamination of groundwater with flammable hydrocarbons from hydraulic fracturing processes is already observed and, as a consequence, the water acquires flammability and poses a real risk to the population.

"In Parker County, Texas, we find homes with very high levels of methane when the water bubbles up due to gas," Jackson said. "The biggest risk from methane in water is explosions, which could happen in a basement or sheds where the gas accumulates. In addition, methane leaks could be occurring to groundwater". The [US] government does not classify dissolved methane in drinking water as a health hazard. This contamination was typically attributed to natural gas wells with insufficient cement barriers to separate them around rock and water, or incorrectly installed steel casings that allow the gas to travel upwards. Hydraulic fracturing wells that have been installed at depths of 3,000 feet or less pose a risk for groundwater contamination. Jackson found that there were at least 2,600 of these shallow hydraulic fracturing wells in the United States, many of which were drilled directly into freshwater aquifers. [9]

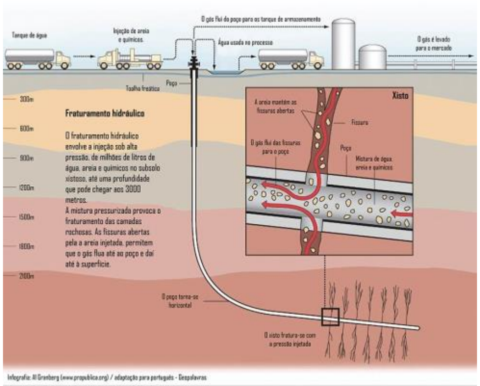

Fig. 2. Hydraulic fracturing detail.
Source: Al Granberg (2013) apud [10]

According to [11], the extent of impacts from groundwater contamination can extend up to 1 km away from active wells.

Most of the time, the gas leak is not that big and can be remedied. However, in one case attributed to the drilling of wells in the Marcellus aquifer, stray gas accumulated in the water of confined wells and exploded near northeastern Pennsylvania, in the town of Dimock. A study of 60 groundwater wells in this area, including up to the border in upstate New York, showed that mean and peak methane concentrations were higher in samples taken up to 1 km away from active gas wells, compared to more distant samples [11].

The pressure of the search for new energy sources and the pressure for the preservation of water resources must be balanced, so that the next generations can live with quality.

The number of shale oil and gas wells continues to increase, mainly in the US, but also around the world. The US has vast reserves of oil and natural gas, which are now commercially accessible as a result of advances in horizontal drilling and hydraulic fracturing technologies. But as hydraulic fracturing is increasingly used, concerns have been raised about the potential stress on surface and groundwater from withdrawing water used in the process. Equally important is the growing volume of tailings generated from hydraulically fractured oil and gas wells, requiring recycling. [12]

Decision makers must assess whether the priority is the energy security provided by the exploitation of gas or water security.

III. Exploration of Shale Gas

The exploration of shale gas in the United States is already a reality and the impacts of this energy exploration on the continent can already be observed.

The rapid rise of shale gas development from horizontal drilling and high volume hydraulic fracturing has expanded the extraction of hydrocarbon resources in the U.S.. The increase in shale gas development has sparked intense public debate about the potential environmental and health effects of hydraulic fracturing. [...] four potential risks to water resources are identified:

- contamination of shallow aquifers by released hydrocarbon gases (i.e. atmospheric air contamination), which can also potentially lead to salinization of shallow groundwater through leakage from natural gas wells and flow of subsurface;
- contamination of surface and shallow groundwater from spills, leaks and/or the disposal of inadequately treated wastewater from shale gas exploration;
- the accumulation of toxic and radioactive elements in soil or sediment flow near disposal sites or spills; and
- the excessive extraction of water resources for high volume hydraulic fracturing that could induce water scarcity or conflicts with other water users, particularly in areas with water scarcity. Analysis of published data (as of January 2014) reveals evidence of atmospheric air contamination, surface water impacts in areas of intense shale gas development, and the accumulation of radium isotopes at some disposal and spill sites. Direct contamination of shallow groundwater and deep groundwater from hydraulic fracturing fluids, however, remains controversial [13].

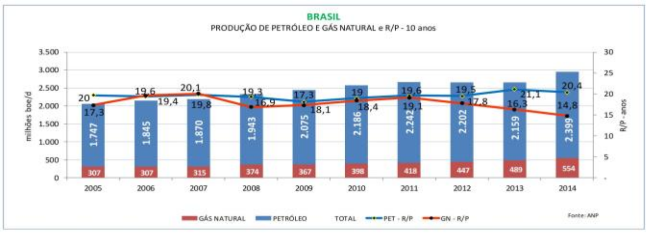

Fig. 3. Evolution of oil and natural gas production and R/P (reserve/production) in Brazil - 2005/2014.
Source: [14]

In Brazil, proved reserves of natural gas, both onshore and offshore, are growing. As illustrated by Fig. 3- Evolution of Oil and Natural Gas Production and R/P (Reserve/Production) in Brazil - 2005/2014, Brazilian natural gas reserves total 554 million barrels of oil equivalent (boe) per day. Proved natural gas reserves in 2014 increased by 2.8% compared to 2013. The growth at sea was 3% and on land was 2.1%. Thus, the R/P (reserve/production) of oil for 2014 is 20.4 years and that of natural gas is 14.8 years [14].

A Fig. 4- ANP auction of blocks for gas exploration shows the blocks distribution that shows the distribution of blocks that would be auctioned by the National Petroleum Agency (ANP) in 2013, for the exploration of shale gas in Brazil. However, not all blocks continued the negotiations, due to judicial interpellations, as published by 17.

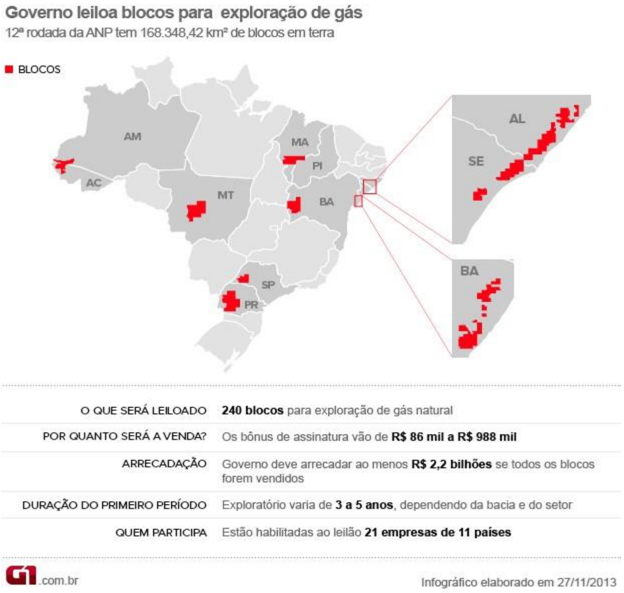

Fig. 4. ANP auction of blocks for gas exploration.
Source: [15].

On May 15, June 6 and September 26, 2014, the ANP signed 62 concession contracts related to the 12th Bidding Round. The signature bonus collected from the concession of these blocks amounted to R$154.3 million in signature bonuses and the commitment to exploratory investments amounted to R$388.5 million. By virtue of a court injunction issued in the records of Public Civil Action No. 5005509-18.2014.404.7005, the effects of the concession contracts relating to blocks PAR-T-300 and PAR-T-309, signed on May 15, 2014, and the signing of concession contracts for blocks PAR-T-271, PAR-T-272, PAR-T-284, PAR-T-285, PAR-T-286, PAR-T-297, PAR-T-298, PAR-T-308 and PAR-T-321. All blocks are located in the SPAR-CS sector of the Paraná basin. In addition, the Collegiate Board of Directors of the ANP, by virtue of a court decision, annulled the signature of the concession agreement for the PN-T-597 block, located in the SPN-O sector of the Parnaíba basin. [16]

The Fig. 5- Schematic Map of the Guarani Aquifer System illustrates in detail the Guarani Aquifer System. In the context of hydrocarbon exploration, some of the blocks being auctioned by the ANP are located on the SAG. In particular, areas of potential direct recharge are the most susceptible to contamination by surface contaminant sources, as would be the case with the allocation of eventual tailings dams from the hydraulic fracturing process.

The Brazilian State has a large reserve of hydrocarbons, enough to be used in the next 40 years, according to 19. Until recently, Brazil had 14 billion certified barrels, which would be enough to supply our country for 20 years.

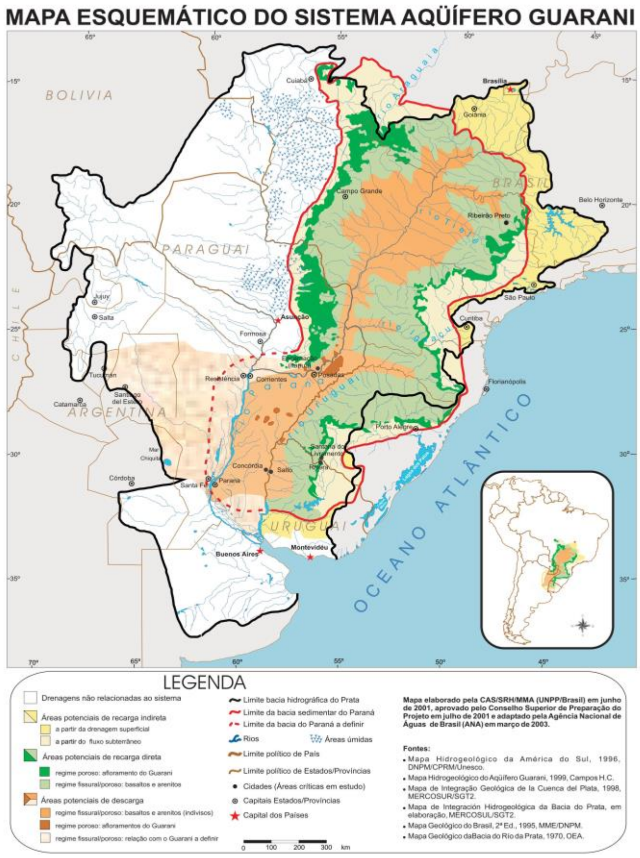

Fig. 5. Schematic map of the Guarani aquifer system.
Source: [17].

After the discovery of the pre-salt layer, we were able to add another 14 billion barrels. Therefore, we have doubled our capacity. And our reserves have become enough for 40 years. Three days ago, a new field was discovered, or certified, with around 2 billion barrels. In other words, in just four pre-salt fields, we already have more oil than in all other oil provinces in the country. We have, therefore, reached 30 billion barrels. Of course, these 16 billion correspond to 30%, or part of 30% of the pre-salt. We cannot yet say, in advance, how much will come from the other 70% of the pre-salt area. Today, 82 million barrels of oil are produced in the world per day. Of these, the United States consumes 23%, around 20 million barrels per day, of which they produce 8 million and import 12 million. China, and this is a curious fact, already consumes 8 million barrels a day. It produces 4 million and has falling reserves that should be extinguished in five years. This demonstrates the growing worsening of the world situation in terms of oil supply. And China, within 15 years, will be consuming as much as the United States. It's the forecast. There are many intensive consumers, including India, Japan and several others [18].

IV. Conclusions

Although we are experiencing an energy crisis, with reduced availability of energy resources and growing demand for energy, Brazil still has a relative advantage with the discovery and dimensioning of the Pre-Salt, which gives it autonomy in the energy sector.

The hydraulic fracturing process comes to the world scene as an unconventional process for obtaining hydro hydrocarbons. It gained geopolitical importance that caused the price of a barrel of oil to plummet all over the world, after the use of this technique on a large scale in the United States.

Considering the soil as a natural resource where we find, water resources, mineral resources and energy resources, and also considering that in order to obtain energy resources, oil and gas, we have through the use of water resources, which configures, therefore, an inseparable and conflicting scenario of the multiple uses of resources.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

All authors conducted the research; analyzed the data; and wrote the paper; and all authors had approved the final version.

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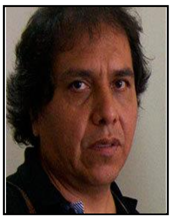

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