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Characterization of the shale gas production: A case study in a sector of the Lusitanian Basin

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Sumário

Este estudo visa caracterizar a exploração de gás de xisto em Portugal através dos impactos gerados pela sua técnica de extração – fracturação hidráulica- a nível ambiental, social e económico. A extração do gás de xisto tem vindo a ser um assunto polémico essencialmente pela sua influência nos preços do petróleo e pelos impactes ambientais negativos que estão envolvidos no seu processo – em particular, associados à água contaminada que regressa à superfície após o processo de perfuração, a *flowback water*. Para suportar esta análise, foram elaborados três casos de estudo diferente: 1) análises químicas a um exemplar de *flowback water* proveniente da formação *Marcellu, USs;* 2) delimitação de uma área de estudo na Bacia Lusitaniana através das suas características geológicas; 3) análise de sensibilidade de investimento através da aplicação do método do valor atual líquido (VAL). Na primeira análise os valores de contaminação da *flowback* revelam que estes se encontram dentro dos parâmetros esperados, sendo confirmada a elevada toxicidade da mesma. De seguida, através da análise de sondagens efetuadas na Bacia Lusitaniana, delimitou-se a área de estudo localizada entre as sondagens Benfeito, Torres Vedras 4 e Sobral. Por fim, a análise de sensibilidade indica que a variação das despesas de capital representa o parâmetro com maior influência nas receitas e no período de retorno do investimento. Em conclusão, os resultados deste estudo indicam que a exploração do gás de xisto em Portugal conduziria a grandes benefícios para a economia nacional apesar do seu sistema de taxas para esta indústria não ser considerado adequado em comparação com os sistemas praticados em outros países e tendo em consideração as suas implicações a nível de impactes ambientais.

Palavras-chave:

Gás de xisto; Fracturação hidráulica, Água de retorno, Impactes ambientais; Bacia Lusitaniana; Decisões de investimento

Abstract

This study aims to characterize the shale gas exploration in Portugal through the impacts generated by its extraction technique – the Hydraulic fracturing – on the environmental, social and economic sector. The extraction of shale gas has been a controversial issue mainly due to its influence on oil prices and the negative environmental impacts involved in the exploitation process – in particular, the contaminated water that returns to the surface after the drilling process, i.e. the *flowback water*. To support this analysis, it was performed three different analyses: 1) a chemical analysis of a flowback water sample from the Marcellus formation, US; 2) delimitation of the study area in Lusitanian Basin based on its geological characteristics; 3) an investment sensitivity analysis applying the method of net present value (NPV). The chemical analysis revealed flowback water values within the expected parameters, confirming its high toxicity. Then, based on the analysis of surveys carried out in the Lusitanian Basin, the study area was delimited from *Benfeito, Torres Vedras* 4 to *Sobral*. Finally, the sensitivity analysis finds that, comparing with the base case scenario, the variation of Capital expenditure is the parameter that most influences the profits and payback period. To conclude, shale gas exploitation in Portugal would lead to high economic benefits, despite the existence of a relatively more inefficient fee system that fails to truthfully reflect its negative environmental impacts.

Keywords

Shale gas; Hydraulic fracturing; Flowback water; Environmental impact; Lusitanian Basin; Investment decision

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Abbreviations and symbols

Al - Aluminum
APA - Portuguese Environment Agency
Ba - Barium
Bcf – Billion of cubic feet
Br - Bromide
BTEX - Benzene, toluene, ethylbenzene and xylene
Btu - British thermal unit
Ca - Calcium
CAPEX - Capital expenditures
Cf – Cubic feet
Cl - Chloride
Cr - Chromium
DOH – Department of Health
EI - Energy Institute
EIA - Department of Energy’s Energy Information Administration
EPA - United States Environmental Protection Agency
FB – Flowback
GDP – Gross Domestic Product
GWP – Global Warming Potential
HCO_3 - Bicarbonate
H_2S – Hydrogen sulfide
Hg - Mercury
IPMA – Portuguese Sea and Atmosphere Institute
INE - National Institute of Statistics of Portugal
IRR – Internal Rate of Return
K - Potassium
Li – Lithium
LNEG – National Laboratory of Energy and Geology
MCL - Maximum contaminant level
Mcf – Millions of cubic feet
mg/l - Milligrams per liter
M – Thousand
MM – Million
Mn - Manganese
MSDS - Material Safety Data Sheet
Na - Sodium
nd - Not determined
N_2 - Nitrogen
Ni - Nickel
NO_2 - Nitrite
NO_3 - Nitrate
NOAA - National Oceanic and Atmospheric Administration
NOM - Natural Organic Matter
NORM - Naturally occurring radioactive materials
NPT - Nonproductive time
Pb - Lead
PM – Particles matter
ppb - Parts per billion
ppm - Parts per million
RS - surface rental
SO_4 - Sulfate
Ra – Radium

OPEX - Operating expenditures
TC – Total Carbon
TN – Total Nitrogen
UNEP – United Nation Environmental Program
USGS - United States Geological Survey
VOC - Volatile organic compound

1. Introduction

Hydraulic fracturing is a technique used in "unconventional" gas production. This technique involves the injection of pressurized fluids to stimulate or fracture shale formations and release the natural gas. After this process, the internal pressure of the rock formation causes fluid to return to the surface through the wellbore. This fluid, known as *flowback water*, contains the injected chemicals plus naturally occurring materials. Hence, the main issue of hydraulic fracturing is its potential negative environmental impact, mainly due to the flowback water.

In Portugal, the interest in shale gas exploration has been growing and several energy companies are currently studying the economic potential of the Portuguese basins, in particular the Lusitanian Basin. Moreover, given the taxation system of petroleum industry in Portugal, it is important to mention the low rates applied considering both the costs of local pollution and rates charged in other countries.

Objectives and research

Q_1 – What are the environmental impacts associated to the flowback water caused by hydraulic fracturing?

Q_2 – What is the economic potential of gas production in shale formations of Lusitanian Basin?

Q_3 – How different taxation systems may influence the investment decision in shale gas?

Furthermore, this study aims to evaluate the potential benefits of hydraulic fracturing together with its environmental and social impacts. For example, it was established a relationship between the each flowback water component and its consequences on the environment and public health. It was also characterized the Lusitanian Basin in order to describe the potential sectors affected by the shale gas exploitation, e.g. water recourses or the seismic reflection. Regarding the economic factors, it is important to establish different scenarios according to the existing concessions contracts signed in Portugal and discuss the discount factor that should be applied in this type of investment.

Dissertation structure

This work is organized in 8 chapters:

1. Introduction - work scope and relevance, main objectives and structure;
2. Literature review - description of the central theme and relevant terms and previous work developed;
3. Materials and methods – description of how the study were conducted
4. Results and discussion – interpretation of the results
5. Conclusions – main outcomes;
6. References

   Annexes

2. Literature review

2.1 Shale gas extraction

2.1.1 Characterization of shale rock

Shale is a sedimentary rock formed from compaction of silt and clay-size mineral particles that are usually called ‘mud’. The mud is a precursor to natural gas and oil deposits as a result of its high organic material content (Rozell and Reaven, 2011). This rock can be silty or calcareous, and grade into other lithology (siltstone/limestone).

There are two types of shale: organic-rich (black) and organic lean (gray or red). Shale can be distinguished from other mudstones because it is fissile and laminated, which indicates that the rock is made up of many thin layers (Passey et al., 2010).

The main difference between shale and other gas reservoirs is represented by the low reservoir permeability and the fact that the generated hydrocarbons do not suffer any migration, being the host rock to reservoir rock itself. The low permeability of shale has been limiting the production of gas shale resources. Thus, hydraulic properties such as permeability and porosity reflect the ability of rocks to hold and transmit fluids such as water, oil or natural gas (Cho et al., 2013).

Properties such as porosity and medium permeability of rocks reservoir are rarely mentioned in the literature, on Hall, (2011) it is refereed that the expectable porosity of shale gas rock is till 6% although this value cannot be considered as absolute (Baptista, 2011).

Figure 2.1 shows the growth and projections in unconventional energy production in the United States (US).

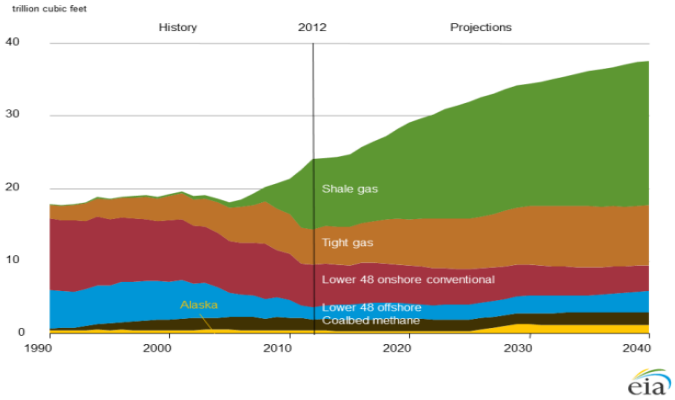
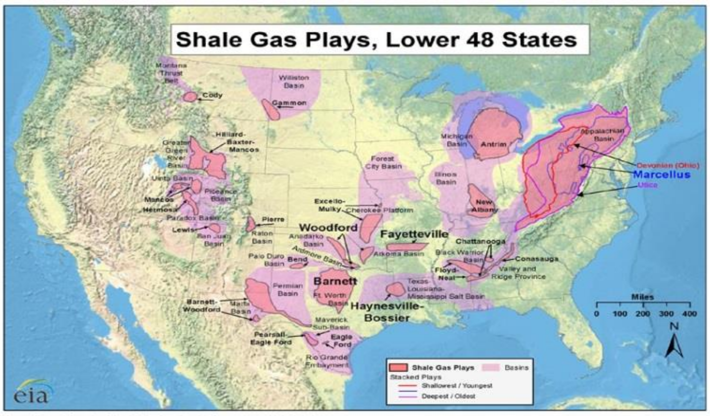


Figure 2.1. Projected U.S. Natural Gas Production by Source (1990-2040) (EIA, 2014)

2.1.1 Shale gas in USA

Shale formations in the United States have been increasing as a source of natural gas and oil. The U.S. Energy Information Administration’s (EIA), National Energy Modeling System (NEMS) began representing shale gas resource development and production in the mid-90s. However, only in recently shale gas has been recognized as a “game changer” for the U.S. natural gas market (Meade, 2015). Figure 2.2 represents the natural gas shale basins and plays of US.



Source: Energy Information Administration based on data from various published studies.
Updated: March 10, 2010

Figure 2.2. US shale gas plays (UTU, n.d.)

According to Vengosh et al., (2013), recent advances in drilling technologies and production strategies, such as horizontal drilling and hydraulic fracturing, have significantly improved the production of hydrocarbons by stimulating the flow of gas and liquids from impermeable geologic formations.

These technological improvements have overvalued the exploration of oil and gas in several unconventional areas throughout the U.S., particularly in the Barnett, Haynesville, Bakken, Fayetteville, Woodford, Utica, and Marcellus shale formations (Figure 2.2). EIA, (2013) estimates that by 2035 about 50% of the total expected gas production in the U.S will be provided from shale gas production, increasing to 340 billion cubic meters (bcm) per year.

2.1.1 Shale vs coal

Today, in the “golden age of gas” (IEA 2011), the high potential of shale gas that some authors defend, is controversial due to its environmental impact. Researchers have been doing comparative analysis including positive and negative aspects of the extraction of gas, such as shale gas and some other conventional gas like coal.

The main problem while evaluating this issue is the environmental impacts of shale gas vs coal on air. Natural gas burns approximately half carbon dioxide (CO_2), three fourth less nitrogen oxides (NO_x) than coal. In addition, its burns almost no sulfur dioxide (SO_2), carbon monoxide (CO), black carbon, particulates and mercury (Jenner and Lamadrid, 2013). However, several authors defend different opinions regarding the long-term consequences associated with the methane (CH_4) released from the shale gas, being a reason to doubt about the better footprint of shale compared to coal (Tollefson, 2012).

According to Parenteau and Barnes, (2013):“In certain respects, this surge of natural gas has benefited the environment and public health. Low natural gas prices have dramatically altered the energy mix in the electricity sector, particularly with respect to coal—the dirtiest fuel that imposes the highest social costs. One result of displacing all of this coal is that United States carbon emissions are, for now at least, the lowest they have been in twenty years.”

On the other hand, methane is the principal component of natural gas and produces 30 times more radiative forcing than CO_2 over a 100-year time frame (Omara et al., 2016). Howarth et al., (2011) affirms:

“The footprint for shale gas is greater than that for conventional gas or oil when viewed on any time horizon, but particularly so over 20 years. Compared to coal, the footprint of shale gas is at least 20% greater and perhaps more than twice as great on the 20-year horizon and is comparable when compared over 100 years.”

2.1.1.1 Marcellus Shale

Marcellus shale formation is the most expansive shale gas play in the U.S. covering an area of 240 000 km^2 along six states and underlies nearly 75 % of Pennsylvania (Soeder and Kappel, 2009).

Marcellus shale is a sedimentary rock formation buried hundreds of meters beneath the earth’s surface. As in figure 2.3, Marcellus formation stretches from upstate New York south through Pennsylvania to West Virginia and west, including to parts of Ohio (Wallace, 1993).

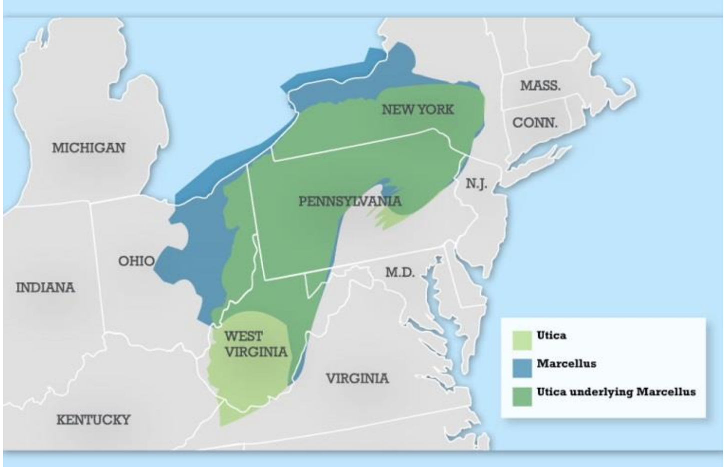


Figure 2.3. Marcellus and Utica shale formations (Marcellus Shale Coalition, 2015)

Marcellus shale forms the bottom or basal part of a thick sequence of Devonian age (416 - 359 million years ago) sedimentary rocks in the Appalachian Basin (Waples, 2012). This shale contains significant quantities of natural gas and belongs to a group of black, organic-rich shales (Kargbo et al., 2010).

In Marcellus Shale, the natural gas varies from wet in the western portion of the state to dry in the northeast. The organic-rich, gas-producing layers of Marcellus shale range from less than 1,5 m thick to more than 72 m and are located around 2 800 m below the earth surface. In general, the higher the depth, the natural gas contains higher proportions of methane and less “wet” gas components, such as propane, butane and ethane (Lampe and Stolz, 2015).

The organic matter deposited within Marcellus formation was compressed and heated deep within the earth over geologic time, forming hydrocarbons, including natural gas. Besides that, the gas occurs in fractures, in the pore spaces. This is the main reason why Marcellus Shale is considered an important gas resource (Byrd, 2007). Thus, Marcellus Shale is an important component of the US National Energy Program that seeks both greater energy independence and greener sources of energy (Harper, 2008).

Hydraulic fracturing technology, coupled with horizontal drilling, has enabled exploitation of large natural gas reserves in Marcellus Shale (Ziemkiewicz and Thomas He, 2015). Between 2005 and 2014 in Pennsylvania, about 4 000 Marcellus wells were drilled horizontally and hydraulically fractured for natural gas (Balashov et al., 2015).

2.1.2 Shale gas plays in Europe

According to European Parliamentary Research Service (EPRS, 2014), “Some European regions have significant shale gas resources, but more exploration is needed to find out whether they can be developed commercially”. However, Europe has a high population density and has more rules restricting the exploration of oil and gas than the US regulating how to explore for oil and gas (Kavalov and Pelletier, 2013).

Besides that, according to EPRS, (2014), “Most analysts agree that shale gas in Europe will be more expensive than in the US, due to different geology and the need to address public acceptance and environmental impact. Shale gas will not resolve short-term energy security issues as exploration and development will take 5 to 15 years. In any case, the volumes produced will not make Europe self-sufficient in gas, but could help to reduce gas prices”.

The World Energy Outlook (IEA, 2012) mentioned that natural gas demand in the European Union (EU) is not expected to rise above the 2010 levels before 2020. On the other hand, EPRS (2014) projected the increase of worldwide energy demand by 27% up to 2030, which also has an impact on Europe's energy security.

According to EPRS (2014) the EU imports 53% of its energy needs. In 2013, the EU imported 305 bcm of natural gas – 66% of its consumption. In 2014, in the global perspective of shale gas, Europe represents of 10% of existing shale gas resources worldwide (Figure 2.4). Poland and France have the largest estimated shale gas resources in the EU, representing about 60% of existing resources in Europe with 29% and 28%, respectively.

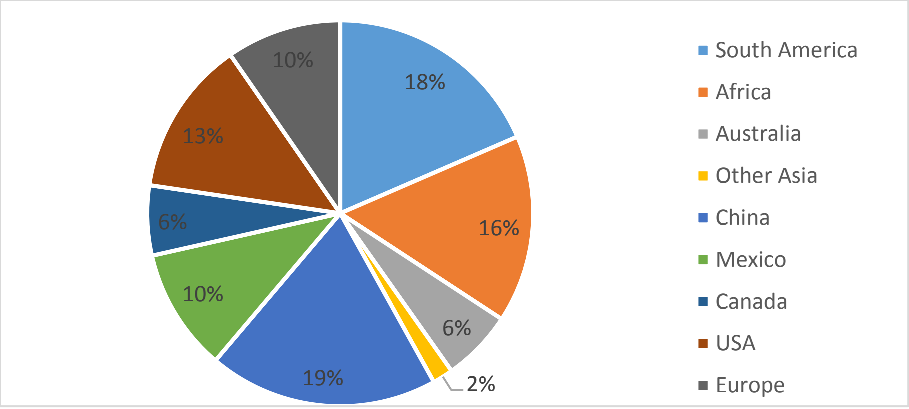


Figure 2.4. Shale gas in regions and countries (EIA, 2015)

Six EU Member States are dependent on Russia for their entire imports of natural gas and 71% of Russian gas exports go to the European market. For this reason, countries in Eastern Europe like Poland, Ukraine and Lithuania are more open to shale gas, both to generate jobs and to ease their dependence on Russian gas (EPRS, 2014).

Turkey started hydraulic fracturing operations in 2013 to extract shale gas in the Thracian and south-eastern regions. This may help reduce the country's dependence on energy imports, but Turkey is not expected to become a gas exporter (EPRS, 2014).

In the U.K., the underground mineral rights do not belong to the landowner, as they often do in the US, but to the British Government. In December of 2014, the current government was in favor of shale gas development, and had adopted regulations for that. However, as Edward Dave stated, “We are still in the very early stages of shale gas exploration in the U.K., and it is likely to develop slowly” (Department of Energy & Climate Change of the Government of the United Kingdom, 2012).

France, Bulgaria, and parts of Spain have already banned fracking, concerned about the environmental risks. For example, in France, on April of 2015, the French Minister for the Environment, Ségolène Royal, stated in a press release that "reopening the shale gas debate may jeopardize the economic recovery created by the law on energy transition," and that energy companies should instead concentrate on investing in renewable energy. Additionally, she concluded the debate by saying that shale gas extraction was no longer a "viable" topic (Urbain, 2015).

2.1.2.1 Shale gas plays in Portugal

Natural gas was introduced in Portugal in 1997 in order to provide a competitive, convenient and ecological energy source (Arentsen and Künneke, 2003). Further allowing the diversification of Portugal's energy resources, natural gas also reduces oil dependence and increases the competitiveness of the Portuguese oil and gas industry (Kondratowicz and Brzdek, 2013).

Portugal is part of the list of countries with shale gas formation. However, there are no detailed studies on the potential of shale gas in Portugal. Besides that, according to Portuguese legislation, to produce any exploration or drilling with unconventional methods such as hydraulic fracturing in Portugal, an environmental study will be required.

According to studies performed on national territory, the Lusitanian basin in the municipalities of *Alenquer, Bombarral* and *Cadaval,* is pointed as the most potential area rich in shale in Portugal. The *Algarve* and *Alentejo* basins also have potential. However, the amount of shale is not so significant and they are in environmentally protected areas (LNEG, 2014).

At the end of 2006, only one company operated in Portugal, Mohave Oil & Gas, which owns two concessions in the onshore of the Lusitanian Basin. During its period of concession of Lusitanian Basin, Mohave has confirmed the presence of gas in the *Brenha* formation and also affirmed similarities of *Brenha* formation with the Barnett Shale Formation, in the USA.

In 2015 it was signed the concession agreement for oil exploration in the areas of *Aljezur* and *Tavira* in *Algarve*. According to the National Authority for the Fuel Market (ENMC, 2015), the contracts for the concession, research, development and production of oil for these areas predict just research on land using traditional methods, for a period of eight years.

In September 2015 the company Australis Oil & Gas Ltd. signed through direct negotiation the only concession of the Lusitanian basin. There is no information on the type of work that is currently being done by this company once the concession contract covers all stages of exploration, research, development and production of oil.

Figure 2.5 presents the map of concession in Portugal, with the Lusitanian Basin marked with a red cycle. According the information collected from the ENMC, Lusitanian Basin is the most researched basin for hydraulic fracturing in Portugal, with a drilling density of 2,4 per 1 000 km^2 (ENMC, 2015a).

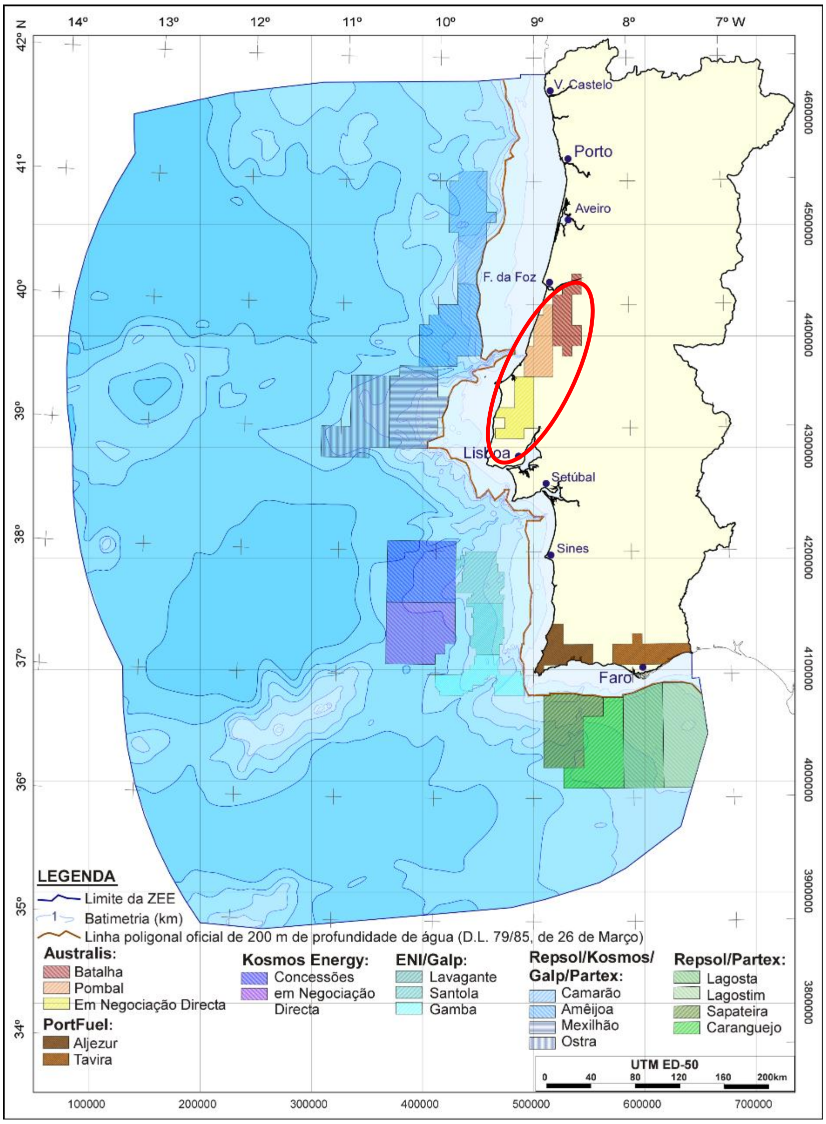


Figure 2.5. – Map of concessions in Portugal (ENMC, 2015b)

2.2 Hydraulic fracture

2.2.1 The technique

Hydraulic fracturing, or “fracking”, is a method which has been used in the oil and gas industry for decades (Engle and Rowan, 2014). The process involves drilling and injecting fluid into the ground at a high pressure in order to fracture shale rocks and to release the natural gas that is trapped inside (Arthur et al., 2008).

In order to achieve the shale gas, a vertical well is first drilled and then, using directional drilling equipment, the well is drilled horizontally (Rahm, 2011). During hydro fracturing, millions liters of water with sand and a large amount of chemicals are pumped into a well under pressure in order to open or create fractures in the shale (Balashov et al., 2015).

Once the rock is fractured, the gas can flow through the horizontal part of the well, up the vertical part, for collection (Rahm, 2011). Figure 2.6 presents the process of hydraulic drilling that includes the following steps:

- Site selection

Site selection is made by the Reflection Seismic Method which uses an advanced technology of sound waves that gives a view of the subsurface to pinpoint the best drilling location. This methodology works by sending sound waves to the underground using small explosive charges or vibration created by special trucks. The sonic vibrations returning back from the formation are dependents on the topography and when they are detected, they are measured by geophones at the surface and sent to a truck collecting data (Ghazanfari, 2014). This information is converted to 3D images from the surface and this data helps to have a better perception to determine the drilling location.

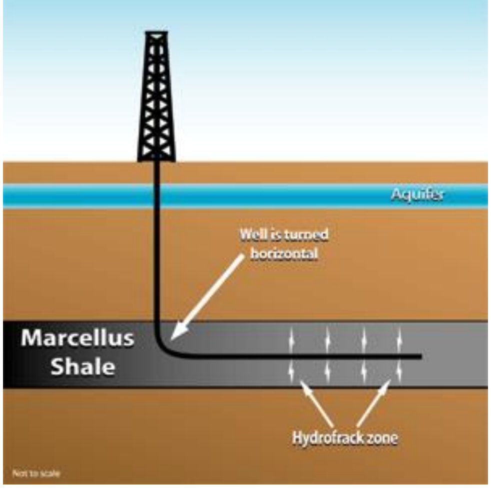


Figure 2.6. Hydraulic fracture process (Barr, n.d.)

- Vertical drilling process

Vertical drilling ranges from 1 500 m to 2 800 m below the ground depending upon the depth and thickness of the gas reservoir. Vertical drilling occurs through sediment layers and the water table, in order to reach the shale rock formations, where the oil and gas are located (Ghazanfari, 2014).

- Horizontal drilling process

When the shale is reached, the well changes its direction, and the drilling is then angled horizontally for another 900 m to 3 000 m or more, where a cement casing is installed and will serve as a conduit for the massive volume of water, chemicals and sand. This pressurized mixture causes the crack of rock layer (Bazant et al., 2014).

- Gas extraction

The fracking process occurs after drilling a well and inserting a steel pipe in the well bore. The casing is perforated within the target zones that contain oil or gas, so that when the fracturing fluid is injected into the well it flows through the perforations into the target zones (Bazant et al., 2014). These fissures are held open by materials called proppants (usually sand or ceramic beads) so that natural gas from the shale can flow up the well (Yu et al., 2015).

- Flowback and produced water

After hydraulic fracture is completed and the wellbore pressure released, 10–30% of the injected fluid returns to the surface via the well casing (Ziemkiewicz and He, 2015). These fluids include flowback and produced water. Produced water returns to the surface during hydraulic fracturing. On the other hand, flowback returns to the surface after the completion of hydraulic fracturing (Ziemkiewicz and Thomas He, 2015). It is necessary to have options to collect this water that flows back out the well and these wastes are typically stored in open pits or tanks at the well site prior to disposal (Kuwayama et al., 2015). Thus, the water is generally reused in future fracking, or desalinated and disposed of through sewage and wastewater systems (Shaffer et al., 2013). Figure 2.7 represents the common cycle of flowback in hydraulic fracture process:

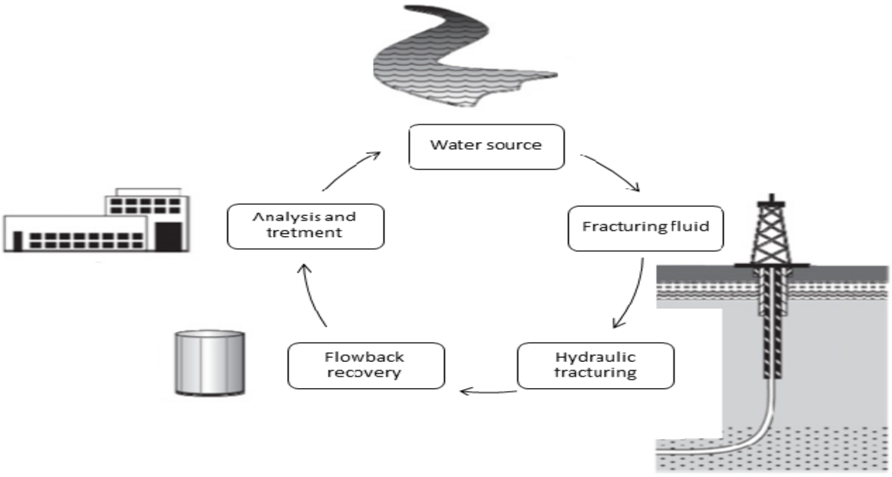


Figure 2.7. Injected fluid cycle in hydraulic fracture (Adapted from Frumkin, 2015)

2.2.2 Injected fluid

The hydraulic fracturing technique consists in injecting a mixture of water, sand and chemicals. (figure 2.8). Although the large amount of chemicals, its volume is less than 1% of the injected fluid (Rogers et al., 2015). The multiplicity of these chemicals is further taken into account with some public confidence, but it is estimated that more than 600 different types of chemicals are used in each hydraulic fracturing operation, representing about 80-300 ton of chemicals.

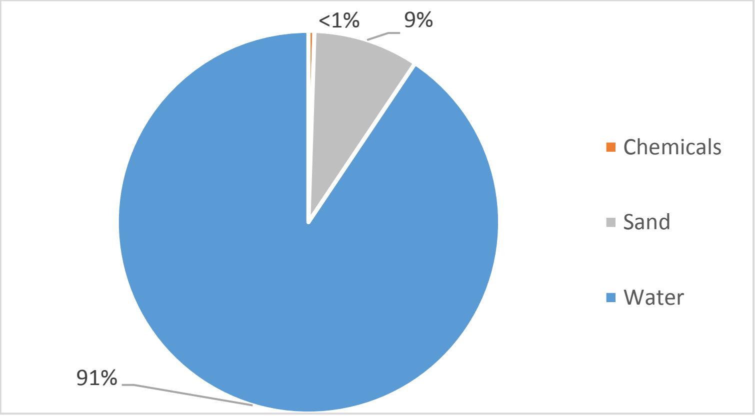


Figure 2.8. The components of hydraulic fracture fluid (Gregory et al., 2011)

Only a small percentage of the referred chemicals are used per well. However, this "one-well" is a miss representation, as fracking operations in a gas play typically consist of thousands of wells and therefore, the cumulative impacts is much higher.

Scientists have been studying the composition of the fluid, revealing that several of the chemicals used pose a significant threat to human health and well-being, such as volatile organic compounds e.g. methanol or benzene, toluene, ethylbenzene, and xylene (BTEX) components, among others.

According to Frac Focus, (n.d.) (which records the chemicals used in hydraulic fracturing in the US), there are 71 of those chemicals (Table A.1, Annex 1) that are most used in this technique. Through the data provided in Gregory et al. (2011), table 2.1 presents the main constituents of hydraulic fluid and their function and figure 2.9 presents the percentages of the most important chemicals in the mix and understand their associated functions.

Table 2.1. Main constituents of hydraulic fluid and their respective purposes (Gregory et al., 2011)

Constituent	Composition by volume (%)	Example	Purpose
Water and sand	99,5	Sand suspension	“Proppant” sand grains hold microfractures open
Acid	0,123	Hydrochloric or muriatic acid	Dissolves minerals and initiates cracks in the rock
Friction reducer	0,088	Polyacrylamide or mineral oil	Minimizes friction between the fluid and the pipe
Surfactant	0,085	Isopropanol	Increases the viscosity of the fracture fluid
Salt	0,06	Potassium chloride	Creates a brine carrier fluid
Scale inhibitor	0,043	Ethylene glycol	Prevents scale deposits in pipes
pH-adjusting agent	0,011	Sodium or potassium carbonate	Maintains effectiveness of chemical additives
Iron control	0,004	Citric acid	Prevents precipitation of metal oxides
Corrosion inhibitor	0,002	n,n-Dimethyl formamide	Prevents pipe corrosion
Biocide	0,001	Glutaraldehyde	Minimizes growth of corrosive and toxic bacteria

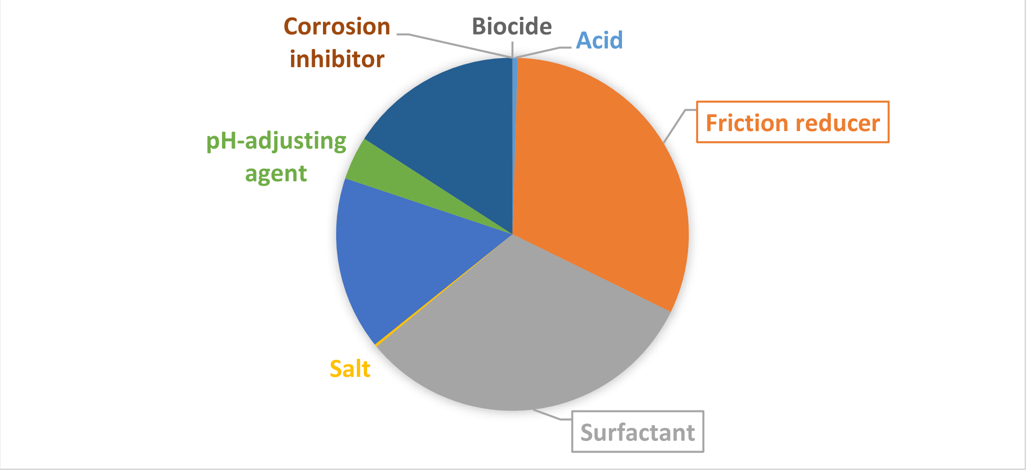


Figure 2.9. Percentage of the different types of chemicals in hydraulic fluid (Gregory et al., 2011)

Water

The exact quantity of water used in fracking depends on the well where it is applied but, usually, it requires 10-20 million liters per facture per well. Of this quantity of water, 68% normally comes from surface water, 32% from public supply that is usually purchased (Peraki and Ghazanfari, 2014).

Sand

Sand is usually can be used in fracking as a “proppant” (figure 2.10) in order to facilitate the natural gas or crude oil to be extracted (Ziemkiewicz and Thomas He., 2015). Once the shale rock formations are injected with water and chemicals, the function of the sand it is to keep the newly formed cracks open after they are made in the rock.

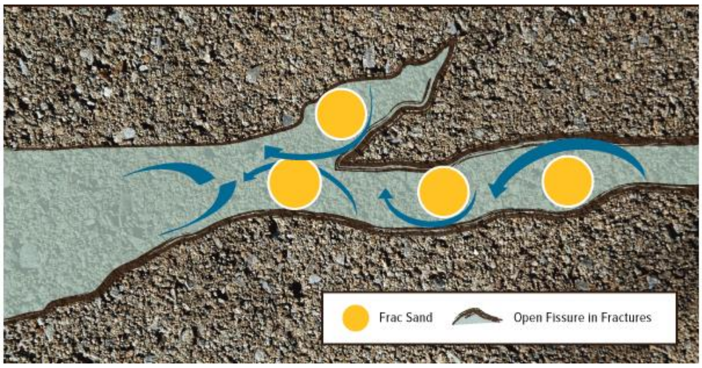


Figure 2.10. Sand acts as a proppant in Hydraulic fracture (U.S. Global Investors, 2014)

<u>Chemicals</u>

The chemicals inserted during the fracture process have many functions, e.g. to insure that the fracturing is effective and efficient, to limit the growth of bacteria or to prevent the corrosion of the well casing.

2.3 Shale Gas Development

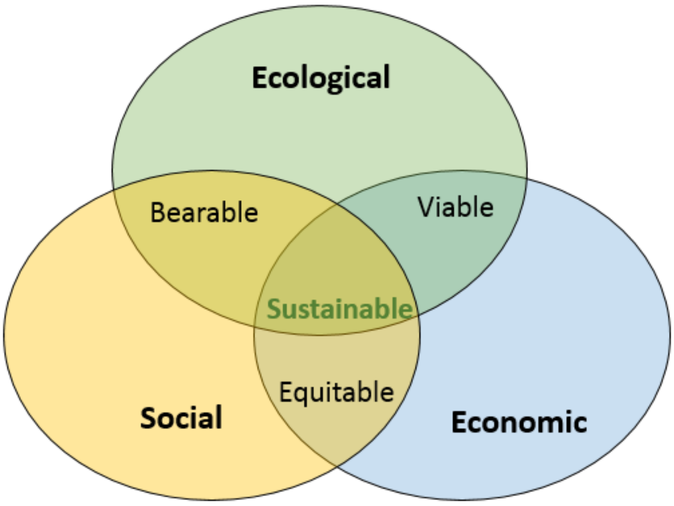


Figure 2.11. Three pillars of sustainability

Sustainability analysis evaluates each one of the three factors (figure 2.11) and makes connections between them. In hydraulic fracturing characterization there are many discrepancies of benefits and costs between these three elements. If it were only focus on the economic factor, it would easily have concluded that the exploitation of shale gas is an ideal option. On the other hand, if it ignores the other aspects and focus only on the ecology, the scenario changes completely and the conclusions will be the opposite. Regarding that, it is really important to balance these three elements.

Unconventional oil and natural gas extraction enabled by horizontal drilling and hydraulic fracturing is described from “revolutionary” to “disastrous.” (Jackson et al., 2014). In order to present a clear and succinct explanation of this two distinct opinions around fracking, this study will be adjusted to the model presented in table 2.2, which summarizes some potential benefits and costs of a shale gas exploitation.

Table 2.2. Model of cost-benefit analysis for shale gas development (Adapted from Muresan and Ivan, 2015)

Potential Benefits		**Possible Costs**	
Revenue for local budgets from fees, taxes and contributions	Economic	Decline in other sectors (tourism, agriculture, cultural)	Economic
Revenue for national budgets from fees, taxes and contributions	Economic	Air pollution	Environmental
Proceeds from severance taxes	Economic	Biodiversity effect	Environmental
Reducing the price of electricity in the operational phase	Economic	Increased seismic activity	Environmental
Greenhouse gas emissions reduction	Environmental	Increased traffic	Environmental
Employment creation	Social	Land take	Environmental
		Water quality	Environmental
		Water usage	Environmental
		Decrease in the price of real estate	Social
		Degradation of health of the local population	Social

2.3.1 Potential benefits

In 2013, EIA projected that natural gas production in the U.S would grow 44% among 2011 and 2044, generally due to a 113% increase in the total amount of natural gas produced from shale (EIA, 2013). Beyond its use as an energy supply, natural gas derived from hydraulic fracturing also has the potential to reduce greenhouse gas emissions since it releases less CO_2 than coal when converted into electricity. (Maniloff and Mastromonaco, 2014).

Although the average cost of shale gas production vary from site to site, it tends to be about 50–66 percent cheaper than production from new conventional gas wells, and technological improvements could also drive costs down further (Sovacool, 2014).

2.3.1.1 Natural gas prices

After the shale gas revolution, the prices of natural gas dropped drastically in US (Aruga, 2016). The shale gas boom had contributed not only to the birth of a new era of cheap natural gas, but also to the decoupling of US natural gas price from the crude oil price, which has a significant influence on the global gas pricing system (Wang et al., 2014).

Shale gas decreased the prices of natural gas in the US significantly compared to other major markets. In fact, without the shale gas development, the natural gas prices could be more than 2,5 times higher than they otherwise would be by 2050. These lower energy prices from increased supply would likely increase energy consumption overall and encourage switching to natural gas from other energy sources, including coal, nuclear, and renewables (Jackson et al., 2014). Thus, natural gas has become an increasingly important fuel for electricity generation. This expansion in the supply of inputs into the electricity market, lowers costs to the gas-fired electricity producers as well as electricity prices for consumers (Mason et al., 2014).

On the other hand, the Organization of the Petroleum Exporting Countries (OPEC), informally led by Saudi Arabia, has been struggling with the growing production of shale gas. In order to deal with its competitors at the time that demand was slowing decreasing, OPEC decided to reduce oil prices and increase the quantity produced. Thus, the objective with these measures is to bring the price of gas down, to a point where it would not be feasible to shale gas producers to compete, as they will be making losses and would not be able to pay for its hydraulic fracture infrastructures (Rava, 2015). The results of these measures can be quantified by observing the latest Commodity Markets Outlook report from World Bank (World Bank, 2016).

Therefore, IEA report estimates that oil prices should not return to the minimum set in January 2015 and affirms that the collapse in prices in recent years is already having results in a production fall by countries outside the countries of OPEC as US (EIA, 2016).

2.3.1.2 Economic development

The economic development is known as the main benefits of hydraulic fracture as it comprises the employment, jobs, infrastructure, revenues, and taxes (Sovacool, 2014). These factors also affect economic development indirectly, providing higher incomes and landowner royalties.

Pennsylvania, where the majority of Marcellus play are situated, saw its shale gas boom create 29 000 new jobs in 2008 with revenues of $2,3 billion and tax revenues for governments of $238 million (Kargbo et al., 2010). In 2009, production on the Marcellus Shale across West Virginia and Pennsylvania brought $4,8 billion in gross regional product, generated 57 000 new jobs, and created $1,7 billion in local, state, and federal tax collections (Scott, 2013).

Nowadays, the oil and gas industry is passing by a new crisis: OPEC’s global oil price war (Rodrigues and Weijermars, 2016). Consequently, decline of oil prices was led to the abandonment of about half of the extraction wells in shale rocks in 2014. However, a gradual recovery in oil prices is expected as the energy industry is not a short-term business, it's a long-term cycle and consequently, requires a long-term investment. In fact, while some producers have closed in some wells, others are being added. According to (Forbes, 2014), further declines in oil prices could continuing happening and reducing this growth of shale gas industry but the most productive basins for shale oil and gas will remain profitable.

On the other hand, in 2016 US shale gas has been imported into Europe for the first time which represents more economic development for US, including new jobs and market opportunities.

2.3.1.3 Carbon reduction

As mentioned above, natural gas burned for electricity generates half the CO_2 that coal does during combustion. However, natural gas derivate of shale are still fossil fuel, which release greenhouse gases when burned and the most worrying factor is the large quantities of released methane emissions (Howarth et al., 2011).

According to the reports from the EIA and the EI, carbon emissions from fossil-fuel combustion in the US has decreased gradually in recent years (EIA, 2014) and this fact is usually associated to the actual energy production changing process associate to shale gas industry.

Given all recent methane emission estimates for unconventional gas production are based on sparse and poorly documented data, the knowledge on current and future emission levels from shale gas and hydraulic fracturing remains highly uncertain (Olivier et al., 2013).

2.3.2 Possible costs

2.3.2.1 Environmental factors

Despite the advantages of the shale gas exploitation, it is also important to state that its development has been followed by several scientific concerns related to the negative impact that it creates, affecting the water, air and the quality of life in the region where its production occur (He and You, 2016).

Due to the complexity and importance of the topic, it is worth subdividing the main theme into two different section, in order to include all the externalities faced by the process of hydraulic fracture. Therefore, the first section will focus on the environmental factors and the second section will approach the social factors as health effects to the human beings that live close to an exploitation.

The negative effects on the environment can be explained in figure 2.12 where it is possible to realize that water is the main focus of this problematic. The land take and seismicity are effects that are not present in the figure as they cannot explain visual represented, however they are equally important as the rest of the problems.

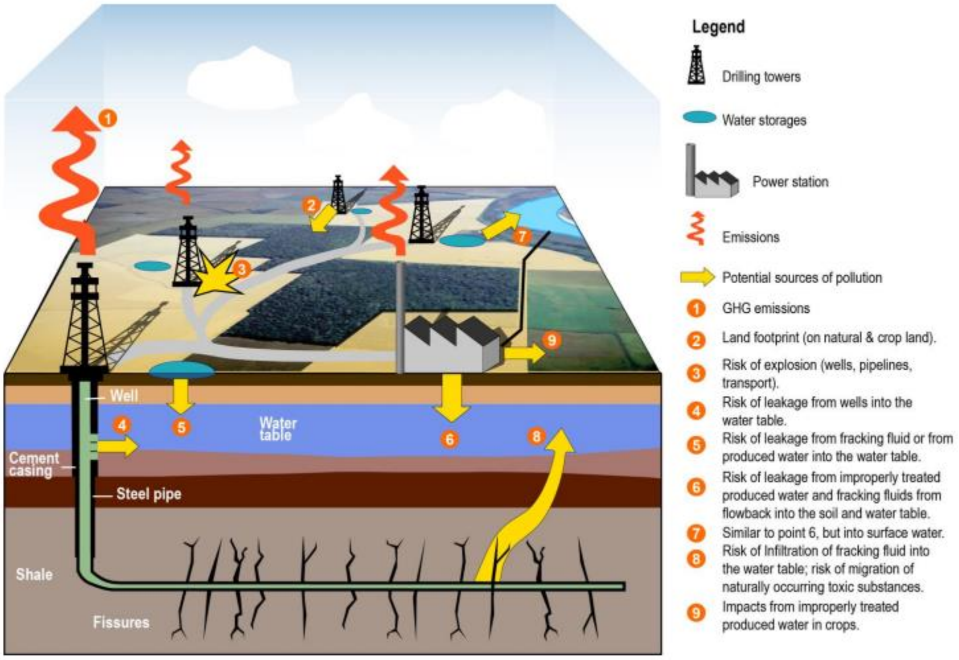


Figure 2.12. Schematic representation of infrastructures and potential impacts (UNEP, 2012)

I. Land take

The land take from hydraulic fracture vary depending on numerous factors: the locations of the well (well pad), the well pad density and size, and the number for well pads. Other indirect factors are associated as access, pipes and other supply lines. It is important to take in to account that the places where the wells are located require more than a single well, it is necessary to have ponds, tanks, fracturing equipment, emission reduction equipment, dehydrators, separators, and brine tanks.

The full exploitation of shale gas usually requires four phases of stimulation which are estimated to last 40 years (Broomfield, 2012). In fact, the land use requirement is highest during the hydraulic fracturing stage, and lower during the production stage. Due to the prevalence of horizontal drilling, wells may be situated in isolation or, more commonly, drilled in clusters on multi-well pads.

This innovate technique of multi-well pads (Figure 2.13) not only reduces land use compared to the application of a single well, as reduces the drilling costs and decrease the time of nonproductive time (NPT), which reduces the waste of time in transfer from one location to another equipment. Another advantage of multiple well is the reduction of the surface footprint of the operations and work to restore the land after construction (Durst et al., 2012).

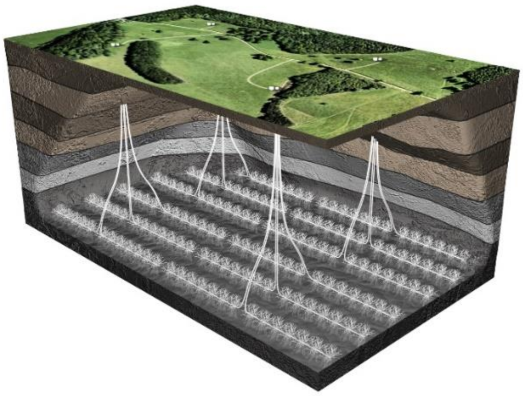


Figure 2.13. Multi well pad representation (Statoil, 2010)

II. Water usage

According to Sovacool (2014), the majority of sites in the United States need between 10–20 million liters of water per well. Nicot and Scanlon (2012), studies the water usage in different basins, affirming that Barnett Shale requires around 11 000 m^3 of water per well, Haynesville Shale, TX requires around 21 500 m^3 and Eagle Ford, TX around 16 100 m^3. Table 2.3 presents different perspectives of water used per well in Marcellus Shale, PA.

Table 2.3. Water used per well in Marcellus Shale

Basin	Water use per well (m^3)	Source
Marcellus Shale, PA (<2010)	7 700−38 000	Kargbo et al. (2010)
Marcellus Shale, PA (2008−2011)	11 500−19 000	Lutz et al. (2013)

This high demand of water that is required to hydraulic fracture has two important implications:

1. The difficulty to produce shale gas in areas where water is limited. The majority of the world's water sources are already under stress and Gleeson et al., (2012) predicted that global groundwater needs are 3,5 times higher than the actual area of aquifers, and they warned that 1,7 billion people live in areas “where groundwater resources and/or groundwater-dependent ecosystems are under threat”.
2. The potential risk that shale gas production might cause in the quality of the water. Shale gas production generates waste from drilling muds, flowback and produce brines, all requiring proper treatment and disposal (Peraki and Ghazanfari, 2014).

In Europe the mother-rocks are deeper than US, requiring more water for each well, and increasing the amount of water used. Given the information provided in Frac focus, (n.d.) most water used in hydraulic fracturing comes from surface water sources such as lakes, rivers and municipal supplies. However, groundwater can be used to augment surface water supplies where it is available in sufficient quantities.

Another factor that is important to be consider is that wells may have to be fractured several times for the stimulation of the well by injecting over pressurized water for the creation of the cracks and that means that is necessary even more water in hydraulic fracturing (Lechtenböhmer et al., 2011). Each additional fracture operation may require more water than the previous one and in some cases, the wells are re-fractured up to 10 times.

These large volumes of water are usually acquired from nearby water surface or pumped from a municipal source. In Portugal, the water abundance is very dependent on the time of the year and location. According to IPMA, (2015), in august over 70% of continental territory was passed for a severe drought, the second most serious in 70 years.

III. Groundwater contamination

Groundwater contamination from shale gas operations can occur through a variety of mechanisms (Cooley and Donnelly, 2012). However, there is limited data on the effect of fracking in the quality of water as shale gas production is currently exempted from the U.S. Safe Water Drinking Act (SDWA). Thus, it becomes difficult to systematically monitor possible groundwater contamination (Sovacool, 2014).

Hydraulic fracturing can result in the unintentional contamination of groundwater with methane, chemicals and other toxic substances released from the fracturing of shale layers, including heavy metals. The most harmful contaminants in the shale formations that are dissolved into the fracturing fluid are CH_4, CO_2, H_2S, N_2, He, trace elements such as Hg, As, Pb, Ra, Th, U, and VOCs such as benzene.

A survey made by State University of New York College in five different states, estimates that 2% of wells that are used for hydraulic fracture may end up contaminating groundwater with fracking fluids (Bishop, 2011).

The effects of a potential groundwater contamination are classified as disastrous as might potentially affects the supply of drinking water for a big number of populations. Therefore, vibrations and pressure pulses associated with drilling can cause short-term impacts to groundwater quality, including changes in color, turbidity, and odor (The Energy Institute, 2012).

The most expected sources of groundwater contamination are the leakage through inadequate cementation coating or from the surface contamination from spills (Smith, 2015). Maintaining well integrity, reducing surface spills and diminishing improper wastewater disposal should be the main concerns in order to minimize contamination from fracturing fluid (Jackson et al., 2014).

Old and abandoned wells can also serve as migration pathways for contaminants to enter groundwater systems (Cooley and Donnelly, 2014). Coalbed methane is generally found at shallower depths and in closer proximity to underground sources of drinking water and therefore this rote can also serve as a conduit for groundwater contamination (Cooley and Donnelly, 2012).

According to Michie and Koch (1991), the risk and importance of aquifer contamination from leaks inside the well to the drinking water resource decreases by a factor of approximately one thousand when surface casing extends below the bottom of the drinking water resource.

IV. Flowback

Around 80% of the injected volume of water remains bound to the dry shale matrix and only 10-20% is recovered as a wastewater stream, known as flowback water (Kondash and Vengosh, 2015).

Flowback water is the mixture that returns to the surface having the chemical of initial fluid and also the constituents originating from the shale formations. The predominant constituents of flowback water are the dissolved salts as calcium, magnesium, chloride, or barium, among others (Peraki and Ghazanfari, 2014). In addition to hazardous substances contained in fracturing fluids, flow-back may contains heavy metals and radioactive materials from the deposit.

Naturally occurring radioactive materials (NORM) are part of any geological formation, though with a very small share in the ppm to ppb range. The organic matter in black shales is the material that generates the gas but in seawater and sediment geochemistry, the organic material also has an affinity for attracting radionuclides, mainly uranium (Engelder et al., 2014). Through the hydraulic fracturing process, these radioactive materials such as uranium, thorium and radium bound in the rock are transported to the surface with the flow-back fluid. NORM can also move through the cracks in the rock into the ground and surface water. Usually, NORM accumulates in pipes, tanks and pits (Peraki and Ghazanfari, 2014).

Generally, flowback can be placed in containment pits, treated at wastewater plants, stored in underground injection wells or recycled. Various technologies have been developed and tested over the past years for the treatment of flowback water. For example, thermal treatment, membrane treatment, and various hybrid and advanced treatments technologies have been emerging (Miller et al., 2013).

In order to support the study of environmental impacts of shale gas exploration it is important to analyses the composition of flowback water, as it represents the main source of direct environmental impacts (Rahm et al., 2013).

- Total Organic Carbon (TOC)

TOC is a good indicator of the water quality and their control can help to determine the efficiency of the treatment that will be applied to flowback water. Thus, TOC provides an estimate of the amount of natural organic matter (NOM) in the water source (Leenheer and Croué, 2003).

In the following section of surface water contamination (2.3.2.4) is presented a comparison between the typical TOC concentrations in different types of water contamination.

- Total Nitrogen (TN)

TN represents all forms of nitrogen (organic and inorganic) and symbolizes an essential nutrient for plants and animals. However, an excess amount of nitrogen in a waterway may lead to low levels of dissolved oxygen and might have a negative impact in different plants and organism's life. The importance of nitrogen in the aquatic environment varies according to the relative amounts of the forms of nitrogen present such as ammonia, nitrite, nitrate, or organic nitrogen (Rabalais, 2002). In fact, total nitrogen is the sum of total kjeldahl nitrogen (ammonia, organic and reduced nitrogen) and nitrate-nitrite.

The natural level of ammonia or nitrate in surface water is typically low (less than 1 mg/l) and total nitrogen is reported as mg/l and an acceptable range of total nitrogen is 2 mg/l to 6 mg/l. Excess nitrates can cause hypoxia (low levels of dissolved oxygen) and can become toxic to warm-blooded animals at higher concentrations (10 mg/l) or higher) (Spellman, 2006).

- pH

In order to ensure the efficiency of surfactant additives that facilitate the infiltration of injected fluid into bedrock, the pH of fracking fluid is maintained within a narrow range. Thus, organic acids, such as acetate and formate, are added to fracking fluid to adjust the pH. These organic acids can act as a carbon source, increasing the growth of anaerobic bacteria which results in the production of corrosive and toxic hydrogen sulfide (Fisher et al., 2013). Additionally, as the fracking solution is not totally recovered, bacteria's can grow within the interstitial cracks following a fracking event and block gas flow over the long term, inhibiting well productivity.

Most natural waters have pH values from pH 5.0 to pH 8.5. Unexpected changes in pH values serve as warning signals that water quality may be adversely affected through the introduction of contaminates. Generally, small changes in pH are usually associated with relatively large changes in water qualities.

- Metals

In most flowback waters, the concentrations of toxic elements such as barium, strontium, and radioactive radium are positively correlated with the salinity. The correlation of toxic and radioactive elements with salinity suggests that many of the potential water quality issues associated with wastewaters from unconventional shale gas development may be attributable to the geochemistry of the brines within the shale formations (Vengosh et al., 2014).

The table 2.4 lists the metals that are expected to be found in the flowback water.

Table 2.4. Potential metals in flowback water (Jack et al., 2014)

Aluminum
Antimony
Arsenic
Barium
Beryllium
Boron
Calcium
Cadmium
Cobalt
Chromium
Trivalent Chromium
Copper
Iron
Lead
Lithium
Magnesium
Manganese
Molybdenum
Nickel
Potassium
Sodium
Selenium
Strontium
Titanium
Thallium
Zinc

- Dissolved Organic Matter (DOM)

Water travels through the environmental carrying dissolved organic matter (DOM), made-up of various chemicals compounds. The amount of DOM in water and its chemicals composition vary in space and time.

Fluorescence spectroscopy can provide information about the amount and type of DOM in a water sample. The chemicals composition of DOM is determined by its original source material and the process occurring in the environment through which it travels. Futhermore, DOM characterization using fluorescence spectroscopy can help find the source of DOM (Hudson et al., 2016).

- Total Dissolved Salts (TDS)

The predominant constituents of flowback water are the dissolved salts. According to Hayes and Severin (2012), the concentration of TDS in the flowback water of the Marcellus formation varies between 30 000 mg/l and 200 000 mg/l. The most common compounds of TDS are Ca, Mg, Cl, Na, SO_4, Ba and Fe.

V. Surface water contamination

Surface water contamination is mainly associated with the operational phase of exploration, as a well pads requires the transport of materials to the site, the use of those substances, storage of wastes and the subsequent transport of wastes generated. Thus, there is an increased risk of the following situations that can promote contamination of surface waters (Ferreras, 2014):

1. Spillage of
    - Concentrated fracturing fluids during transfer and final mixing operation (with water) that occurs onsite;
    - Flowback fluid during transfer to storage (pipework or frac tree failure during the operation, insufficient storage capability and overflow), during transfer from storage to tankers for transport or during transport to wastewater treatment works;
    - Water ingress or leaching from cutting/mud pits (limited storage capacity, storm water or flood water ingress or poor construction).
2. Loss of containment of stored flowback fluid (tank rupture; overfilling of lagoons due to operator error or limited storage capacity).

After the fracturing event, the pressure is decreased and the direction of fluid flow is reversed, allowing fracturing fluid and naturally occurring substances to flow out of the well bore to the surface Some injected fluid returns to the surface and by implication, some injected fluid remains underground. Table 2.5 presents an example of water use and wastewater from a well of Marcellus formation.

Table 2.5. Water use and wastewater per well

Basin	Water use per well (m^3)	Wastewater per well (m^3)	Source
Marcellus Shale, PA (2014)	16 124	5 201	Kondash and Vengosh (2015)

The fast and intense growth of unconventional drilling could lead to a higher possibility of surface spills or leaks and consequently, increase the potential contamination of drinking water sources (Werner et al., 2015). In some cases, overflows from wastewater pits have caused surface water contamination. Spills or leaks of hydraulic fracturing and flowback fluids can pollute soil, surface water, and shallow groundwater with organics, salts, metals, and other constituents (Vengosh et al., 2014). Furthermore, water contamination can also occur though the disposal of untreated wastewater from shale gas operations.

Various methods are used to control polluting discharges to surface waters in order to assess the ecosystems quality of life. Measuring organic and inorganic carbon in surface waters is a method to evaluate the pollution of water and the following parameters are used:

- Total Organic Carbon (TOC)
- Dissolved of organic Carbon (DOC)
- Chemical Oxygen Demand (COD): Contains all substances that can be solubilized by chemical oxidation. It is at the same time the conventional parameter for the calculation of wastewater charges
- Biological Oxigen Demand (BOD): Contains only the compounds that can be microbiologically oxidized

Table 2.6 establishes the level of contamination of waters from its typical TOC concentration.On one hand, the lines of surface water (rivers and streams) can easily recuperate pollutant discharges due to the combined effect of dilution and bacterial decomposition. On the other hand, when this contamination is high (as flowback water), these natural methods are not efficient or sufficient.

Table 2.6. Surface water Typical TOC Concentrations (Shimadzu, n.d.)

Surface water Typical TOC Concentrations (mg/l)	Typical TOC Concentrations (mg/l)
Clean spring water	1 – 2
Weakly polluted rivers and streams	2 – 5
Nutrient-rich stagnant lakes	5 – 10
Polluted waters	50 – 100

Surface waters are often contaminated with particles and harmful substances. For these reason, surface waters can only be used as drinking water after being treatment. Tables 2.7 and 2.8 present the large discrepancies between the constituent elements of the injected fluid and flowback, as well as the standard constitution of seawater in order to available the impact that flowback discharge into sea water would have on marine ecosystems.

Table 2.7. Constituent of injected fluid, flowback and sea water (Rose, 2013)

Constituent	Injected fluid (mg/l)	Flowback (mg/l)	Sea water (mg/l)
Ph	7,0	6,2	~8
Cl	82	98 300	19 400
Br	<10	872	67
SO_4	59	<50	2 700
Ca	32	11 200	410
Mg	3,7	875	1 290
Na	80	36 400	10 800
K	0,7	281	390
Fe	<50	47	0,0034

Table 2.8. Elements of injected fluid, flowback and sea water (Rose, 2013)

Element	Injected fluid (mg/l)	Flowback (mg/l)	Sea water (mg/l)
N	14	140	15
P	0,36	0,55	0,09
Al	0,3	0,5	0,001
B	0,5	20	4.4
Li	0,04	95	0,17
Sr	0,82	2 330	8,1
Ba	0,6	1 990	0,021
Mn	0,07	5,6	0,0004
Zn	0,08	0,09	0,005
Ra		2 640 pCi/l*	

VI. Air quality

Air quality and its effects in climate change are two factors that also represent some concern about shale gas production. Emission factor is used in order to compare the emissions released to the atmosphere from natural gas and other fossil fuels. An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere. Table 2.9 presents the emission factors associated with the different types of fossil fuels.

Table 2.9. Emission factor of fossil fuels (Galp, 2016)

Fuel	Emission factor (t C / TJ)
Gasoline	18,9
Diesel	20,2
Anthracite	26,8
Fuel oil	21,1
Natural Gas	15,3

According to table 2.9, natural gas emits less pollutants than others fossil fuel. However, emissions from numerous well developments could significantly affect the air quality and the increase in conventional air pollution may pose a threat to air-quality in shale gas extraction regions (Alvarez and Paranhos, 2012).

Air contaminants are released through the various drilling procedures, including construction and operation of the well site, transport of the materials and equipment, and disposal of the waste (Sovacool, 2014). Figure 2.14 presents the shale gas life cycle.

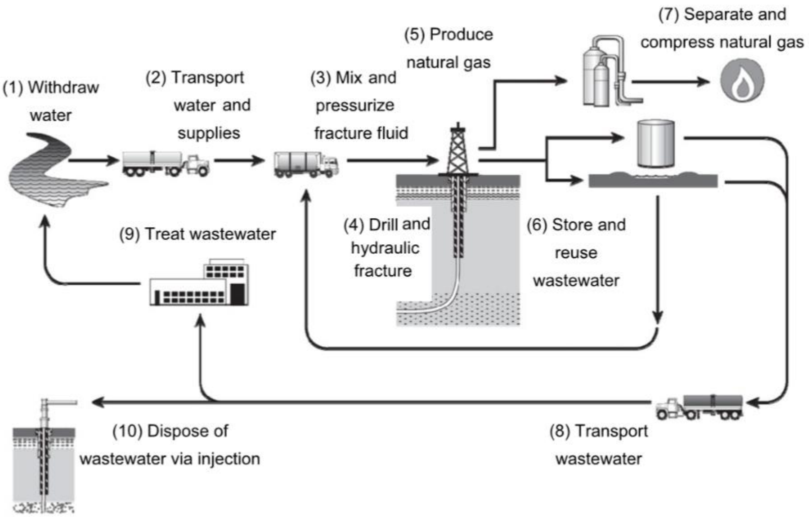


Figure 2.14. Shale gas life cycle (Frumkin, 2015)

Emissions of pollutants can occur across different stages of shale gas extraction represented in figure 2.14. The main activities of concern relative to emissions in hydraulic fracture process are:

- Diesel and road dust emissions from trucks transporting water and equipment to the site, and wastewater away
- Pollutants from gases and hydraulic fracturing fluids dissolved in waste water during well completion or recompletion
- Emissions from well drilling and hydraulic fracturing, including diesel combustion
- Emissions from the production of natural gas, including on-site diesel combustion and fugitive emissions
- Combustion emissions from natural gas powered compressor stations

The main component of natural gas is methane (Zhang and Soeder, 2015). Fugitive emissions of methane are associated with the formation of photochemical ozone as well as climate impacts. As a powerful greenhouse gas, methane has a global warming potential that is far greater than that of carbon dioxide (Howarth et al., 2011). According to the US EPA (2010), natural gas systems remain one of the most significant methane emitters in the United States. National Oceanic and Atmospheric Administration (NOAA) (2012) estimated that 4 percent of the methane produced by shale gas wells is escaping into the atmosphere (Pétron et al., 2012).

Pollutants from natural gas can also include volatile organic compounds (VOCs,) nitrogen oxides (NO_x) and particles (PM) (Kemball-Cook, 2010). However, estimates of the quantity of these emissions in Pennsylvania in 2011 suggest that they represent only a small fraction of the total state emissions (Litovitz et al. 2013).

Methane emissions occur in the stages of preparation, drilling and fracturing, transport of water and chemicals, well completion, production and transportation of the product. As methane escapes from flowback, the higher emissions from shale gas happen during the hydraulic fracture process (Holahan and Arnold, 2013). Additionally, methane dissolved in the flowback water could slowly be released if stored in open tanks, adding to fugitive emissions.

Table 2.10 presents the emissions of methane in different US basins after the hydraulic fracturing stage. The differences between these locations can be explained by the productivity and the amount of water required to achieve the shale layer in each basin.

Table 2.10. Methane emitted during flow-back in different states of US (Howarth et al., 2011)

States	Methane emitted during flowback (10^3 m^3)
Haynesville (Louisiana, shale)	6 800
Barnett (Texas, shale)	370
Piceance (Colorado, tight sand)	710
Uinta (Utah, tight sand)	255
Den-Jules (Colorado, tight sand)	140

Well or site abandonment may also have some impacts on air quality if the well is inadequately sealed, but they may be considered low because the majority of emission are associated with the drilling process (Broomfield, 2012).

VII. Seismicity

Induced seismicity associated with high-volume of hydraulic fracturing and energy extraction has received considerable attention in the US.

The impoundment of reservoirs, surface and underground mining, withdrawal of fluids and gas from the subsurface or the injection of fluids into underground formations are known for their capability of inducing earthquakes. The earthquakes caused by the injection of fluids have become an important point of study giving the new drilling technologies that enable the extraction of oil and gas (Ellsworth, 2013).

According to Jackson et al., (2014), the main evidence for induced seismicity is divided in two steps of unconventional energy extraction. The first one is hydraulic fracturing, which rarely induces earthquakes large enough to be felt by people, and the second one is the deep injection of wastewater, which has caused significantly higher-energy earthquakes.

Hydraulic fracturing consistently produces micro-earthquakes (with magnitudes below 2) as part of the process, but as the process is currently practiced appears to pose a low risk of inducing destructive earthquakes. However, in areas with a seismic history and/or specific geological conditions, the injected fracking fluid can facilitate sliding movements of pre-existing faults and trigger major events.

Several cases have been reported in which earthquakes large enough to be felt but too small to cause structural damage were associated directly with hydraulic fracturing. Additionally, some studies associate the seismic hazard of induced earthquakes with disposal of wastewater into deep layers or basement formations (Ellsworth, 2013).

A study by National Research Council (The National Academies Press, 2013) confirms that hydraulic fracturing may cause tremors, affirming that the number of earthquakes associated to fracking is too small. However, this study also concludes that increased risk of earthquakes due to hydraulic fracturing does not come from rock drilling or breaking it with injected fluid.

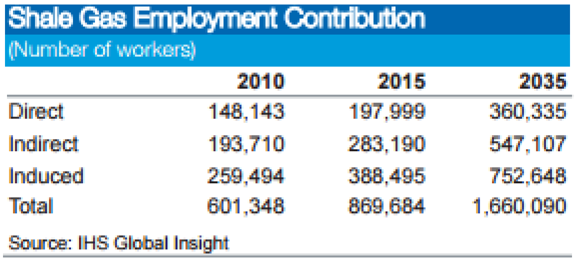
2.3.2.2 Social Factors

Many of the social problems and their impacts are not reflected in most cases directly and sometimes they are not studied, either for reasons of strategic order of what is considered as a priority measure or through technical and financial inability to develop those measurements. In this study will be considered two different topics: Job creation and Public health.

I. Job creation

The development of shale has increased the employment creation in the oil and gas industry. As was already stated in the benefits of fracking chapter, job creation is a valuable asset in terms of economic and social level of the country.

According to a report of IHS, (2011), in 2010 shale gas represented 27% of US natural gas production (Figure 2.15). Thus, it is estimated than during the next five years (2015) this share will grow to 43% and is expected to increase to 60% by 2035. The numbers point that natural gas has the potential to support more than 1,6 million jobs and contribute more than $230 billion to GDP in 2035 in US.



Shale Gas Employment Contribution
(Number of workers)

	2010	2015	2035
Direct	148,143	197,999	360,335
Indirect	193,710	283,190	547,107
Induced	259,494	388,495	752,648
Total	601,348	869,684	1,660,090

Source: IHS Global Insight

Figure 2.15. Shale Gas Employment contribution in US (IHS, 2011)

Shale gas employment contribution is calculated by the sum of its direct contribution, its indirect contribution from shale's supplier industries and an induced economic contribution resulting from additional spending throughout the US economy. In 2010, the shale gas industry supported over 600 000 jobs in US, which included 148 000 direct jobs, nearly 194 000 indirect jobs in supplying industries and more than 259 000 induced jobs. According to the estimates of this study, by 2035, the shale gas industry will support a total of over 1,6 million jobs, involved of more than 360 000 direct jobs, over 547 000 indirect jobs and over 752 000 induced jobs (IHS, 2011).

IHS Global Insight also demonstrates the different types the job that are generated by an exploration of gas shale. Figure 2.16 illustrates the jobs in 2010 distributed by different sectors associated to hydraulic fracturing process in US.

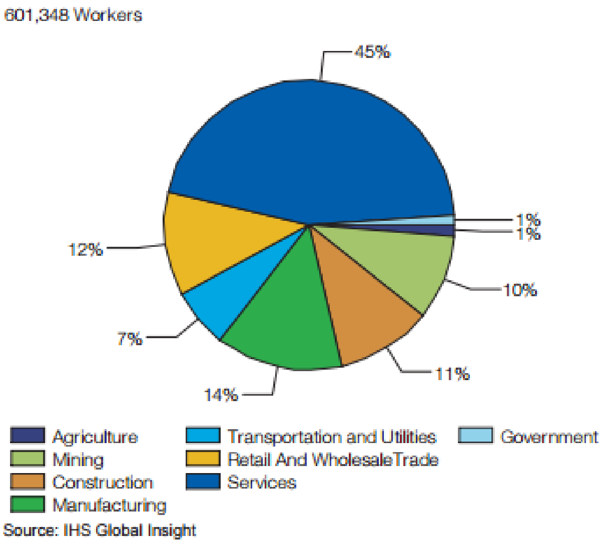


Figure 2.16. Shale gas employment contribution, 2010 (IHS, 2011)

On the other hand, more recent studies and news comes on to reveal that the employment rate in this sector has declined. For this reason, it is difficult to estimate the development of employment in US, only the jobs that has subsided.

II. Public health

Though the development of hydraulic fracture technologies, communities living near of the drilling operations have becoming a growing concern in terms of health issues. Consequently, the study of environmental toxicology has been rising and existing studies have provided conclusive evidence about how unconventional natural gas development affects nearby communities (McDermott-Levy et al., 2013).

The closer a population is from a well, also increases the danger potential of fracking chemicals in the health of those who are exposed. Health problems ranging from autism, asthma, cancer, heart disease, kidney failure, birth defects, allergies, and imbalances of the immune system. However, as some components are known carcinogens, many others are unknown, given that manufacturers consider their composition to be proprietary information or a trade secret (McDermott-Levy et al., 2013).

Table 2.11 presents the most common symptoms that occur in humans and animals. The close proximity of these operations to small communities has created a variety of potential hazards not only to humans, but also in companion animals, livestock and wildlife (Bamberger and Oswald, 2012). The animals have the same susceptibility to diseases that humans but because they are more exposed to the air, soil and water aquifers without treatment, and have more frequent reproductive cycles, exhibit the fastest diseases, allowing the prediction of disease in humans.

Table 2.11. Common health effects in human and other animal in consequence of fracking exposition

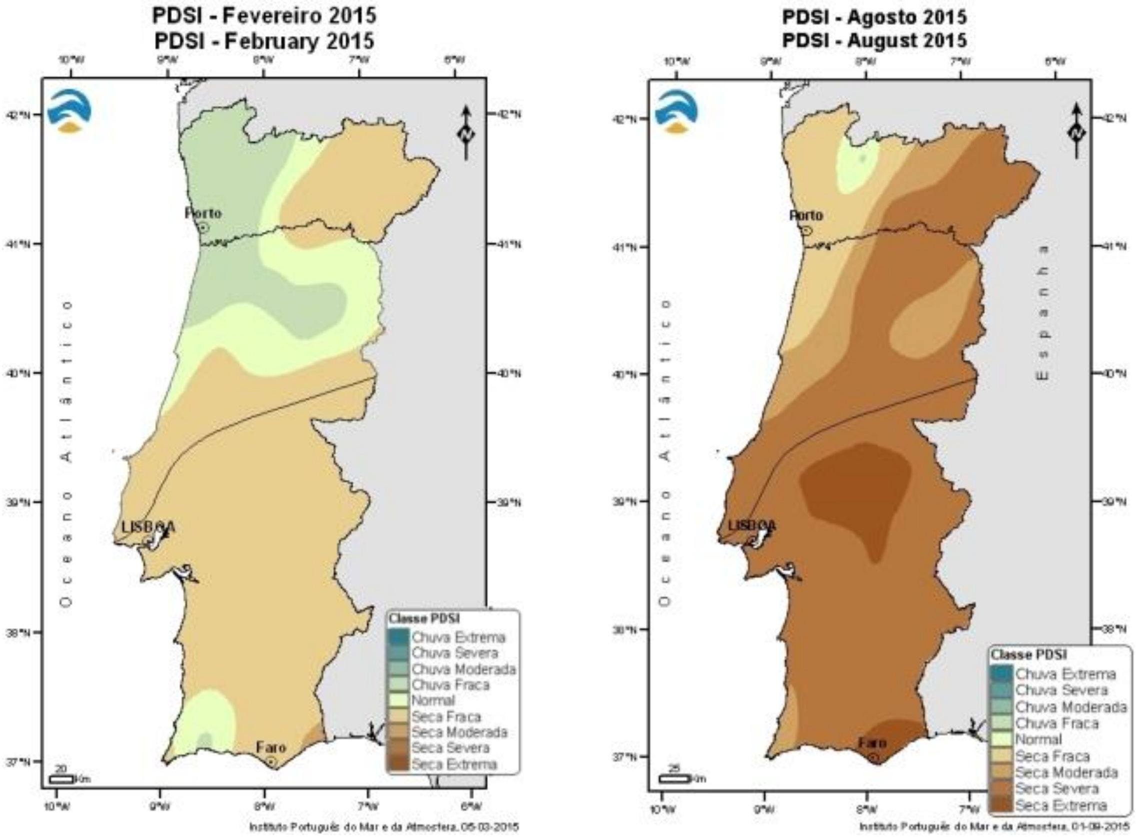
Health Category	Humans	Animals
Neurologic	Headaches	Lameness
	Incoordination	Incoordination
	Seizures	Seizures
	Inability to stand	Inability to stand
	Short-term memory loss	
	Skin numbness and tingling sensations	
	Difficulty concentrating	
	Dizziness	
	Fatigue	
Respiratory	Coughing	Coughing
	Wheezing	Wheezing
	Burning in the nose and throat	Heaving
	Difficulty breathing	Difficulty breathing
	Asthma	
Gastrointestinal	Vomiting	Refusal of food
	Diarrhea	Vomiting
	Cramping	Diarrhea
	Weight loss	Colic
	Weight gain	Dysphagia
Dermatologic	Hair loss	Hair loss
	Rashes	Feather loss
	Burning eyes	Hoof problems
	Dermatologic irritation	Rashes
Endocrine	Endocrine disruption	
Reproductive		Failure to breed
		Failure to cycle
		Abortions
		Stillbirths
Growth		Stunting
		Failure to thrive
Vascular	Nosebleeds	Nosebleeds
	Stroke	

In addition, hydraulic fracturing occurs over 2 to 5 days and may be repeated multiple times on the same well during the lifetime period of a well (25 to 40 years). Therefore, some health effects from chemicals could appear only in the long-term (Bamberger and Oswald, 2012).

2.4 Characterization of Lusitanian Basin

2.4.1 Water resources

Lusitanian basin is located on a region of Portugal where the weather is typically dry. Figure 2.17 represents the weather maps of Portugal on February and August of this year (IPMA, 2015) and it is possible to deduce that despite the drought intensity in summer, the region of Lusitanian basin in winter also do not have abundance of water.



PDSI - Fevereiro 2015
PDSI - February 2015

PDSI - Agosto 2015
PDSI - August 2015

Figure 2.17. Meteorological maps of Portugal in February and August of 2015 (IPMA, 2015)

Regarding this fact, it is important to state that in Lusitanian basin regions the limited availability of water may be a significant barrier to gas resource development.

In Portugal, the demand for water was estimated to be about 7 500 million m^3 per year (Ministério da Agricultura e do Mar, 2015). The agriculture sector is the largest user of water with a volume corresponding to about 87% of total consumption, followed by the urban water supply to the population (8%) and industrial use (5%) (APA, 2009). In 2006 the volume of water supplied to households led to a pickup of 137 liter/inhabitant.day for Portugal Continental (APA, 2009).

The use of waste water in Portugal is very high, both in the domestic sector and in agriculture. However, it is estimated that 50% of the wastewater produced in Portugal does not have a suitable treatment.

Since July 2015, the EPAL (Portuguese Company of Lisbon Water) is responsible for the delegated management of multi-municipal system of water supply and sanitation of *Lisboa e Vale do Tejo* (ALVT). Currently the area served by EPAL and ALVT covers 96 municipalities that occupy a land area corresponding to 33% of the Portuguese mainland and serves 3.8 million inhabitants.

In 2010, *Águas do Oeste, S.A.* was feeding thirteen municipalities (yellow municipalities in figure 2.18) including the municipalities of *Alenquer*, *Sobral do Monte Agraço* and *Torres Vedras* where the study area is located (Chapter 4.2). Figure 2.18 presents the water supply distribution in district of Lisbon in 2010.

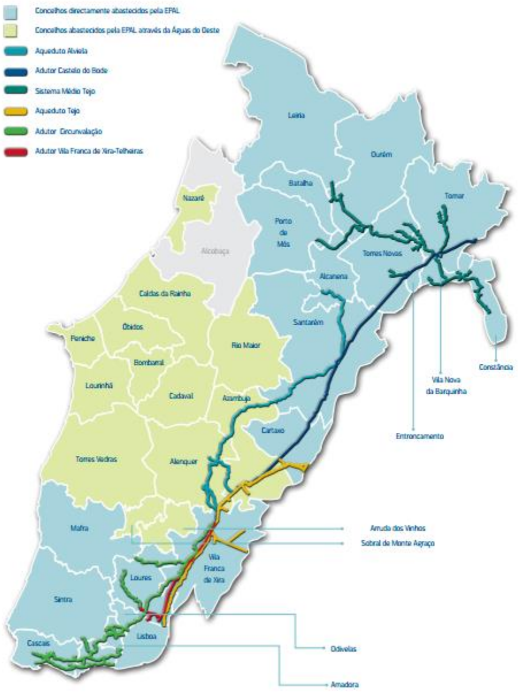


Figure 2.18. Water supply in Lisbon district (EPAL, 2010)

2.4.2 Groundwater

The Lusitanian Basin with Basin of *Tejo* and *Sado* are the largest and most important groundwater resources in Portugal. Both basins are of Meso-Cenozoic age and in the Lusitanian Basin, where its complex sedimentary history has led to the formation of thick karstic and porous aquifers. In both basins the detritic deposits may reach a few hundred meters' thickness, integrating multi-aquifer systems. The depth, confinement and good water quality of the Lower Cretaceous

Aquifers attributes them a strategic character of water reserve that should be protected and efficiently managed (Sampaio et al., 2011). Figure 2.19 illustrates the main aquifers that are distributed in Portugal, named and encoded by the Institute of Water.

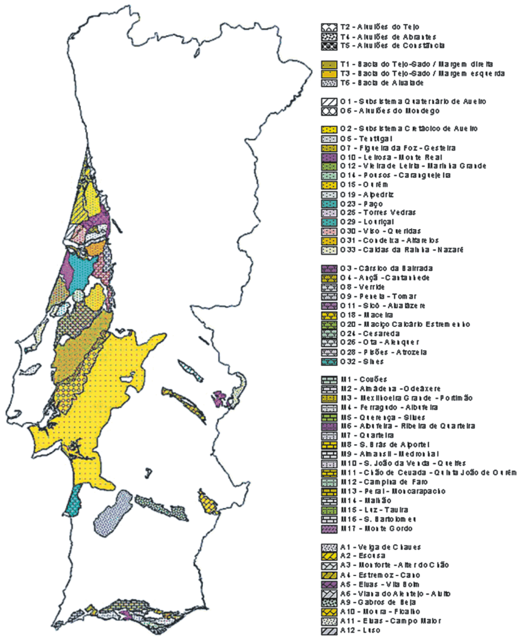


Figure 2.19. Groundwater resources in Portugal (LNEG, n.d.)

Although the distance between the shale layer and the aquifer, the possibility of hydraulic facture in the region of study of Lusitanian Basin is a major concern due to the potential risk of contaminating the water. The *Torres Vedras* aquifer, which is serving the population and the agriculture of *Torres Vedras*, *Cadaval* and *Alenquer,* is currently in danger, with high levels of water contamination, which require already chemical treatment to the water public supplied and consumed by humans. This contamination is result of the livestock activity and quarries, the Landfill in *Alenquer,* traffic, among others.

The area occupied by the aquifer of *Torres Vedras* has two main lines of water, the *Sizandro* river and *Alcabrichel* river, both are seasonal basins and the average depth of the water in this location is 8,08 m. Additionally, these two rivers have protected areas and are passing or nesting sites of protected birds.

2.4.3 Surface water

In Portugal in general, the existing water lines have poor quality because they are subject to pressures on numerous uses and work as effluent sinks, often untreated. Figure 2.20 presents the main lines of surface water in Portugal.

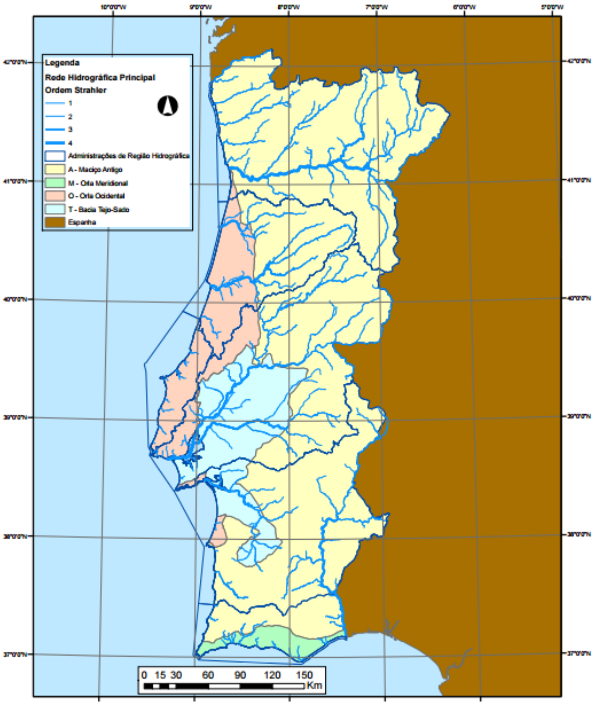


Figure 2.20. Main superficial water in Portugal (SEMIDE, n.d.)

The *Tejo* River (Table 2.12) is the longest river of the Iberian Peninsula and its hydrographic basin is the third largest in the peninsula. The hydrological regime of *Tejo* is determined by precipitation variations, especially with regard to the then integrated mountain formations. The largest flow rates are produced from January to April, while the smallest are given between July and October (*Instituto da Água*, 2009).

Table 2.12. Characteristics of the major river in Portugal (*Instituto da Água*, 2009)

Denomination	Source locality	Mouth locality	Hydrographic basin (Km^2)	Route (km)
Tejo	Serra de Albarracin (ES)	Lisbon	81 000	1 100

The expected impacts for Portugal with the increase in global temperature are a decrease in rainfall, with the risk of heavy rain in short periods of time, which will lead to a higher risk of flooding. Consequence of the lack of rain is the estimated reduction in river flow by 40%. In the warm seasons are also expected more episodes of scarcity and an increase in forest fires.

Finally, the surface waters of Portugal have a poor level of pollution rate and a high risk of scarcity in warm seasons. The increase of contamination of surface water in Portugal will intensify the poor quality of water resources. However, there are no estimates in the literature of the economic value of reducing risks of shale gas extraction related to surface water scarcity (Mason et al., 2014).

2.4.4 Air quality

CH_4 emissions in Portugal comes mainly from deposition of waste (54%), wastewater (23%) and Livestock (13%) (APA, 2012). According to APA, (2014) the national amount of emissions of greenhouse gases (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6) registered in 2012 in Portugal, excluding forestry and land use change, was about 68,8 MMt CO_2e where the quantity of CH_4 is 12,25 Mt CO_2e (around 20% of the total emissions).

2.4.5 Seismicity

Accordintg the variation of facies and thickness of lithostratigraphic units of the *Liásico*, Rocha and Soares, (1984) divided the Lusitanian Basin in three sectors. Thereafter, Kullberg (2000) develop a representative scheme of division of the basin presented in Figure 2.21. These three sectors is characterized as:

a) Sector North, located north of the failure of *Nazaré*;

b) Central Sector, situated between failures of *Nazaré* and the *Tejo* estuary;

c) Sector South, or the *Arrábida* sector.

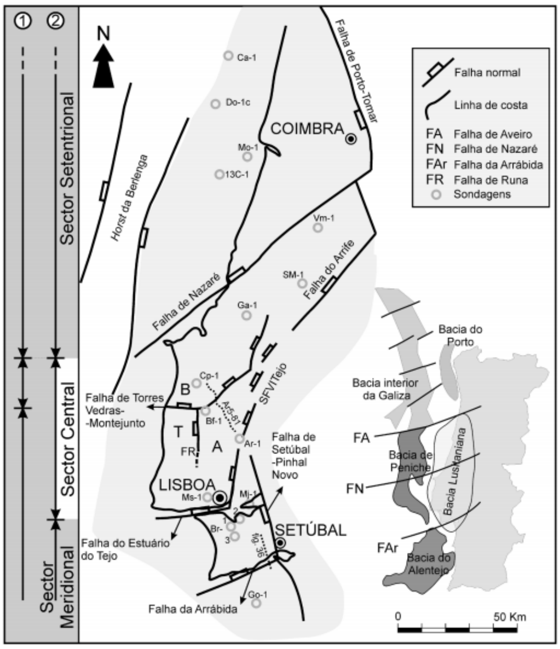


Figure 2.21. Location of the boundaries of the Lusitanian basin and failures (Kullberg et al., 2013)

According to Ribeiro, (1979) the tectonic evolution of the Lusitanian Basin was affected by failures that formed during the episode of fracturing “*tardi-Varisca*” approximately between 300 and 280 M.a.

During the Mesozoic, the location of failures with extensional regime (Figure 2.22) was due to impulses or phases of rift, as suggested by several authors, such as Kullberg (2000). Later in the Cenozoic, the stress field has undergone a change and the basin was subject to a compressive regime (episode tectonic inversion).

The hazard from earthquakes depends on proximity to potential earthquake sources, their magnitudes, and rates of occurrence. This hazard is usually expressed in probabilistic terms (1, 40). The map of potentially seismogenic faults obtained from seismic reflection, for example, gives the exceedance probabilities for a variety of ground motion measures from which the seismic design provisions in the building codes are derived.

Figure 2.22 presents the potentially seismogenic faults of Lusitanian Basin area, obtained from seismic reflection (continuous red lines), the geological outcrop and potential-field data. The map is covered to an altimetry map and instrumental seismicity (after International Seismological Centre).

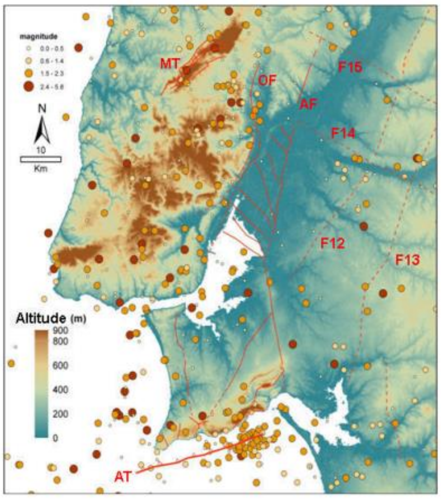


Figure 2.22. Map of potentially seismogenic faults obtained from seismic reflection (Carvalho et al., 2012)

It is estimated that when hydraulic fracturing induces earthquakes of larger magnitudes, these earthquakes are generally the result of the reactivation of nearby pre-existing faults (Maxwell et al., 2010).

Human induced seismicity when large volumes of water are injected over long time periods into zones in or near potentially active earthquake sources fundamentally causes earthquakes in the same way: they change the stress conditions on faults, which can facilitate failure (Rubinstein and Mahani, 2015). Therefore, according to Keranen et al., (2014), seismicity may be induced at 20 km or more from the injection point, however, deeper studies about the energy dissipation from human induced seismicity are required.

2.4.6 Social characterization

Job creation can be studied also under economic factors, however, in this characterization it will account as an social factor, due to the impact that it has on population life, especially in Portugal, where in the last years, the unemployment as increased as a result of the financial crisis of 2008 and is leading to high emigration specially among young adults.

Portugal has an unemployment rate of 12,5% (last updated on January, 2016) and the potential of employment improvement takes on added significance at a time when jobs have become a top national issue (INE, 2016).

The characterization of possible public health effects were estimated based on bibliography obtained from the MSDS, as well as governmental toxicological reports and on demographic data of *Torres Vedras* municipality, as *Torres Vedras* is the biggest and closest municipality is under study.

Making the particular analyze of the study area, *Torres Vedras* is the largest municipality within the study area with a population density of 412 inhabitants per km^2. Besides that, according to Rabinowitz et al. (2014), the residents within a kilometer of a well had up to twice the number of health problems as those living at least two kilometers away.

Figure 2.23 presents the resident population in *Torres Vedras*, which is balanced with greater affluence in ages between 35 and 39 years.

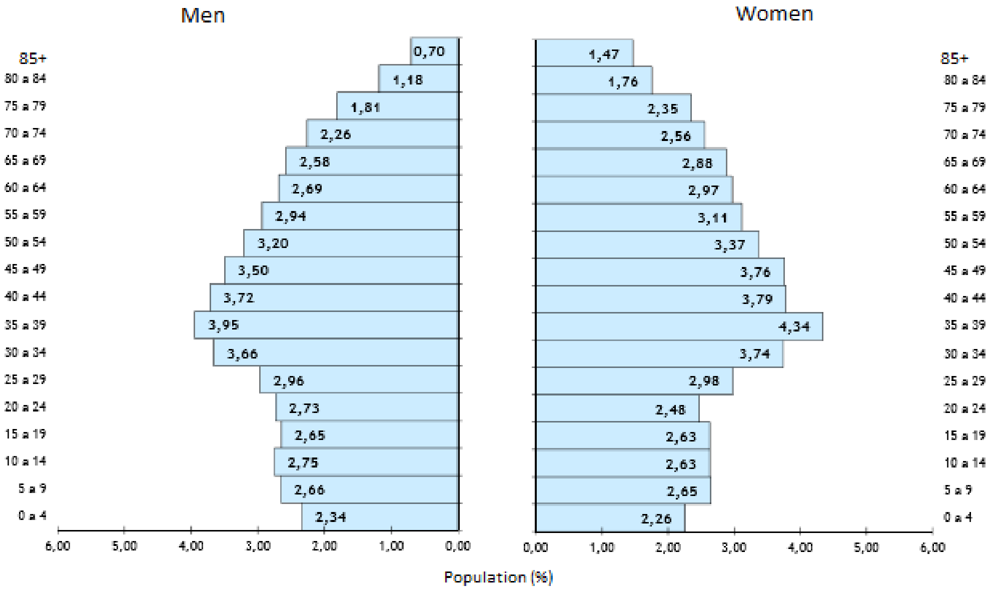


Figure 2.23. Resident population according to age group and sex (INE, 2012)

Regarding the population ages, older adults become more vulnerable to climate-related extremes in temperature and air pollution environment because of comorbidities and age-related changes, such as decreased respiratory reserve and the slowing of cardiac compensatory mechanisms.

According to INE, (2012) around 20% of population of *Torres Vedras* is over 65 years old which represent a harmful percentage knowing that over 93% of the volatile chemicals can damage the respiratory system, 86% can damage the brain and nervous system, 72% can harm the cardiovascular system and blood, and 66% can harm the kidneys (National Toxics Network, 2011).

Children represents 15% of the total population in *Torres Vedras* (INE, 2012) and requires more importance given that over 78% of the chemicals are associated with respiratory effects and children have a higher risk than adults for developing asthma and suffering complications from asthma owing to poor air quality (National Toxics Network, 2011).

In addition, pregnant woman's that are exposed to benzene during pregnancy has been displayed to increase rates of childhood leukemia as benzene is one of the air pollutants frequently found in areas with shale gas development and is known as carcinogen.

Furthermore, between 22% and 47% of the chemicals are associated to possibility of cause longer-term health effects such as cancer or organ damage to the population that are constantly expose to them (National Toxics Network, 2011).

2.5 Economic characterization

In order to evaluate the development of hydraulic fracturing is necessary to characterize the economic factors associated such as the electricity prices (Muehlenbach and Olmstead, 2014).

The economic impacts of fuel production and consumption are often left out of discussions on sustainability, in part because of their difficulty to quantitatively compare to other sustainability issues (Olson et al., 2015). Consequentially, the majority of the scientific literature to date has focused on the economic benefits, with less research on the negative externalities. However, it is important to take into account all the externalities in order to have a complete and correct economic analysis.

In this section, an analysis of the economic viability studies published until now are accessed, some that do not take into account all the costs and benefits, and other studies that already include them. Many of the risks of hydraulic fracture have not yet been discussed or monetized, which would be the next necessary step to perform a cost-benefit analysis.

2.5.1 Existing studies of viability

There are several studies confirming that shale gas production has major positive economic effects on both national and local economies (Kinnaman, 2011). These studies point out obvious benefits such as job creation, the enhancement of energy security or lower natural gas prices and economic development.

Weijermars (2013) evaluates the economic viability of five potential shale gas plays in Europe (Austria, Germany, Poland, Sweden and Turkey). The study is based on generic equations for discounted cash flow analysis and well productivity decline analysis. However, it does not take into account the environmental issues and the externalities to determine the economic viability that each plays (Weijermars, 2013).

In their study about the economic benefits of the Shale revolution, Gilje et al. (2015) use information contained in asset prices to evaluate the contribution of shale oil to the U.S. economy. Additionally, they find that technological shocks to shale supply captures a substantial fraction of total stock market fluctuations, suggesting that shale oil is an important contributor to the future U.S. economic growth.

On the other hand, the sustainability impacts of fuels are a complex topic to have in an economic analysis. It is important to have in consideration that the impacts of fuels have many dimensions and those are difficult to quantify. These impacts can be negative or positive, objective or relative, direct or indirect, and scientifically validated or reflective of unresolved issues. These multiple dimensions make comparison and universal quantification challenging (Olson et al., 2015).

According to Wiedmann et al., (2007) have emerged a more sophisticate environment-economic model using multi-region, multi-sector input–output framework. An example of this is described by Muresan and Ivan (2015), which identifies the opportunities and risks of shale gas development in Eastern Europe (e.g. Romania’s case) and argues that shale gas development requires a contextualized understanding of regional issues, creating a cost-benefit analysis model, that can serve as a necessary tool to economic and social policy holders in any area with potential in the development of shale gas operations.

Kinnaman, (2011) presented a review about existing studies of economic impact of shale gas extraction, where all costs of hydraulic fracture are external to the market and must be estimated using imperfect but helpful economic research tools. The author implements a cost-and-benefit analysis of the hydraulic fracture process and finds that if the economic value of the gas exceeds the sum of the internalized production costs to industry, plus the user costs, plus the external cost, then the economic benefits of gas extractions exceed the economic costs. Additionally, Kinnaman,

(2011) discusses the need to develop a more appropriate econometric model to estimate well drilling as a function of current price and other relevant variables.

Another perspective is given by Christopherson, (2011) where the author talk about the importance of distinguishing between the short-term impacts of hydraulic fracture as the creation of jobs, revenues, and costs to communities and, the long-term consequences for economic development. The author argue that fracking has environmental and economic effects beyond the well pad, and that those effects are cumulative, i.e. they intensify with increases in the pace and scale of drilling. Still in the same topic, Olson et al, (2015) defend that is necessary to continue to work to better understand the sustainability impacts of fuel.

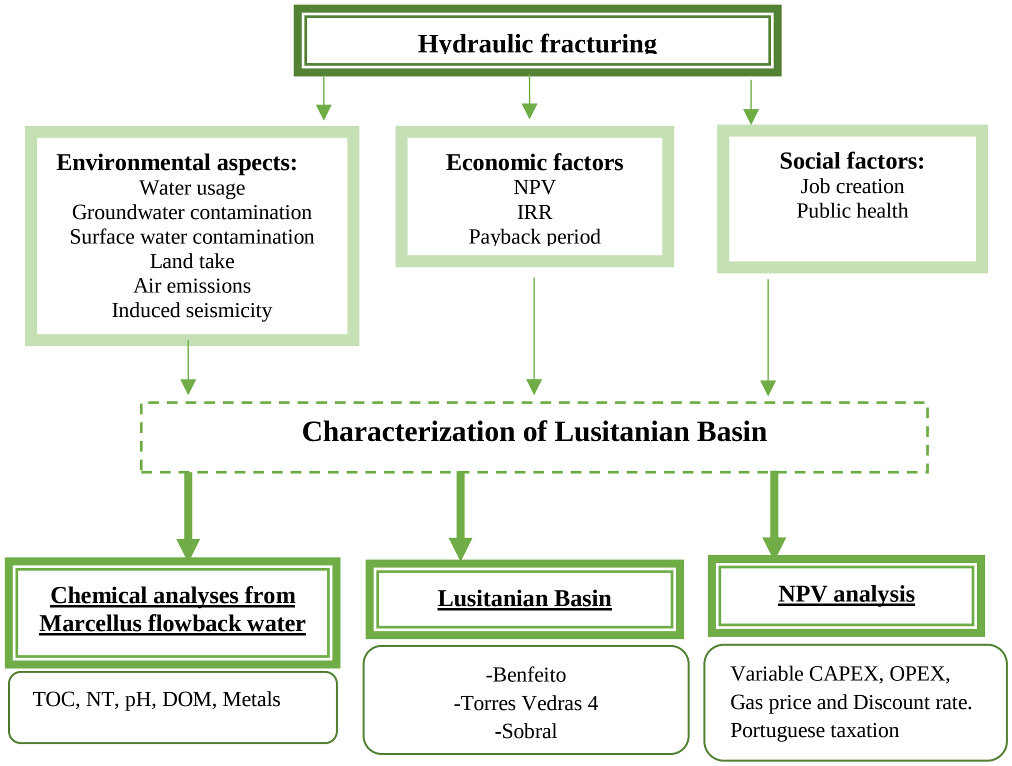
Sovacool (2014), examines four topics in order to justify the fervor over shale gas: abundance of supply, decrease in natural gas prices, cleaner environmental footprint (compared with other fossil fuels), and the economic development associated with it. On the other hand, as it has been referred, this technique affects both the environment and the human health and, when all the externalities (negative and positive) are accounted in an economic analyses, the article concludes that it produces more economic costs than benefits.

Mason et al., (2014) describes the economic benefits of the shale gas, including direct market impacts and positive externalities, concluding that the lack of economic benefits is extraordinarily large, and that continued research on the magnitude of negative externalities is necessary to inform risk-mitigating policies.

If we look for further studies that try to estimate the costs of some environmental problems associated with shale gas, the literature contains several estimates for surface water, groundwater and air quality. Bernstein et al. (2013) for example, studied the value of reducing general surface water risks from shale gas development. Cutter, (2007) estimates the marginal damage associated with reduced ability to withstand drought in groundwater-dependent urban areas. Additionally, Muehlenbachs and Olmstead (2014) estimate the willingness to pay to avoid the risks to groundwater contamination using transaction records of properties in proximity to shale gas wells with and without access to piped water.

3. Materials and methods

This study aims to better understand the shale gas exploration in a Portuguese scenario, particularly in the Lusitanian basin. For that, it will compare the available data of Marcellus play and the estimated data of the Lusitanian basin. This study will be a characterization of hydraulic fracturing in Lusitanian Basin, according to the main cost and benefits of this industry.



In order to characterize the shale gas production in Lusitanian Basin, three different approaches will be used as a support for this analysis. The first case is a chemical analysis of a flowback sample collected from Marcellus formation given the fact that this issue is the central problem of most environmental impacts. The second case is a geological model that estimates the area with the highest potential for the shale gas exploration in the Lusitanian basin based on the geologic formation. As the shale gas exploitation in Portugal is still in its initial research stages, the assessment of potential environmental impacts is made through the use of both these case studies as data base and doing a comparison with other studies or reports, taking into account the characteristics of the specific area of study in Lusitanian Basin.

The third case consists on economic analysis about the exploitation of shale gas in the Lusitanian Basin that will be based on the bibliography and through the comparison of taxation systems between Portugal and Spain.

3.1 Chemical analyses from Marcellus flowback water

For this case study, a simple analysis to the main elements of flowback water was conducted in order to use own data to prove the expected values of flowback constitutes. Numerous sources were consulted in order to obtain accurate information on the experience performed.

Samples of flowback water were collected in 4th February 2015 from Marcellus Shale formation, Pennsylvania. During their collection, volatile chemicals could have been lost and other transformations could have occurred. After collection, the samples were transported in 2 bottles of 2 L to laboratory in University of Vermont and were stored and refrigerated in polypropylene bottles.Figure 3.1 presents the procedure used in the laboratory.

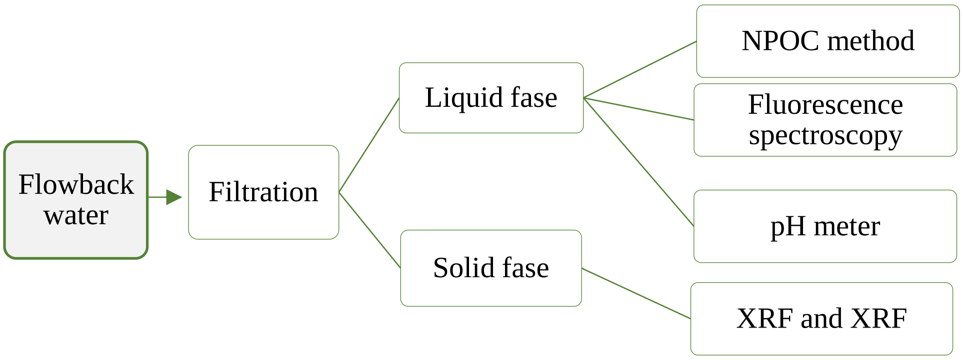


Figure 3.1. Laboratory procedure

The first stage of the laboratory work was the filtration with a nylon filter (diameter of 25 mm and pore size of 0.2 µm) for the extraction of the solids. Then, the liquid fase was divided into four different samples (numbers 1 to 4). A more detailed laboratory procedure is available on annex 2.

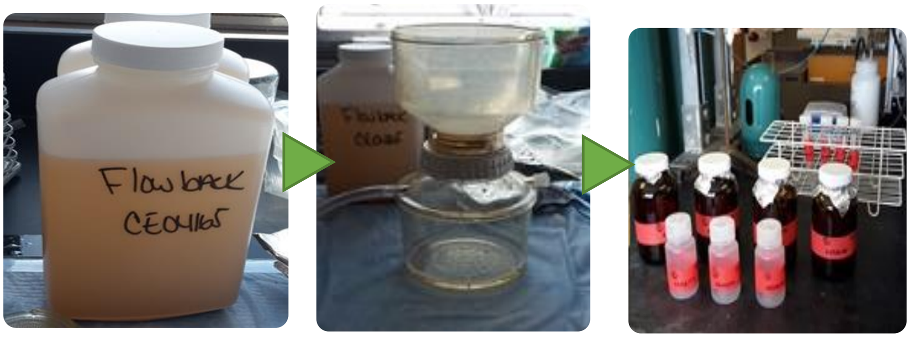


Figure 3.2. Laboratory procedure

Commonly referred to as TOC, the total organic carbon remaining in an acidified sample after purging the sample with gas. The direct method (NPOC method) is mainly used for on-line TOC analyzers. To obtain the TOC it is necessary to remove the Inorganic Carbon (IC) from the Total Carbon (TC) present in the sample:

$$TOC = TC - IC$$

In this study, all samples were analyzed for non-purgable organic carbon (NPOC) by a Shimadzu analyzer. Total Nitrogen is measured as well by a Shimadzu analyzer and takes less than 4 minutes to measure, it does not require reagents or chemicals, and produces no hazardous wastes. Samples containing nitrogen are introduced into an oxygen rich combustion tube with platinum catalyst at a temperature of 720 ºC. Bound nitrogen is then converted to nitrogen monoxide (NO), further oxidized to Nitrite (NO_2) in the presence of ozone, and is then detected by the chemiluminescence detector.

The measure of pH in the aqueous solution is made though a pHmetor. This equipment is composed for an electrode connected to a potentiometer, which allows the conversion of the electrode potential value in pH units.

Fluorescence spectrophotometry was employed by Aqualog analysis in order to qualitatively characterize the composition of dissolved organic compounds that diffused across the different polymeric membranes.

In order to extracts the solids from the flowback water, the samples were on the over for 6 days. Figure 3.3 presents this procedure.

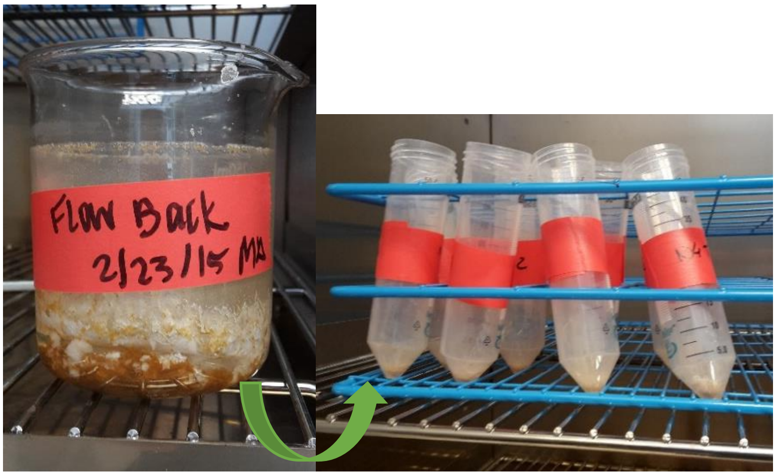


Figure 3.3 - Collection to XRF and XRD analysis

With these solids that was extract from the flowback water the methodology used to prepare the samples for XRF and XRF was:

1. Used an agate mortar and pestle to grind and homogenize crystalline samples
2. Packed them into XRF detection canisters for analysis
3. Ran each sample (~30 second runs) three times using a Niton handheld XRF analyzer

X-ray fluorescence (XRF) is the emission of characteristic fluorescent X-rays from a material that has been excited by bombarding with high-energy X-rays or gamma rays. The phenomenon is widely used for elemental and chemical analysis, particularly in the investigation of metals, glass, ceramics and building materials. A typical X-ray spectrum from an irradiated sample will display multiple peaks of different intensities once the signals are processed through a digital pulse processor.

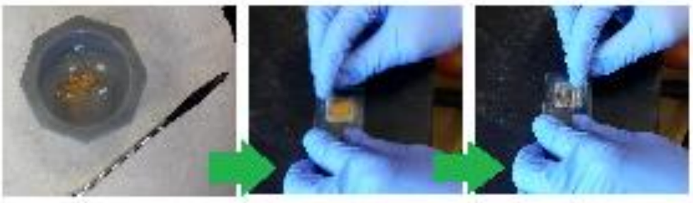


Figure 3.4 - Laboratory procedures to XRF

X-ray diffraction (XRD analysis or XRPD analysis) is a unique method to determining the crystallinity of a compound. XRD is primarily used for ID of crystalline material. X-ray diffraction can estimate the different polymorphic forms, the characteristic between amorphous and crystalline materials, and quantifies the percent crystallinity of a sample.

3.2 Lusitanian Basin

The choice of the study area was made according to some “survey logs” provided by the Professor J. Kullberg from Department of Earth Sciences, Faculty of Science and Technology, New University of Lisbon (FCT-UNL). According to technical data information, the Brenha formation configures shale gas type of rock, eventually explored through unconventional methods. Figure 3.5 presents the geological map of Portugal and it is possible to observe the blue area (Jurassic) in region of Lusitanian Basin.

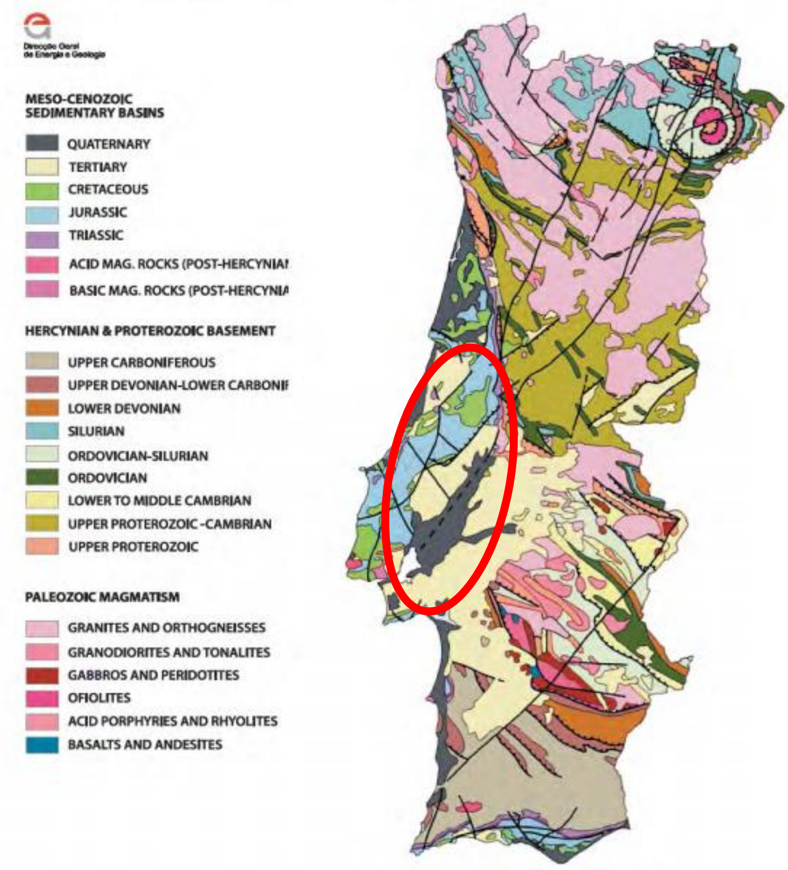


Figure 3.5. Geological map of Portugal with Lusitanian Basin painted (1:1 000 000) (Adapted from LNEG)

According to ENMC, geochemical analysis of samples from North Lusitanian Basin in *Coimbra* and *Brenha* formations revealed source rock thicknesses between 140 to 190 m, TOC values between 0,2 and 5,8% and maturation levels ranging from 0,7 to 2,0%. Thus, some shale layers of *Brenha* formation are rich in organic matter and the gas that forms in this type of rock is a result of the concentration of organic matter that has been deposited.

Analyzing the results of the surveys logs, three points were chosen from the lower Jurassic, in the formation of *Brenha*, located just before the formation of *Coimbra*. This Jurassic formation is locally very thick and with a large geographical extension through the Lusitanian Basin.

Taking into account that the layers are not linear, an approximation of the layer thickness under study area was performed. The volume calculation between the base and the top layer was made as follows:

1º. Thickness = difference between the top layer and the base
2º. Volume = Sum (thickness * pixel area (50x50m))

In addition, using ArcGIS (module arc scene, version 10.1) was possible to calculate the volume of the layer of the study area and make a 3D surface mapping.

In order to characterize the environmental and social impacts associated with the risk of shale gas exploration in the study area, it is estimated in the first place the number of wells that can be possible to implement (land take) and then analyzed the following factors:

- Water usage
- Groundwater contamination
- Surface water contamination
- Air quality
- Job creation

3.3 Exploratory investment decision analysis

To study the investment decision of shale gas exploration this study will perform a Net Present Value Analysis (NPV). NPV is a tool used in capital planning to analyze the profitability of a projected investment, determining the present value of the project's projected future income (Ross et al., 2000). Therefore, NPV represents the difference between the present value of cash inflows and the present value of cash outflows. Figure 3.6 presents the method of calculating NPV based on its formula.The formula for calculating NPV is:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0$$

Where C_t is the net cash inflow during the period t, C_0 represents the total initial investment costs, r the discount rate, and t the number of time periods.

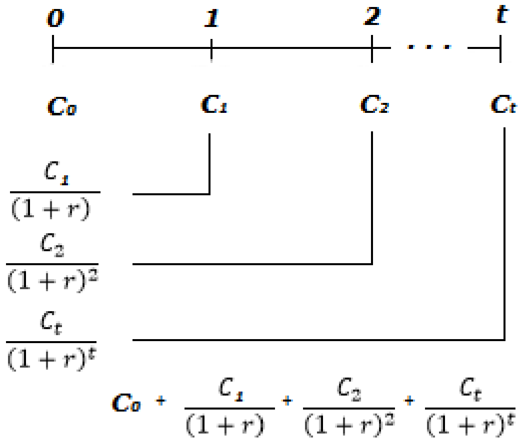


Figure 3.6. Present value of a cash flow stream (Brealey et al., 2001)

In NPV calculation it is important to choose an appropriate discount rate. The discount rate is the interest rate used to calculate present values of future cash flows (Ross et al., 2000). Thus, riskier investments must have a higher discount rate than a safe investment and longer investments should use a higher discount rate than short time projects.

It is also important to refer that this method has some limitations. The biggest disadvantage of NPV is the fact that is a partial analysis, not taking to account the alternatives investments. Another disadvantage of the NPV calculation is that it requires projections and it is difficult to predict cash flows. Furthermore, NPV assumes a constant discount rate over life of investment but a small increase or decrease in the discount rate will have a considerable effect on the final output.

In addition, in order to evaluate the economic viability of the project it will be also studied the following profitability parameters:

- Internal Rate of Return (IRR);
- Payback period.

IRR is used to determine the profitability of potential investments and consists on the rate of return that makes the net present value of all cash flows from a particular investment equal to zero. The IRR can also be defined as the discount rate at which the present value of all future cash flow is equal to the initial investment or, in other words, the rate at which an investment breaks even (Ross et al., 2000). IRR is calculated rely on the same formula of NPV and the payback period is established by counting the number of years it will take to recover the capital expenditures.

The payback period consists on the length of time that is required to recuperate the cost of an investment. This indicator is an important determinant of whether to invest in a certain activity. Typically, longer paybacks periods are less attractive to investors.

3.3.1 The Lusitanian Basin case

In order to apply an economic model for Portugal, the study will be based on two case studies:

1. “Economic appraisal of shale gas plays in Continental Europe” (Weijermars, 2013) - evaluates the economic feasibility of five emergent shale gas plays on the European Continent.
2. “Hydraulic fracking sustainability assessment: case of study Luena (Cantabria, Spain)” (Ferreras, 2014) - identifies the impacts on the environment and the main economic and social factors. For the economic factors, this study applies the same model used in study 1, however, due to the inexistence of real data the results will be estimated by varying some parameters.

The analysis of the economic factors will consist on a comparison between the results obtained by Ferreras, (2014) in his study applied to Spain and using the legislation and taxation applicable to Portugal.

In Spain general taxes for this sector are established in 40% and the 5th march, 4/2004 Act, indicates how to calculate taxes. According to Spain legislation, in case of negative profit for companies, it is allowed to compensate negative values in a maximum quantity of 50% (before taxes), in the following 18 years. The quantity of compensation by year is the division of aggregate negative*50%, by the rest of the years.

3.3.1.1 Portuguese legislation

In Portugal, the petroleum legislation is established in decree-law nr 109/94 of 26th April 94. The current legislation related to the access to, practice of prospecting activities, exploration, development and currently existing oil production includes the issuance of successive licensing titles, culminating in the concession contract granted when the declaration of a commercial discovery is completed.

In article 3 of decree-law nr 109/94 of 26th April 94, petroleum is defined as: “all natural concentration or mixtures of hydrocarbons in the liquid or gaseous state, including all substances of any other nature that are found in combination, suspension or mixture with hydrocarbons, with the exclusion of natural solids hydrocarbons and all concentrations whose exploitation of which can only be made by extraction of the reservoir rocks themselves.”

In Portugal, existing underground resources belong to the State and all areas allocated for prospecting, exploration and production of petroleum are open to concession. Therefore, royalties and land acquisition are established in decree-law nr 109/94 and concession contracts as “the concessionaire is subject to annual payment of a surface rental (RS) at a rate per square kilometer to be established in the concession contract.” Table 3.2 represents the surface rentals applicable to *Pombal* and *Batalha* concession contract:

Table 3.1. Surface rentals in Pombal and Batalha concession contract

	Surface rental	**€/km^2**
Initial period (8 years + 2 prorogation years)	First 3 years	15
	Last 5 years	30
	Prorogation year 1	40
	Prorogation year 2	60
Production period (25 years)		100

3.3.1.2 Data

As mentioned, in Portugal there is no exploration of this type of unconventional gas and the shale gas production is yet unknown. Given these factors, it has become very difficult to apply an economic model with real data.

Thus, the economic model applied requires a number of different parameters that will vary depending on the site location, which varies according to a different set of factors, from the geological to legal regulation.

a) Capital expenditures (CAPEX)

CAPEX consist in the amount spent to acquire or improve a long-term asset such as equipment or properties. The cost (except for the cost of land) will then be charged as a depreciation expense over the useful life of the asset. The capital expenditure for a shale gas development is generally determined by its subsurface properties and technology solutions selected for extraction. Despite that, this study will already include in CAPEX the cost of land acquisition.

According to EIA, (2016) the average cost for a deep well can be determined, for United States it ranges from 6 to 9 MM $ including various stimulation intervals. However, in Europe, including stimulation completed various intervals, may be around 25 MM €.

b) Operating expenditures (OPEX)

The OPEX for large conventional oil and gas projects is often indexed at 5% of total CAPEX. OPEX consists in the costs of producing and developing reserves and vary according the different type of concessions, the inventory used for production (the number and type of wells), the surface facilities and the type of technologies selected.

c) Gas price

Gas price in Europe is based on World Bank projections (table 3.2).

Table 3.2. Gas natural price forecast. Source: World Bank

	Units	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Natural gas, Europe	$/mmbtu	11,8	10,1	7,6	7,7	7,9	8,0	8,1	8,3	8,4	8,6	8,7	8,8	9,0
Natural gas, Us	$/mmbtu	3,7	4,4	2,8	3,0	3,3	3,5	3,8	4,1	4,4	4,8	5,2	5,6	6,0

To analyze the profitability of a shale gas well applied to the Portuguese mining, two different scenarios of tax regulations will be performed:

1- With the application of royalties
2- Without the application of royalties

Based on bibliography, table 3.3 represents the selected rates for European shale gas basins and the Portuguese rates that will be used for this analysis. **CAPEX**, **OPEX** and **Gas price** will be varying according to the Spanish parameters and Portuguese legislation. Will also vary **discount rate** in sensitivity analysis since the discount rate can be adjusted to reflect things such as risk, opportunity cost, and changing yield curve premiums on long-term debt.

Table 3.3. Selected rates European shale gas basins

	Sweden	Poland	Germany	Austria	Turkey	Spain	Portugal
Eur/well (Bcf-25 years)	3,25	3,25	3,25	6,55	1,97	3,25	3,25
Productivity year 1 flow rate (bcf/year)	0,5	0,5	0,5	1	0,3	0,5	0,5
Well CAPEX ($/MM)	15	14	13	24,5	8,1	10-25	10-25
OPEX ($/Mcf)	0,6	0,5	0,6	0,4	1,2	0,5-3	0,5-3
Other OPEX ($/Mcf)	1,4	1	1,2	1	1	1	1
Royalty rate (%)	0	1,5	8	10	13	0	3-9
Corporate tax (%)	28	19	30	25	20	35	25
Depreciation (%)	10	10	10	10	10	10	10
Discount rate (%)	5	5	5	5	5	5	2,5 – 5
Source	Weijermars, 2013					Ferreras, 2014	

Revenues are calculated based on the average production declining curve and price forecast for natural gas by Worldbank (latest version). Gas production declining curve is calculated on the base of the following exponential function:

$$Qn = Q_i \times (1 - a)^n$$

Where Q_n is the flow rate in year n, Q_i the starting flow rate in first year, “a” the annual decline rate, and “n” the number of years. It will be maintained the values applied in Ferreras, (2014), with the flow rate (Q_i) of 0,5 and the annual decline rate (a) of 0.15 (Figure 3.7).

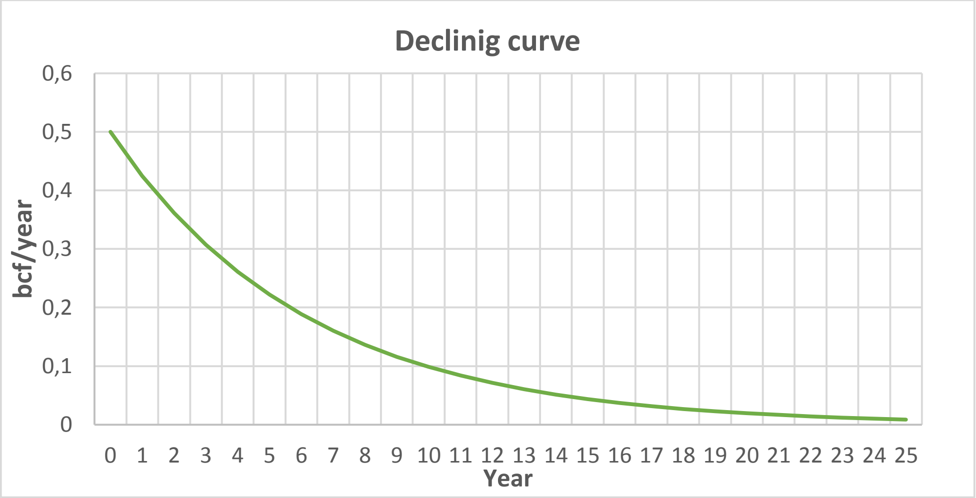


Figure 3.7. Gas production declining curve

The amortization is made by declining digits method:

$$A = \frac{CAPEX \times y}{\sum(y_1 + y_n)}$$

Where y represents the year of production, y_1 the first year and y_n the last year of amortization, depending on the chosen amortization period. In this study, the amortization was estimated for a period of 10 years and the digits sum is equal to 55.

Taxes

The economic analysis of shale gas wells is critically dependent on information of regional rates for royalty, tax liabilities, depreciation and discount rates.

a) Royalties

According to article 51 of decree-law nr 109/94, of April 26, on the annual value of liquid petroleum produced by each field, a progressive tax is applicable based on the following scales in onshore concessions:

Table 3.4. Royalties per annual production

	Annual production	**Tax (%)**
Onshore fields	<300 000 t	0
	300 000 t - 500 000 t	6
	>500 000 t	9

However, production of natural gas and associated condensate is not taxable under the terms of this article.

Despite the fact that the petroleum legislation does not impose a fee for the natural gas, in the concession contracts may be agreed to pay to ENMC gradual taxes according to the number of barrels commercialized. In this analysis a particular scenario will be developed taking into account what is established in *Pombal* and *Batalha* (in Lusitanian Basin) concession contract with ENMC and *Australis Oil & Gas Portugal*:

- After discount operating costs of production, it is required to pay to ENMC a percentage of sales defined according to the amount of barrels produced and effectively commercialized by petroleum field (1 barrel = 119,24 liters).

Table 3.5. Royalties per barrel commercialized

%	**Barrels**
3	< 5 000 000
6	5 000 000 - 10 000 000
8	>10 000 000

4. Results and discussion

4.1 Chemical analyses from Marcellus flowback water

In this section will be presented the results of chemicals analyses of flowback water sample from Marcellus formation perfumed in University of Vermont, US.

Table 4.1 presents the results of NPOC measurement from Shimadzu analyzer. Secondly, table 4.2 presents the results of pH from flowback water sample. From aqualog analysis, figure 4.1 presents the fluorescence spectra obtained with the four flow back water samples (FB1 – FB4). Finally, table 4.3 presents the different metals that were identified by the XRF analysis and figure 4.2 presents a photograph of XRF instrument used to measure the metal concentrations in flowback water that illustrates the metals with the higher concentrations.

Table 4.1. Non-purgeable organic carbon and total nitrogen results

Parameter	Sample	Result (mg/l)		
		IC	NPOC	TN
NPOC/TN	FB 1		44,26	90,82
NPOC/TN	FB 2		43,25	89,93
NPOC/TN	FB3		42,30	86,48
NPOC/TN	FB 4		41,55	84,64
IC	FB 1	48,21		
IC	FB 2	44,73		
IC	FB 3	45,95		
IC	FB 4	44,77		

Table 4.2. pH results from the flowback water samples

Sample	pH
FB1	7,69
FB2	7,70
Fb3	7,73
FB4	7,73
Average	7,71

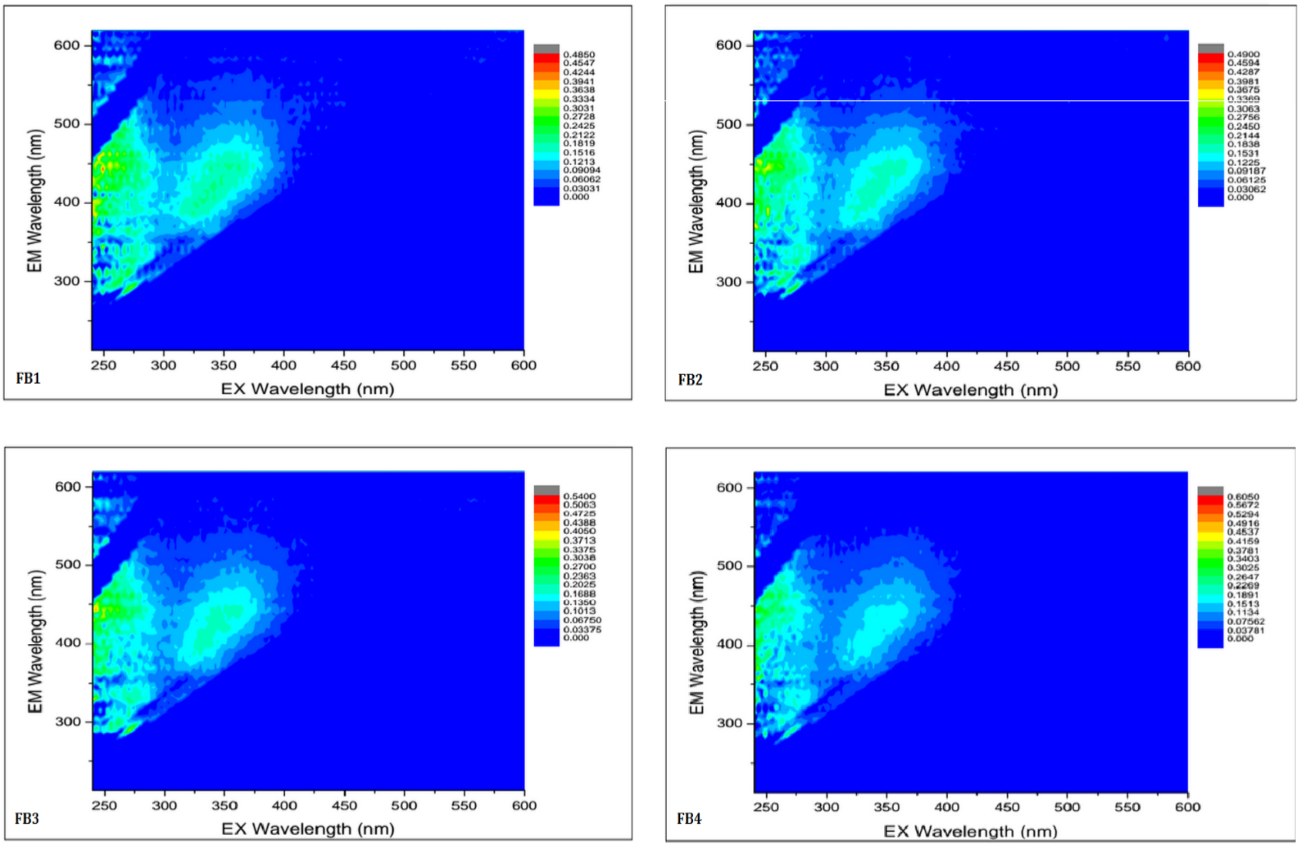
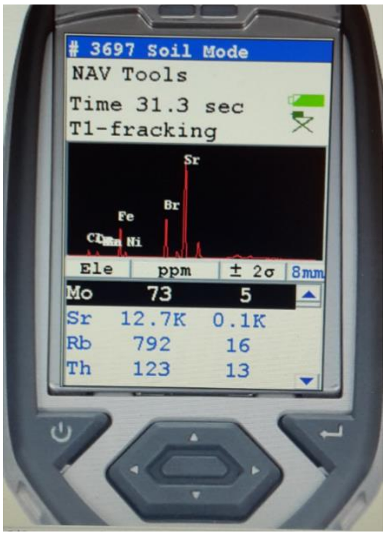


Figure 4.1 — Fluorescence spectrophotometry results.

Table 4.3. XRF analysis results in ppm

Elements	T1 FB1	T1 FB2	T1 FB3	T2 FB1	T2 FB2	T2 FB3
Arsenic (As)	18,2	20,6	20,3	17,1	25,3	34,6
Cobalt (Co)	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Iron (Fe)	47 860,5	49 556,0	54 317,1	41 003,7	54 478,0	63 669,0
Lead (Pb)	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Manganese (Mn)	339,5	457,8	464,0	409,2	438,0	583,4
Mercury (Hg)	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Molybdenum (mo)	73,2	72,3	70,8	68,2	85,9	91,7
Nickel (Ni)	< LOD	< LOD	< LOD	< LOD	160,8	< LOD
Rubidium (Rb)	791,5	711,0	682,9	711,5	817,8	898,9
Selenium (Se)	< LOD	8,03	9,32	< LOD	< LOD	13,63
Strontium (Sr)	12 701,5	11 122,9	11 064,4	11 134,6	12 447,9	13 740,5
Thorium (Th)	123,3	120,1	121,0	108,3	123,9	141,3
Tungsten (W)	166,2	191,2	147,1	308,7	356,8	425,2
Uranium (U)	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Zinc (Zn)	153,8	171,8	198,5	143,2	190,4	213,2
Zirconium (Zr)	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD



3697 Soil Mode
NAV Tools
Time 31.3 sec
T1-fracking

Ele	ppm	± 2σ
Mo	73	5
Sr	12.7K	0.1K
Rb	792	16
Th	123	13

Figure 4.2 – Concentration of metals in flowback water (ppm)

Generally, the values obtained in this procedure are within the parameters expected for a flowback water sample, confirming its high index of pollution.

NPOC can be considered as the Total Organic Carbon (TOC) and according to table 2.7 (chapter 2.3.2.3) the results obtained from flowback water are within the values of a polluted water.

The average of pH results was 7,71 which means that the sample has a neutral pH range. Typical pH levels vary due to environmental influences, but the most recommended pH range is between 6.0 and 9.0.

Flowback water has typically high Dissolved Organic Matter (DOM), including volatile compounds and hydrocarbons. Fluorescence spectroscopy can detect groups of DOM compounds sensitive to these processes and the lights interaction with DOM is a function of its chemicals structure. From the four flowback water samples (FB1 – FB4) fluorescence spectroscopy provides the source of DOM fractions and it helps to understand DOM transformations in aquatic systems, as much DOM has an intrinsic fluorescence.

Regarding metals concentration, Strontium (Sr) presents the highest concentration compared with other constituents. The Sr standard is 10 mg/l (or 10 ppm) and the values of these flowback water samples vary between 11 000 mg/l and 13 000 mg/l (Table 4.3). Some flowback waters, such as these samples collected from Marcellus shale, are also enriched in arsenic and selenium and are associated with the high metal contents present in shale rock.

The results reveal that strontium and iron are the elements that are most present in the water. However, the quantity of a metal in water does not measure the toxicity of it, as both are not proportionately related. The different maximum level accepted for drinking water parameters is a consequence of this fact. Manganese and arsenic e.g according to Department of Health (DOH) have a maximum level in drinking water of 300 ppb (equivalent of 0,3 mg/l) and 10 ppb (0,1 mg/l), respectively, and the results shows a range of 450 mg/l and 20 mg/l in flowback water.

It was not possible to proceed with the XRD analysis as the sample was a pure crystalline material that did not have a match in the crystal database.

4.2 Lusitanian Basin

After analyzing the results of the surveys logs, ***Benfeito***, ***Torres Vedras*** and ***Sobral*** were the chosen points (figure 4.4).

Table 4.4. Characteristics of the point chosen

	Coordinates		Depth (m)		Thickness (m)
	X	Y	Base	Top	
Benfeito	39°7'57.40" N	9°7'10.80" W	2960	2870	90
Torres Vedras 4	39°4'59.745" N	9°15'15.832" W	1990	1900	90
Sobral	38°57'28.29" N	9°11'39.00" W	2365	2230	135

In order to have a better perception of the study area, intercepted so the coordinates on the map and estimated area between the 3 points.

Figure 4.3. Study area localization

Figure 4.4 presents the 3D surface mapping obtained by ArcGIS. The volume reached was 10,02 km^3, which means 10 billion m^3 of layer between the surfaces estimated based on the 3 surveys. The layer has a thickness average around 110 m based on these data and tilted slightly to NE (darker areas in figure 4.4).

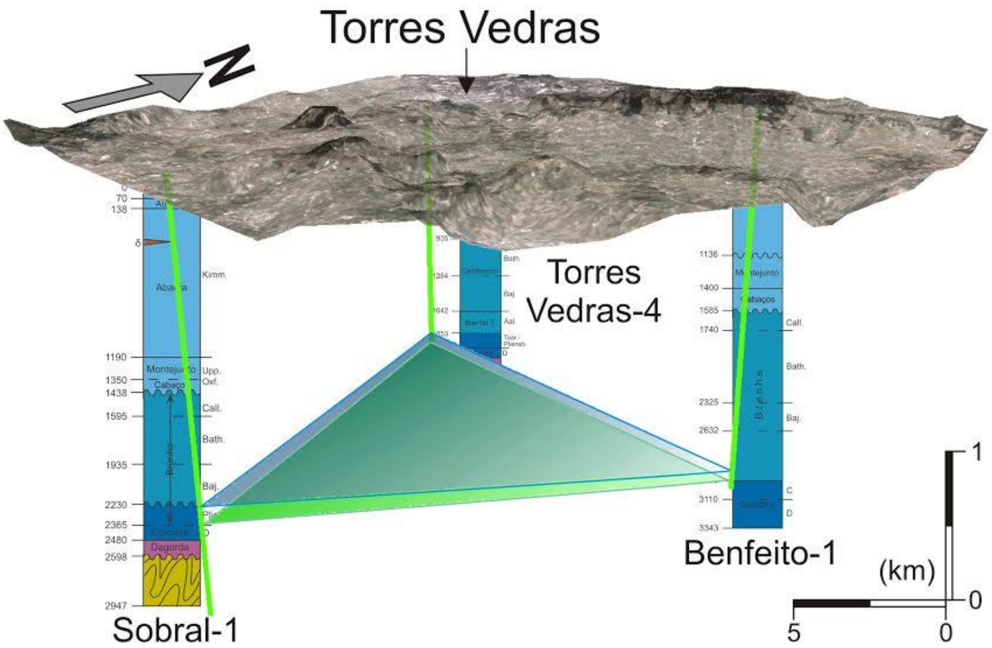


Figure 4.4. 3D study area representation

4.2.1 Land take

The existing wells in Lusitanian Basin are vertical wells, being associated to a type of outdated technique to be adopted in this local. According to the estimated surface area and assuming that is a multiple well with an average density of 1.15 wells per km^2 as referred by Lechtenböhmer et al, (2011), a number of 110 wells is obtained.

These results must be an object of economic studies due to the high number of wells estimated, high depth of shale layer and the thickness of the unit. Given these factors, it is predictable that the investment would not be viable taking into account the high costs associated for a minor probability of production.

4.2.2 Water usage

In 2010, the drinking water supply of *Águas do Oeste, S.A.* was 22 099 090 m^3 (EPAL, 2010) which represented an average of 60 545, 5 m^3 per day. Thus, the water resources depletion for a single well is evaluated given the previous values and considering that it is necessary about 7400-22000 m^3 of water per well. Table 4.5 presents the impact of shale gas exploration in water resource depletion giving the 110 wells estimates for the study area in Lusitanian Basin.

Table 4.5. Water resources depletion for single well

	Water resources depletion for a single well (m^3)				
	7400	10 000	15 000	20 000	22 000
% of the water supply (per well)	0,033%	0,042%	0,067%	0,09%	0,099%
% of the water supply (110 wells)	3,7%	5%	7,5%	10%	11%

It is important to state that these results are not taking into account that a well may be fracked multiple times during its usage period. These results estimate the water resources depletion for a single well per hydraulic fracture and the water resources depletion for 110 wells, per one fracture each.

4.2.3 Groundwatercontamination

When making a connection with the chemical analyses of flowback water and what was previously mentioned about the high levels of water contamination of *Torres Vedras* aquifer, water contamination becomes a major issue. Contamination of groundwater is, in most situations, a persistent issue, and its recovery becomes a very slow and challenging process. Groundwater protection is therefore a strategic objective with a great importance for a balanced and sustainable development. Thus, the potential aggravation of groundwater contamination of Lusitanian basin region is a risk that must be taken into account when it comes to hydraulic fracturing, especially in the area of *Torres Vedras*.

4.2.4 Surface water contamination

Analyzing table 2.7 and the results of TOC with a concentration around 40 mg/l (Chapter 4.1.) it is possible to conclude that the flowback water of the analyzed samples from Marcellus Shale are classified between the nutrient-rich stagnant lakes (eutrophication) and polluted waters.

In 2007, the quality of surface water of about 62% of the analyzed stations was rated "Fair" or "Good", and about 36% was considered "Poor" or "Very Poor". In 2011, the water quality of hydrographic basins of *Lis*, *Ribeiras do Oeste*, Vouga, *Ave/Leça*, *Tejo*, *Douro* and *Guadiana* were the ones that presented more concerns and therefore they received very poor rates. This classification was based mainly in the parameters of microbiological and organic matter, which reflects some problems in the efficiency of treatment, both urban waste water, such as livestock farms.

Moreover, the bad ratings of Portuguese surface waters are associated in most of the cases to the presence of microbiological and organic matter. Given the fact that the contamination of surface waters from hydraulic fracturing comes mostly from the flowback water, it is relevant to observe that in mostly cases the flowback water is stored in ponds near the drilling sites and the salinity variations generate chemical stratification within these ponds, which are also associated with anoxic conditions of the bottom waters in the ponds. In fact, the high salinity and temperature of the flowback water and the anoxic conditions can control the microbial community in these storage ponds, increasing the proportion of halotolerant and anaerobic bacteria species (Vengosh et al.,2014).

4.2.5 Air quality

According to Ferreras, (2014) and taking into account the declining production curve used with final recovery of 3,276 bcf per well, the total emissions over the life of a well it is equal to 83,866 t CH_4, equivalent to 75 479 t CO_2e per well.

Assuming the 110 wells estimated, the study area of Lusitanian Basin suggests a total emissions of 8 302 690 t CO_2e in methane, representing around 12% of total emissions of Portugal in 2012 and an increasing of 70% of the total emissions of CH_4 in 2012.

4.2.1 Job creation

Considering that 31 jobs (Mauro et al., 2013) are generated per well drilled, the exploitation of 110 wells planned for the study area would create 3 410 new jobs, and by consequence, would improve 0.15% in the unemployment rate of the region.

There are also unpredictable variables that affect this quantification, such as: there is no insurance of continuity of the job, as the amount of workers needed in the initial stages of the process is not the same as in the other stages; secondly, the number of expected jobs created do not take into account that some positions require special knowledge that might not exist in Portugal, therefore foreign workers might be employed. Finally, as the concessions belong to foreign company, current employees might be preferred, rather than hiring Portuguese employees.

4.3 Exploratory investment decision analysis

As mentioned in section 3.3.1.2 both economic and production data are not available for the Lusitanian Basin. The data used in this section was thus adapted from Weijermars (2013) and refers to five European shale gas basins, table 4.6 reports some of their properties. Table 3.3 shows per well selected rates.

Table 4.6. Selected properties European shale gas basins. (Adapted from Weijermars, 2013)

Property	Alum Sweden	Silurian Poland	Posidonia Germany	Shale Austria	Shale Turkey
Basin area (Sq. Km)	2 010	23 816	7 500	900	18 000
Depth (m)	100–3 500	2 000–4 000	0–2 500	4 500–8 000	2 500–3 500
Thickness (m)	30 – 100	30 – 300	20 – 500	1 500	100 – 400
TOC (%)	2– 25	7	2– 12	1,5– 2	4
Thermal maturity (%)	1,4 – 3,0	1,0 – 4,0	0,5 – 1,5	0,7– 1,6	0,5 – 3,0
GIIP * (tcf, estimated)	39	844	94	750	151
Expected Rf	0,14	0,17	0,18	0,04	0.,15
EUR/Well (Bcf) 40 years	4,8	4,8	4,8	8	2,2

* GIIP - Total Gas Initially in Place

While this data cannot be directly applied to the Lusitanian Basin, the discussion in this section offers a sensitivity analysis to some of the main variables affecting investment decisions. This study therefore closely follows Ferreras (2014), adding an analysis on the impacts of different national taxation systems. Given all these data constraints, it is important to highlight that the results of this study should therefore be carefully interpreted. While it may help shed some light on this discussion, it is still only a very preliminary effort on the enquiry concerning the economic viability of this technology in the case study area.

4.3.1 Base case scenario

The base case scenario for CAPEX, OPEX and Gas price was chosen given the mean values of table 3.3 and according to base case scenario presented in Ferreras, (2014). The results obtained for base case scenario are presented in table 4.7.

- **CAPEX** ($) – 15 x 10^6
- **OPEX** ($/Mcf) – 1,5
- **Gas price** ($/mmbtu) – 10

Table 4.7. Sensitivity analysis - Base case scenario results

	PORTUGAL		SPAIN
	Without royalties	With royalties	
NPV ($)	3 843 296	3 283 653	4 185 504
IRR	10,49%	9,70%	10,93%
Payback period (years)	5	5	5

According to the investment rule of have a NVP positive, all results represents viable investments. However, given the previous described limitations of this method, it is also important to test other parameters.

Subsequently, considering a minimum internal rate of return of 10% to the investment be viable in this industry (MIT Energy Initiative, 2010) and using the values of base case scenario, the investment on this industry in Portugal would be viable only without the royalties established in concession contract.

4.3.2 Sensitivity analysis

After applying the methodology explained, the sensitivity analyses were conducted.

4.3.2.1 Evaluating CAPEX

- CAPEX ($) - variable
- OPEX ($/Mcf) – 1,5
- Gas price ($/mmbtu) – 10

Table 4.8. Sensitivity analysis - evaluating CAPEX

		PORTUGAL						SPAIN		
		Without royalties			With royalties					
		NPV ($)	IRR	Payback	NPV ($)	IRR	Payback	NPV ($)	IRR	Payback
CAPEX	$10x10^6$	7 807 721	21,37%	3	7 248 078	20,23%	3	8 315 621	22,34%	3
	$15x10^6$	3 843 296	10,49%	5	3 283 653	9,70%	5	4 185 504	10,93%	5
	$20x10^6$	-121 129	4,87%	7	-77 438	4,92%	7	55 387	5,06%	8
	$25x10^6$	-2 216 701	2,99%	16	-4 834 323	0,68%	16	-4 472 404	1,14%	15

Figure 4.5. Sensitivity analysis - CAPEX variation without royalties

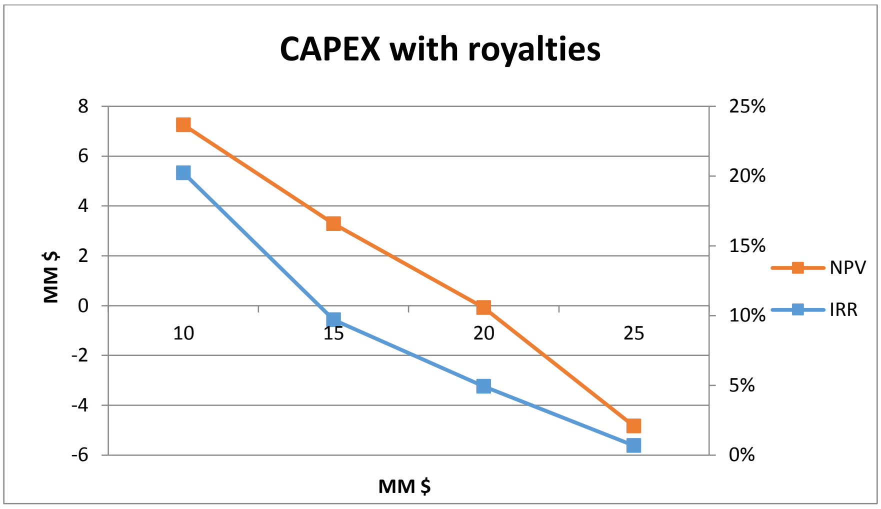


Figure 4.6. Sensitivity analysis - CAPEX variation with royalties

4.3.2.2 Evaluating OPEX

- CAPEX ($) – 15 x 10^6
- OPEX ($/Mcf) - variable
- Gas price ($/mmbtu) - 10

Table 4.9. Sensitivity analysis - evaluating OPEX

		PORTUGAL						Spain		
		Without royalties			With royalties					
		NPV ($)	IRR	Payback	NPV ($)	IRR	Payback	NPV ($)	IRR	Payback
OPEX	1,5	3 843 296	10,49%	5	3 283 653	9,70%	5	4 185 504	10,93%	5
	2	2 870 560	9,13%	5	2 310 917	8,33%	6	3 160 889	9,51%	6
	3	925 090	6,35%	6	365 446	5,54%	7	1 111 660	6,61%	7
	4	-1 020 381	3,48%	9	-1 580 024	2,63%	10	-978 351	3,56%	9

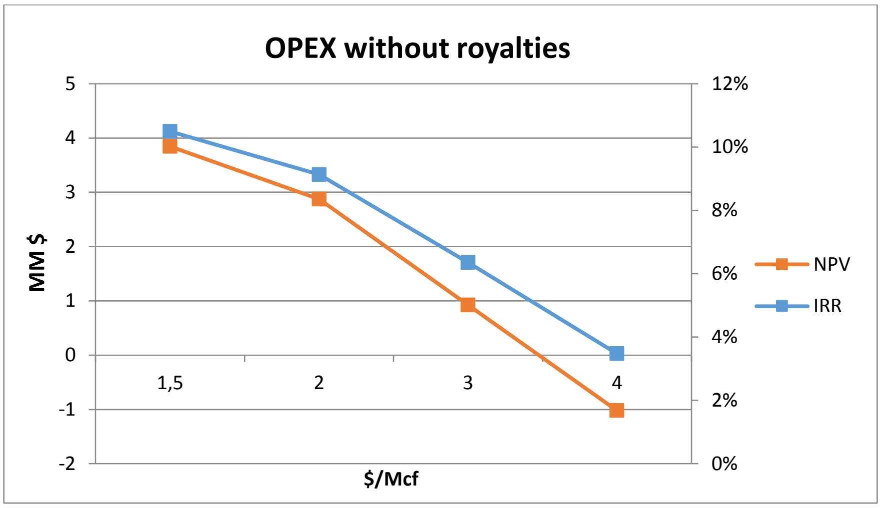


Figure 4.7. Sensitivity analysis - OPEX variation without royalties

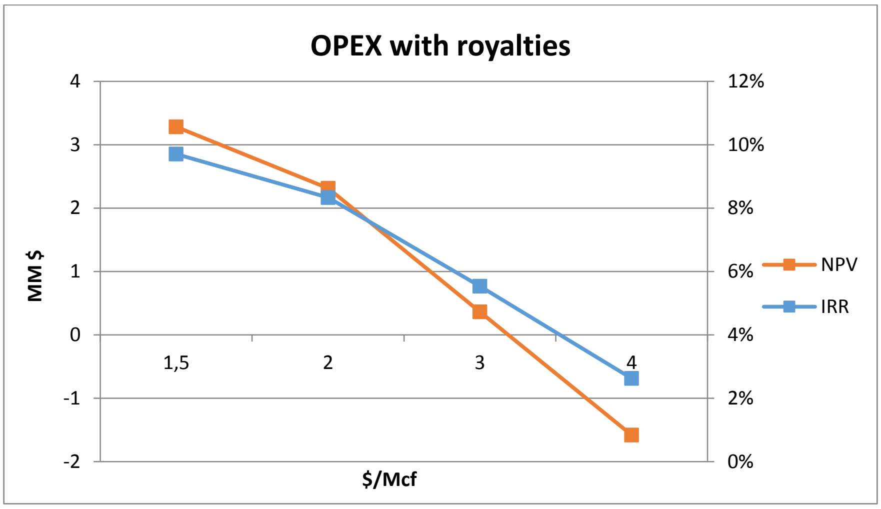


Figure 4.8. Sensitivity analysis - OPEX variation with royalties

4.3.2.3 Evaluating gas price

- CAPEX (\$) – 15 x 10^6
- OPEX (\$/Mcf) – 1,5
- Gas price (\$/mmbtu) – variable

Table 4.10. Sensitivity analysis - evaluating gas price

		PORTUGAL						Spain		
		Without royalties			With royalties					
		NPV (\$)	IRR	Payback	NPV (\$)	IRR	Payback	NPV (\$)	IRR	Payback
Gas price	6	-2 451 332	1,36%	13	-2 511 864	1,23%	13	-4 118 963	-0,91%	26
	8	695 982	6,01%	7	248 267	5,36%	7	255 564	5,37%	8
	10	3 843 296	10,49%	5	3 283 653	9,70%	5	4 185 504	10,93%	5
	11	5 416 953	12,69%	4	4 801 345	11,84%	4	6 150 473	13,66%	5

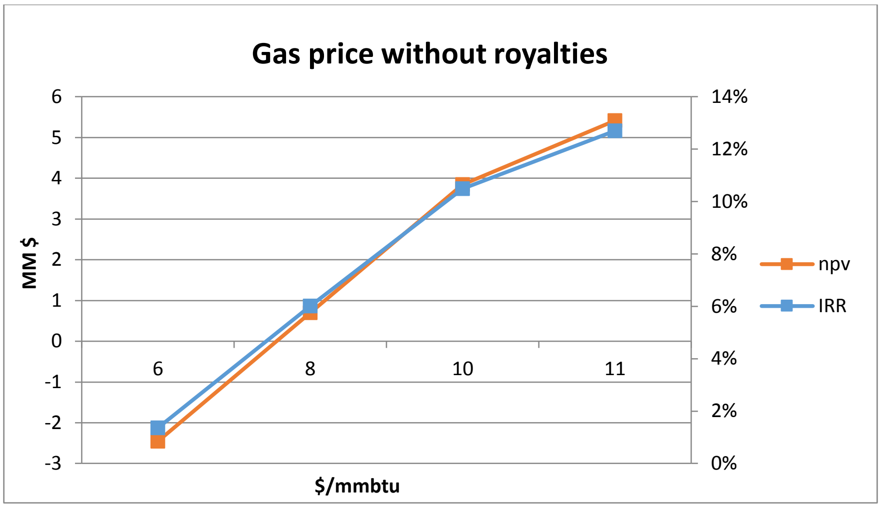


Figure 4.9. Sensitivity analysis - gas price variation without royalties

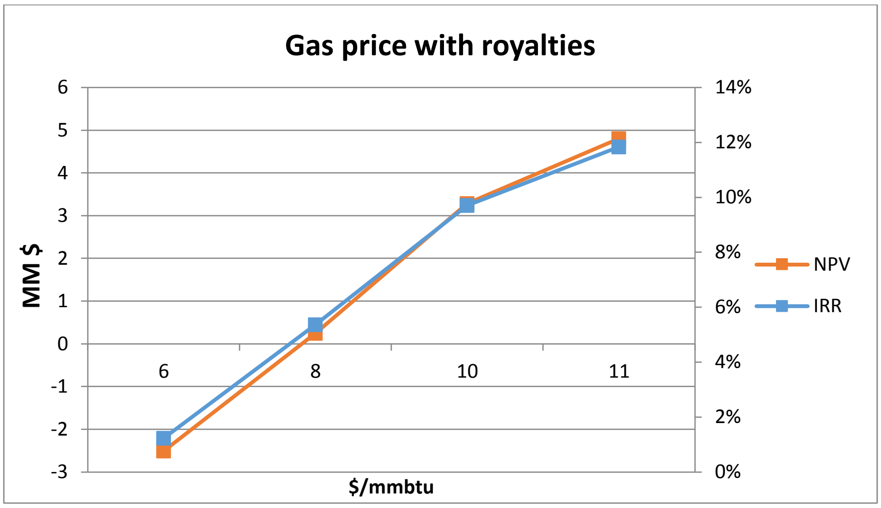


Figure 4.10. Sensitivity analysis - gas price variation with royalties

4.3.2.1 Evaluating Discount factor

Assuming the base case scenario, table 4.11 presents the NPV value after vary the discount rate of 5% to 2,5% and 7,5%.

Table 4.11. NPV with variable discount factor

Discount factor (%)	NPV ($)		
	Without royalties	With royalties	Spain
2,5	6 295 067	5 658 173	6 704 732
5	3 843 296	3 283 653	4 185 504
7,5	1 881 745	1 383 155	2 173 926

4.3.3 Discussion of results

The results for the base case scenario shows that the investment decision can be viable if the concession contract do not apply royalties. Besides that, after performing the sensitivity analysis, it can be observed that even if the costs and investments for shale gas production in Portugal and Spain are the same, the NPV results change, as a result of the differences in the legislation of both countries. As the taxation system in Portugal is not as heavier as in Spain, the profits retained are much higher, regarding the present of royalties in the contract.

A positive NPV indicates that the projected costs will be lower than the expected earning of the investment/project and therefore it will be a good and profitable investment. A positive NPV represent a profitable investment and a negative NPV means that it will result in losses. According to the figures 4.5 – 4.9., to have a positive NPV, the CAPEX needs to be lower than 15 MM$, OPEX lower than 3 $/Mcf and the cost of gas higher than 6$/mmbtu.

The IRR also as a positive correlation with the investment return and profits. The higher the IRR the better is expected to be the return on investment. IRR can be used to rank multiple prospected project, and assuming that the costs for any of the investments is uniform, the most desirable project would be the one with higher IRR, and therefore, the one that should be overtaken. In this perspective, the scenario of 10 MM$ of CAPEX presents the higher IRR and consequently, represents the most appropriate scenario of investment. Figure 4.11 demonstrate the differences in the payback period with and without royalties.

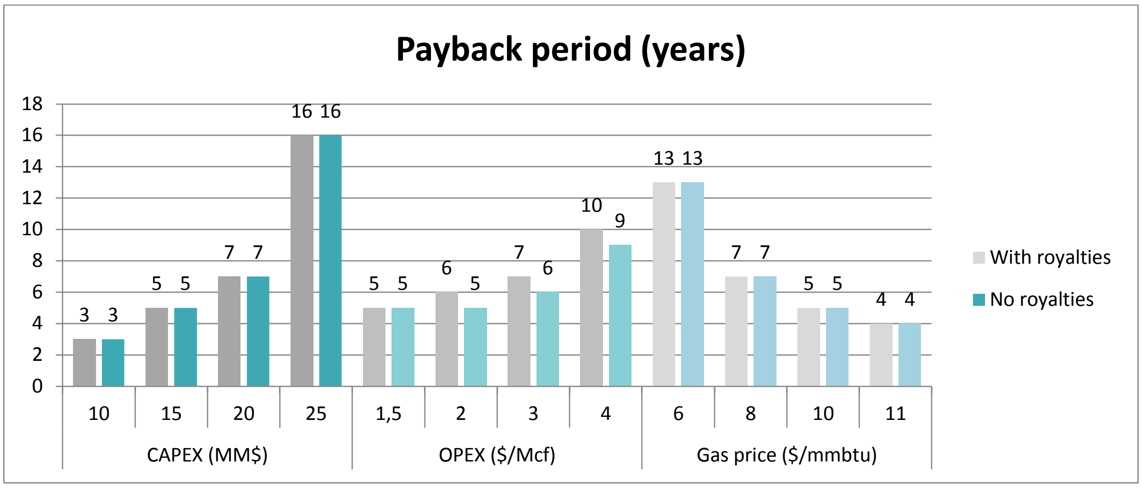


Figure 4.11. Sensitivity analysis – payback period results

Based on payback period, the best scenario would also be with the CAPEX of 10 MM $, returning their investment in 3 years. On the other hand, the worst scenario would be with a CAPEX of 25 MM $, with a payout return in 16 years. Finally, there is no major difference whether a royalty is imposed or not, the maximum discrepancy between the two scenarios is one year. In fact, given the annual production of gas in these scenarios, only a 3% of a royalty was imposed.

Analyzing table 4.8 and comparing the results obtained in both countries, it is possible to observe that by varying the CAPEX, the payback period in the two countries will change. The payback period is equal for Portugal and Spain for a CAPEX of 10 MM $ and 15 MM $ (with or without royalties). However, if the CAPEX is $20x10^6$ $, the payback period will be longer in Spain than in Portugal, and for a CAPEX of $ $25x10^6$, the payback period in Spain will be shorter.

The latter situation can be justified by the fiscal benefits of the Spanish government previous explained that allow companies to compensate negative profits in a maximum quantity of 50% (before taxes), in the following 18 years.

Regarding the OPEX, there are no significant differences between Spain and Portugal. Assuming an OPEX of 2 $/Mcf or 3 $/Mcf (not applying royalties), Portugal reaches the payback a year earlier than Spain. With royalties set out in the concessions contract, Portugal suffers a slightly change, and the payback period increases and changes also the NVP and IRR, which reflects in the profits generated in 25 years.

By varying the gas price and considering a minimum internal rate of return of 10% to the investment be viable in this industry the gas price should be equal or higher than 10 $/mmbtu.

Finally, observing table 4.11 which presents the NPV results with variable discount factor, the rate applied has a significant influences in NPV obtained. As expected, with the higher the discount rate it is obtained the lower net present value, maintaining equal the other parameters. Comparing the NPV obtained using the discount rate of 5%, it doubles when the discount rate applied is 2.5% and passes to half when the discount rate is 2.5% higher.

Generally, the discount rate penalizes an investment that has increased profitability in the future. In this study, the gas productivity is decreasing over the years and for this reason, the discount rate has a minor impact.

5. Conclusion

When it comes to shale gas in the Lusitanian basin, it is difficult to estimate its potential but comparing it with the lithology of other reservoirs such as Marcellus or Barnett formations, some similarities were found. Therefore, the lithology described in studied formations (*Brenha*) can be associated to common characteristics of shale reservoirs.

The study area in a sector of Lusitanian Basin is focused on a region where both surface water and groundwater already have some level of contamination and, therefore, the exploitation of shale gas would increase the pollution situation of the closest hydrological resources. Furthermore, the study area is situated close to population nucleus, which increases the concern of the environmental impacts given its implications on public health. Although this study was not focused on which health effect associated to each chemical component of the injected fluid or flowback, it is confirmed that the chemicals released from hydraulic fracturing have a direct effect on the population.

On the other hand, the exploitation of this resource in Portugal implies also some economic benefits, through the increase of energy independence, job creation and creation of revenue for the state (concession contracts, royalties, etc.), among others. However, it is very difficult to quantify this type of benefits, as the rock productivity depends on the site of the exploitation. There are also unpredictable variables that affects this quantification, such as the number of expected jobs created do not take into account that some positions require special skills nonexistent in Portugal, the small margin of continuity of employment in the industry or the fact that the exploring concession companies are from foreign origin.

The economic benefits associated with this industry were analyzed through an analysis of net present value and the results demonstrate that to have a positive NPV that represent a profitable investment, the CAPEX needs to be lower than 15 MM$, OPEX lower than 3 $/Mcf and the price of gas higher than 6$/mmbtu. However, the Portuguese fee system it is considered low comparing to other countries, implying that is not taking into account the true implications of the environmental impacts.

The most important factor that needs to be taken into account is that the value of productivity of the rocks used is just an estimate based on other European countries, as there is no research or data on Lusitanian Basin that show the existence of gas.

This methodology of NPV analysis has some disadvantages, such as the fact of not taking into account that new technologies that can increase productivity may arise during the period of the study. Another factor that is worth mentioning is that the predictions of this study do not consider when the investment should occur, focusing instead on whether it would be profitable or not today. Moreover, in order to make the exploitation of shale gas in Lusitanian Basin profitable, the technology costs in Europe must decrease and its growth also depends on the economy’s long-run response to oil supply.

Furthermore, regarding the benefits and risks associated to hydraulic fracturing, some occur during the process, while others, such as climate change or declining production, will occur in the future, which might make more difficult to predict the overall costs. In order to characterize the shale gas production in Lusitanian Basin it is important to evaluate all of these variable factors, taking into account the short and long-term benefits and its risks, striving to achieve sustainable results.

Concerning the results of the chemicals analysis of flowback water and giving the richness of its components, it can be interesting and challenging as a future development the improvement of flowback recovery techniques in order to recover the raw materials presented in water.

In conclusion, since the factors of this study were obtained in a general perspective, deeper studies are needed to evaluate the viability of this industry in Lusitanian Basin in Portugal. However, it is estimated that, despite the serious environmental impact associated and assuming the same productivity of other European countries, the exploitation of shale gas in Portugal is expected to be economically viable. In order to achieve an equilibrium between these factors, it is necessary the use of a more efficient technology and stable capital markets to reduce the uncertainty of the investment.

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Annexes

A.1. List of the chemicals used most often in injected fluid.

A.2. Laboratory protocol used in chemical analysis of flowback water

A.1 – List of chemical used in hydraulic fracturing

T.1. List of the chemicals used most often in hydraulic fracturing (Frac focus, n.d.)

Chemical Name	CAS	Chemical Purpose	Product Function
Hydrochloric Acid	007647-01-0	Helps dissolve minerals and initiate cracks in the rock	Acid
Glutaraldehyde	000111-30-8	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Quaternary Ammonium Chloride	012125-02-9	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Quaternary Ammonium Chloride	061789-71-1	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Tetrakis Hydroxymethyl-Phosphonium Sulfate	055566-30-8	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Ammonium Persulfate	007727-54-0	Allows a delayed break down of the gel	Breaker
Sodium Chloride	007647-14-5	Product Stabilizer	Breaker
Magnesium Peroxide	014452-57-4	Allows a delayed break down the gel	Breaker
Magnesium Oxide	001309-48-4	Allows a delayed break down the gel	Breaker
Calcium Chloride	010043-52-4	Product Stabilizer	Breaker
Choline Chloride	000067-48-1	Prevents clays from swelling or shifting	Clay Stabilizer
Tetramethyl ammonium chloride	000075-57-0	Prevents clays from swelling or shifting	Clay Stabilizer
Sodium Chloride	007647-14-5	Prevents clays from swelling or shifting	Clay Stabilizer
Isopropanol	000067-63-0	Product stabilizer and / or winterizing agent	Corrosion Inhibitor
Methanol	000067-56-1	Product stabilizer and / or winterizing agent	Corrosion Inhibitor
Formic Acid	000064-18-6	Prevents the corrosion of the pipe	Corrosion Inhibitor
Acetaldehyde	000075-07-0	Prevents the corrosion of the pipe	Corrosion Inhibitor
Petroleum Distillate	064741-85-1	Carrier fluid for borate or zirconate crosslinker	Crosslinker
Hydrotreated Light Petroleum Distillate	064742-47-8	Carrier fluid for borate or zirconate crosslinker	Crosslinker
Potassium Metaborate	013709-94-9	Maintains fluid viscosity as temperature increases	Crosslinker
Triethanolamine Zirconate	101033-44-7	Maintains fluid viscosity as temperature increases	Crosslinker
Sodium Tetraborate	001303-96-4	Maintains fluid viscosity as temperature increases	Crosslinker
Boric Acid	001333-73-9	Maintains fluid viscosity as temperature increases	Crosslinker
Zirconium Complex	113184-20-6	Maintains fluid viscosity as temperature increases	Crosslinker
Borate Salts	N/A	Maintains fluid viscosity as temperature increases	Crosslinker
Ethylene Glycol	000107-21-1	Product stabilizer and / or winterizing agent.	Crosslinker
Methanol	000067-56-1	Product stabilizer and / or winterizing agent.	Crosslinker
Polyacrylamide	009003-05-8	“Slicks” the water to minimize friction	Friction Reducer
Petroleum Distillate	064741-85-1	Carrier fluid for polyacrylamide friction reducer	Friction Reducer
Hydrotreated Light Petroleum Distillate	064742-47-8	Carrier fluid for polyacrylamide friction reducer	Friction Reducer
Methanol	000067-56-1	Product stabilizer and / or winterizing agent.	Friction Reducer
Ethylene Glycol	000107-21-1	Product stabilizer and / or winterizing agent.	Friction Reducer
Guar Gum	009000-30-0	Thickens the water in order to suspend the sand	Gelling Agent
Petroleum Distillate	064741-85-1	Carrier fluid for guar gum in liquid gels	Gelling Agent
Hydrotreated Light Petroleum Distillate	064742-47-8	Carrier fluid for guar gum in liquid gels	Gelling Agent

Methanol	000067-56-1	Product stabilizer and / or winterizing agent.	Gelling Agent
Polysaccharide Blend	068130-15-4	Thickens the water in order to suspend the sand	Gelling Agent
Ethylene Glycol	000107-21-1	Product stabilizer and / or winterizing agent.	Gelling Agent
Citric Acid	000077-92-9	Prevents precipitation of metal oxides	Iron Control
Acetic Acid	000064-19-7	Prevents precipitation of metal oxides	Iron Control
Thioglycolic Acid	000068-11-1	Prevents precipitation of metal oxides	Iron Control
Sodium Erythorbate	006381-77-7	Prevents precipitation of metal oxides	Iron Control
Lauryl Sulfate	000151-21-3	Used to prevent the formation of emulsions in the fracture fluid	Non-Emulsifier
Isopropanol	000067-63-0	Product stabilizer and / or winterizing agent.	Non-Emulsifier
Ethylene Glycol	000107-21-1	Product stabilizer and / or winterizing agent.	Non-Emulsifier
Sodium Hydroxide	001310-73-2	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Potassium Hydroxide	001310-58-3	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Acetic Acid	000064-19-7	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Sodium Carbonate	000497-19-8	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Potassium Carbonate	000584-08-7	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Copolymer of Acrylamide and Sodium Acrylate	025987-30-8	Prevents scale deposits in the pipe	Scale Inhibitor
Sodium Polycarboxylate	N/A	Prevents scale deposits in the pipe	Scale Inhibitor
Phosphonic Acid Salt	N/A	Prevents scale deposits in the pipe	Scale Inhibitor
Lauryl Sulfate	000151-21-3	Used to increase the viscosity of the fracture fluid	Surfactant
Ethanol	000064-17-5	Product stabilizer and / or winterizing agent.	Surfactant
Naphthalene	000091-20-3	Carrier fluid for the active surfactant ingredients	Surfactant
Methanol	000067-56-1	Product stabilizer and / or winterizing agent.	Surfactant
Isopropyl Alcohol	000067-63-0	Product stabilizer and / or winterizing agent.	Surfactant
2-Butoxyethanol	000111-76-2	Product stabilizer	Surfactant

A.2 – Laboratory protocol

1. Setup
    a. Open Google doc
    b. Get new Millipore water
    c. Label large plastic bottles
2. Soil extracts
    a. Add bottle to balance and tare
    b. Add 14 g soil and record exact mass
    c. Tare
    d. Add 70 g Millipore water and record exact mass
    e. Repeat for rest of samples
    f. Put in shaker on high for 1 hr
    g. Label centrifuge tubes
    h. After 1 hour of shaking, remove the bottles
    i. Transfer samples to centrifuge tubes (2 per sample)
    j. Centrifuge at 3000 rpm for 30 minutes
3. Filtration
    a. Label amber glass bottles, small plastic bottles, and small centrifuge tubes
    b. Rinse nylon filter with DI water
    c. Rinse nylon filter with sample 1
    d. Filter slightly over half of the sample through nylon filter
        i. Add 5 mL to small centrifuge tube and acidify with one drop of concentrated HNO_3
        ii. Pour the rest into small plastic bottle
        iii. Remove filter
    e. Rinse glass filter with DI water
    f. Rinse glass filter with sample 1
    g. Filter less than half of the sample through the combusted (ashed) glass filter
        i. Pour into amber glass bottle
        ii. Remove filter
    h. Rinse with DI water
    i. Rinse with sample 2
    j. Continue until all samples are filtered
4. Shimadzu analysis
    a. Turn on gas tank
    b. Turn on machine
    c. Label glass vials
    d. Make standards (if necessary)
        i. DOC and TN combined
        ii. DIC
    e. Take samples from plastic bottles for DIC analysis
    f. Take samples from amber glass bottles for DOC/TN analysis

  - g. Cap with parafilm and a black plastic cap
  - h. Put sample vials in machine
    - i. Be careful with the casing when you take it off
    - ii. Magnets must align when the casing if put back on
  - i. Set up calibration using standards
  - j. Use methods from 10/10 for sample analysis (pink label)
    - i. Change calibration curve used
  - k. Set the machine to run and turn off when finished
  - l. Never turn off the gas tank

5. pH analysis
   - a. Samples must be at room temperature
   - b. Put samples in small plastic tubes (about 1/3 filled), labeled with tape
   - c. Standardize the electrode using the provided buffer solutions
   - d. Rinse electrode with millipore water every time you put it in a new solution and dry with kimwipe
   - e. Put electrode in sample and let adjust for 5 minutes, with occasional shaking
   - f. Record pH
   - g. Rinse electrode and repeat for all samples
   - h. Turn off electrode when finished and store in solution
6. Aqualog analysis
   - a. Turn on machine to warm up 1 hour prior to use
   - b. Follow steps outlined in guide
   - c. Cuvette handling
     - i. Never put sample in reference (R) cuvette, only millipore water
     - ii. Always touch cuvette with clean gloves
     - iii. Never touch faces; handle by the corners
     - iv. Never touch the middle of the cuvette; handle by top or bottom
   - d. Check absorbance and dilute samples if necessary
     - i. Record dilution factor