

THE ROLE OF LNG AND UNCONVENTIONAL GAS IN THE FUTURE NATURAL GAS MARKETS OF ARGENTINA AND CHILE

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Abstract

The natural gas exports from Argentina to Chile until the last decade represented a milestone for the energy integration aspirations in South America. Since the interruptions of Argentinian gas flows to Chile in 2004, this regional gas trade has been substituted by LNG imports. In 2016, Chile even started delivering gas to Argentina sourced by its LNG regasification terminals. However, tapping into unconventional gas resources in Argentina can reshape the supply-demand balance for these two countries. This study analysed the interplay between LNG and unconventional gas under two scenarios of investments in upstream supported by an integrated modelling tool for gas and power. In the Low-Investment Scenario in upstream, LNG imports increase significantly making it necessary to double the regasification capacity of Argentina by 2030. In the High-Investment scenario, where unconventional gas represents nearly half of natural gas domestic production in 2030, Argentina will rely on LNG only to meet winter demands. For Chile, in both scenarios tested, LNG remains relevant, requiring the construction of new regasification terminals. Still, developing unconventional resources as in the High-Investment scenario allows Argentina to re-take exports to Chile in the next decade, mainly in the summer season, providing another opportunity for discussions on energy integration in the region.

Keyword: Latin America, Shale gas, Gas trade, LNG, Water impacts

1. Introduction

Integration of energy markets in Latin America is a long-lasting goal, with some success but also some failures. Among the greatest successes stands the Brazilian – Paraguayan hydropower dam of Itaipu, with 14.000 MW of install capacity that begun operations with its first turbines in 1984, and the Argentina – Uruguay hydropower dam of Salto Grande with 1.890 MW of capacity, that started operations with its first turbines in 1979. On the failures, is the interrupted natural gas

integration between Chile and Argentina, which started in the 1990s decade and was suspended because of several reasons in 2008¹.

The privatization process of the natural gas industry in Argentina of the early 90s brought important investments in gas transport infrastructure, allowing to connect Chilean consumers in the north, center and south of the country with the productive Argentinean basins. The legal framework that allowed it was the Economic Complementation Agreement ("Acuerdo de Complementación Económica" - ACE) N° 16 (1991) within the Latin American Integration Association (ALADI in Spanish) between Argentina and Chile, complemented through several protocols that regulated how firms participated in the market. As a result of the regulatory framework, seven gas pipelines were built in the 90s².

In 2004, Chile imported about 18.5 MMm³/d of natural gas from Argentina, representing almost 15% of Argentina's natural gas production. In Chile, roughly one third of natural gas imports were used for electricity generation in the two largest electrical systems, Sistema Interconectado Central (SIC) and Sistema Interconectado del Norte-Grande (SING), one third was for Methanex, a methanol plant installed in the extreme southern part of Chile (XII Region), and the remaining one third was for industrial, retail and household consumption, and the State Oil Company refineries. With this, in 2004 about 35% of the installed power generation capacity corresponded to power plants intended to be fuelled with natural gas imported from Argentina, and the National Capital and the cities of Concepcion heavily relied on Argentinean natural gas for household, industrial and commercial consumption.

In the 2000s, a set of factors which are not the focus of this study³, resulted in a decrease in the Argentinian gas reserve/production ratio from 25 years in the 1990s to 10 years in 2004. In 2004, the Argentinean government started restricting natural gas exports to Chile, so that in 2008 natural gas exports from Argentina to Chile were completely halted in some months⁴.

Natural gas demand in both Argentina and Chile are strongly affected by variations in temperature during the year (the coldest month in the Southern Hemisphere are from May to September). As shown in Figure 1, in years of interruption of natural gas to Chile (scarcity years), the buildings sector was prioritized in detriment of power generation and industry. Also in

¹ In 2004 Argentinean government start restricting natural gas exports to Chile, which peak in 2008 when natural gas exports from Argentina to Chile reached 100% in some months. On March 24th of 2004, by Resolution n° 265 of the Energy Secretary, the Argentinean government decided to suspend exports of excess supply of natural gas in order to keep the internal demand satisfied.

² Bandurria (2 MMm³/d), Dungeness (2 MMm³/d) and El Condor-Posesión (2 MMm³/d) in the South, Gasandes (9.5MMm³/d) and Pacifico (3.5 MMm³/d) in the central part of Chile, and Atacama (9 MMm³/d) and Norandino (5 MMm³/d) in the North part of Chile and Argentina. Also, between 1999 and 2000.

³ For further information of the Argentinian flows interruption to Chile see Raineri (2007)

⁴ On March 24th of 2004, by Resolution n° 265 of the Energy Secretary, the Argentinean government decided to suspend exports of excess supply of natural gas in order to keep the internal demand satisfied.

Argentina, to balance supply and demand, thermal power and industry is rationed during the winter prioritizing the provision of natural gas for the buildings sector (Rodrigues and Oliveira, 2015).

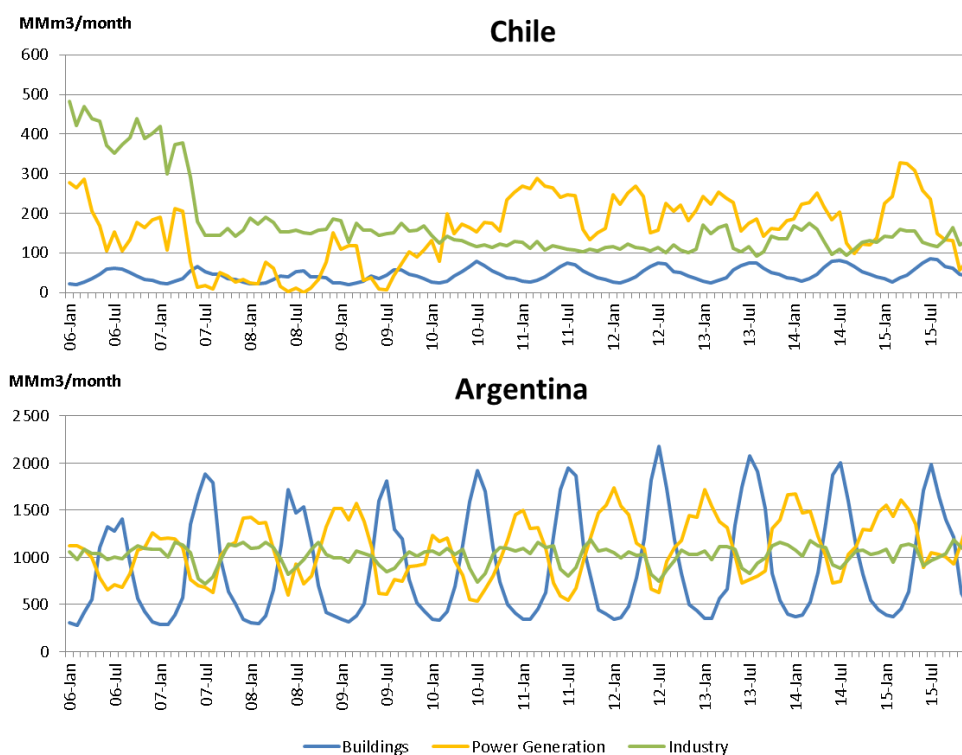


Figure 1. Historical natural gas consumption in Chile and Argentina in Buildings (residential, commercial and public sector) and power generation sectors between 2006 and 2011. Source: CNE (2016); ENARGAS (2015)

In response to the deep energy crisis after the sudden shutdown of Argentinean natural gas exports, Chilean natural gas power plants were converted to run with oil as well. Industry had to find substitutes in other fuels, sometimes without success, leading to reduced operations and even stoppages, as was the case with the methanol plant in the south of the country. All this happened at a time when oil prices peaked to almost \$ 150 per barrel. Two LNG terminals were built by public and private initiative, to receive natural gas from abroad. The first of these terminals began its operations in 2009, in Quintero, to supply natural gas to the capital Santiago and the central part of the country, for power generation of natural gas power plants in the SIC electric system, and for residential, commercial and industrial uses. The second terminal (Mejillones) was built in the north of the country, and began its operations in 2010, to supply for power plants in the SING electric system, where more than 90% of electricity consumption corresponds to industries, and particularly to the large mining sector.



Figure 2. Upstream Blocks and natural gas infrastructure in Argentina and Chile. Source: MINEM (2016a); MINENERGIA (2016a)

As it turns out, LNG was not only a solution for Chile but for Argentina as well. In order to boost natural gas supply for the domestic market in the winter, reducing importation of oil products for power generation, which faced hypothetical disruptions of Bolivian natural gas imports (Dicco, 2011), Argentina started relying on LNG with the start of operations of a Floating LNG Regasification Unit (FRSU) in Bahia Blanca in 2008, with the commissioning in 2011 of another FRSU for the regas terminal of Puerto Escobar.

The Energy Information Administration recent estimates puts Argentina as the second country in the world in terms of unconventional natural gas resources after China (EIA, 2013a). The existence of unconventional hydrocarbon resources were identified in the 60s and 70s with the discoveries by YPF, the State Oil Company, in Puesto Hernandez, Loma La Lata, and more recently in Vaca Muerta and Los Molles fields (rich in unconventional hydrocarbons). However, at that time, neither prices nor technology allowed for their extraction (Di Sbroiavacca, 2013).

Over the past few years, the Argentine government established a program to encourage additional production of natural gas, providing participating companies with a natural gas price floor of US\$ 7.50/ MMBtu for such additional production (YPF, 2016). The higher gas prices

attracted major oil companies, including ExxonMobil, Total S.A., Shell and Chevron Corporation to Vaca Muerta. The new administration that came into office in December of 2015 has brought expectations of regulatory change for towards more market-oriented regulations of hydrocarbons upstream. Argentina's successful extraction of these resources could become a game-changer for the region.

In 2010 a new dialogue was launched between Chilean and Argentinean authorities, with the aim of defining a work agenda to open a new path for collaboration in areas such as energy exchanges, electricity exchanges, fuels and biofuels, and nuclear power. More recently, and since 2016 with the arrival of the new government of President Mauricio Macri, Argentina signed an agreement with Chile to import natural gas in the winter season using the Gas Andes and Norandino pipelines infrastructure and the LNG regasification capacity at Quinteros and Mejillones plants. The agreement is for 3 MMm³/day through Gas Andes pipeline, including the possibility to increase it by 1 MMm³/day through the Norandino pipeline. These transfers already started in the winter of 2016 (MINENERGIA, 2016b). Thus, Chile is now exporting to Argentina, the natural gas received through its LNG terminals, as well as electricity via the transmission line built in the early 2000s that was meant to take electricity to Chile from northern Argentina, where a natural gas power plant was built for that purpose.

One of the earlier works about prospective of the unconventional gas impact in the supply and demand balance in the region was made by Di Sbroiavacca (2013), this author explored three "what if" production scenarios for Argentina on an annual basis until 2050, the role of LNG of international trade was not analyzed in this study. Ferioli (2014) developed a similar scenario analysis as Di Sbroiavacca (2013), with an additional analysis of the equipment and infrastructure required to develop unconventional gas in Argentina and the investments required. Also, Ferioli (2014) constructed gas supply scenarios on an annual basis by different sources, including LNG and gas imports. IAPG (2015a) developed a supply demand balance prospective study until 2035 using a weekly resolution on the demand side. The supply figures were constructed on an annual basis and a "what-if" approach including domestic sources, LNG and international gas trade. Interesting enough, this study also identified bottle-necks in the gas transport network. Gil et al. (2015) also elaborated a prospective scenarios up to 2030 with a focus on conservation and energy efficiency measures to reduce the gas demand. Postic (2015) developed one of the first integrated energy models for the South American energy markets using TIMES with a three timeslices by year (summer, winter and interseason). The objective of Postic (2015)'s study was to assess national climate policies. In this modeling effort, he included shale and tight gas sources for Argentina. Nevertheless, the gas modeling approach neglected economic fundamentals such as the different dynamics of non-associated and associated gas and the economic impact of liquids in the price of gas.

Shale gas production has raised concerns about impacts such as on water (quantity and quality), air quality, seismic, etc. For this reason there is significant concern to shale gas development in many parts of the United States, Western Europe, Brazil and Argentina (EPA, 2010; GWPC, IOGCC, 2013; Vidic et al., 2013; Moreira et al 2014; WRI, 2014; Costa et al., 2017). Fracking activity has been developed during the last few years in Argentina (El Patagonico, 2015; Gómez,

2014). Most studies are focused in the Neuquén sedimentary basin, mainly in Vaca Muerta play and São Jorge play, as they are the current exploration area (Accenture, 2012; LPO, 2013; WRI, 2014). The country also has two other untested sedimentary basins, including the Parana and Austral Magallanes basins.

WRI (2014) indicates Neuquén Basin has medium to low water stress over nearly 70% of its area. One of the reasons could be Vaca Muerta play is located in the headwater of the Neuquén River Basin whose main rivers (the Colorado River and Limay River) are born in the Andes and increase flow with snowmelt. Codeseira (2013) agrees with WRI (2014), however, based on a spatial analysis he indicates that the high flows are not homogeneous with large distances to sources of freshwater, which can mean higher costs of transportation. Furthermore, WRI (2014) refers that San Jorge play faces high to extremely high drought severity on 74 percent of its area. This play is located in arid areas with very low water use, limited supplies and without receiving important contributions (WRI, 2014). On the other hand, Paraná and Austral Magallanes play have a low water stress. Nevertheless, no studies have been found yet in the academic literature on the water demand for prospective unconventional production scenarios in Argentina.

Despite the remarkable results of the studies described before, this paper aims to fill the gap of an analysis using integrated energy models to explore the role unconventional gas and LNG can play in the future supply-demand balance and trade between Argentina and Chile underpinned by technical and economic principles of the natural gas chain and a higher temporal resolution. As a secondary objective, this study will provide insights about the water consumption related to unconventional gas production in Argentina.

2. Methodology

To explore the role of the factors presented in Section 1, we used a modelling approach of the natural gas chain that can provide quantitative insights of the supply and demand of natural gas for Argentina and Chile up to 2030. The results obtained from the models will be further discussed, taking into account the assumptions and limitations of this modelling exercise, and identifying policy opportunities.

A hybrid approach was developed to project the natural gas supply and consumption, by combining a simulation model (LEAP - Long range Energy Alternatives Planning System) on the demand side, with a technologically rich energy system optimization model (TIMES model) on the supply side.

TIMES (The Integrated MARKAL-EFOM System), which is an optimization partial equilibrium bottom-up model (Lolou et al., 2005), was chosen to model the natural gas and power chains in Chile and Argentina providing i) the consumption of natural gas in power generation, ii) the expansion of natural gas processing plants and LNG regasification plants, and iii) the projected natural gas curves according to the different costs of resources, the interplay between indigenous supply and imports of LNG and the trade of natural gas between countries.

TIMES is also commonly used to model demand based on a bottom-up approach using different technologies to supply the end-use energy service demands. However, the information needed for this approach is not available in the countries assessed, especially those related to the industrial, commercial and public sectors. In this sense, natural gas demand was forecasted using the Long range Energy Alternatives Planning System (LEAP), and inputted as fixed values in TIMES.

The time horizon of the analysis is 2012-2030. The start year of modelling is 2012 and from 2013 and 2015 the simulations were calibrated to match historical values. Two different temporal resolutions were used to model the natural gas chain and power generation. Because of their flexibility and quick ramp up times, natural gas technologies play a key role in the security of supply in power systems with higher penetration of renewables, since can react quickly to peak demands as well as supply shortages (Devlin et al., 2016). In order to capture this operational feature, the power generation sector was modelled using an hourly resolution. As tested by Chavez-Rodriguez et al. (2016), if line-pack of gas pipelines are not included, an hourly resolution for natural gas can bring misleading insights about the supply and demand balance of natural gas. Not including line-pack can be solved using a monthly approach, sacrificing temporal resolution for the benefit of consistent outcomes..

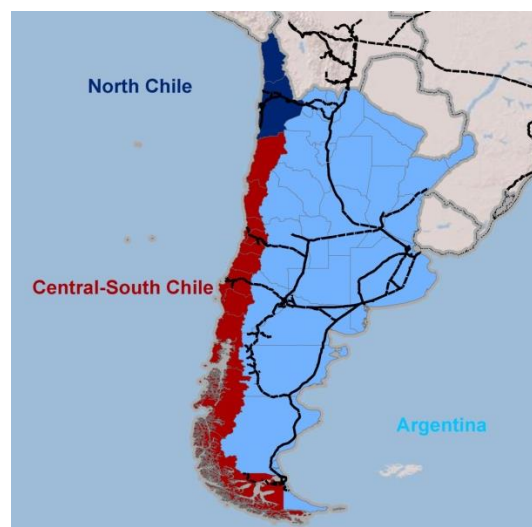


Figure 3. Geographical Disaggregation adopted

Regarding geographical resolution, Argentina was modeled at the national level, while Chile was divided in two regions - North Chile and Central-South Chile (Figure 3), in order to account for the fact that natural gas pipeline networks of these two regions are not interconnected. The North

Chile region includes from Arica and Parinacota regions down to Antofagasta, and the Central-South Chile region includes from Antofagasta down to Magallanes⁵. This sub-division also follows Chile's electricity transmission network, which is made up of four separate grids operating in the country (CNE, 2015): the Sistema Interconectado Central (SIC) is the largest and serves the most populous areas, including the capital Santiago; the Sistema Interconectado del Norte-Grande (SING) is the second largest and serves the northernmost portion of the country, where most of the copper mining industry operates. For the sake of simplicity, the other two smaller grids, the Sistema Electrico de Aysen (SEA) and the Sistema Electrico de Magallanes (SEM), were simulated as part of the Central-South Chile Region with the SIC, despite them not being interconnected.

2.1 Natural Gas Demand

The natural gas demand is divided in the model into two components: end-uses and power generation. Natural gas for end-uses includes the consumption of residential, commercial and public services, transport and industrial sectors. As explained before, due to data limitation to build a bottom-up demand at energy services level or with elasticity coefficients, the natural gas demand for end-uses was elaborated as a perfectly inelastic demand on the final energy level. This means that any changes in the costs of natural gas does not affect the total final demand of natural gas in end-uses in terms of energy. Actually, this assumption is supported by historical evidence as shown in Figure 2, where in spite of the rationing of the supply, the consumption for buildings in both Chile and Argentina did not change significantly. However, this hypothesis might change in the near future with the increasing gas tariffs for residential and commercial consumers in Argentina that are likely to reduce its specific consumption.

On the other hand, natural gas demand for power generation was modelled based on an elastic behaviour as it competes with other fuels (coal, oil, hydro, solar and wind). Therefore, when natural gas prices are high, its demand for power generation purposes drops, and vice versa. Consequently, the composite curve of the natural gas demand results from the sum of a fixed (or perfectly inelastic) demand for end-uses and an elastic demand for power generation.

2.1.1 Natural Gas Demand for End-Uses

Natural gas demand forecasting techniques are predominantly top-down approaches (Soldo, 2012). We have used a hybrid approach in LEAP using bottom-up modeling for residential and transport sectors and econometric techniques to forecast natural gas demand in industrial and commercial/public sectors. A detail description of the methodological procedure to project natural

⁵ In theory, Magallanes and Aysen provinces in Chile are disconnected from Central Chile, the gas demand of these provinces is small, however, for the sake of simplicity they were aggregated to the Central-South Chile region in the model.

gas demand for end-uses can be found in Supplementary Materials A. As the natural gas demand projections for end-uses in Chile was estimated in LEAP at national level, drivers of potential market expansion such as number of households, vehicles, etc, were used to split the increments of demand between North Chile and Central-South Chile.

2.1.2 Power generation

Power generation was modeled using a parametric approach and optimization of the operation. Several technologies were modeled based on general technical and economic characteristics such as effective capacity, conversion efficiency and costs. Conventional technology costs were based on Black&Veatch (2012) and renewable technology costs were based on (IRENA, 2015). In Supplementary Materials B the assumed costs and capacity factors can be found.

Capacity expansion by technology and electricity demand projections were adopted from AGEERA (2012) and CNE (2015a) for Argentina and Chile respectively (Figure 5). The model calculates the consumption of natural gas based on the least-cost operation. As can be observed in Figure 5, in 2030 Argentina will rely strongly in natural gas plants, representing 30% of its installed capacity in that year, hydropower will maintain its major role (28%), however wind and nuclear will have significant increase representing 8% and 16% respectively. Central-South Chile boasts significant renewable installed capacity, with 31% hydropower and about 28% wind, solar and biomass. The deserts of Northern Chile are considered some of the best sites for solar electricity generation (Köberle et al., 2015), and a 100-MW concentrated solar power (CSP) plant is currently under construction. Both wind and solar power potential is significant in both grids (Santana et al., 2014). Coal and natural gas comprise only 36% of the installed capacity (CNE, 2015b).

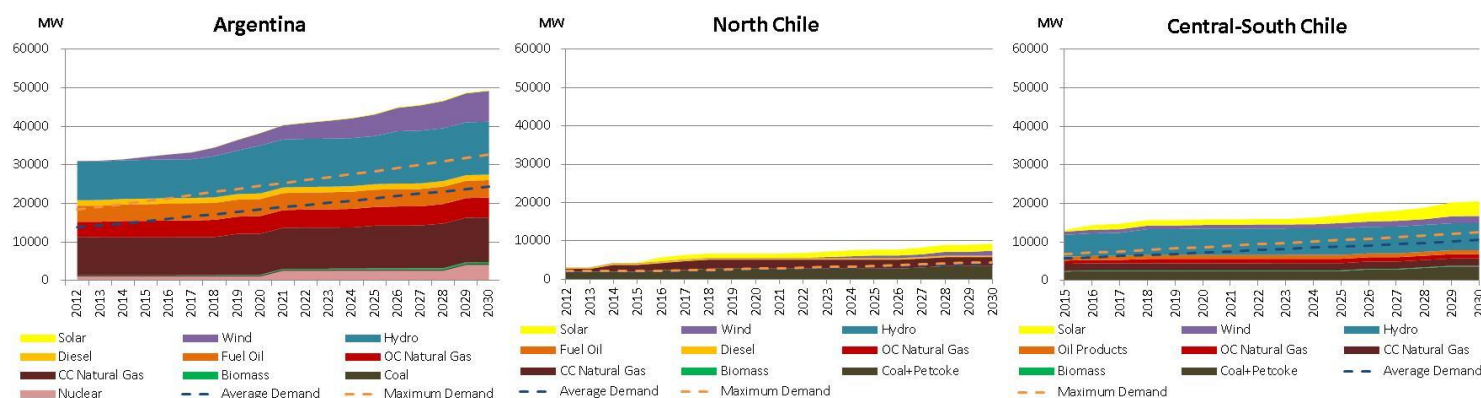


Figure 5. Demand and Power Capacity projected until 2030.

Source: AGEERA (2012); CNE (2015a)

A 610-km of 500 kV and 1500 MW transmission line crossing the sparsely populated distance separating SIC and SING is currently under construction and was planned to enter operations at the end of 2017 (E-CL, 2015); in order to be conservative, the start of this interconnection was set in 2018.

2.2 Natural Gas Supply

The TIMES model elaborated for this study represents the natural gas supply of the energy system covering the following components: primary energy supply (extraction, losses and imports/exports), transformation (including the processing of natural gas and the split of the liquids of natural gas and also the transformation of natural gas into electricity). Differently from power generation where we adopted an expansion of the capacities installed, the natural gas supply chain expands aiming the least-cost at a present value of the system. In this study we have used a 10% discount rate per year and a monthly time-resolution.

2.2.1 Upstream

An upstream production facility involves wells, platforms, storage, piping and separation facilities used in the production, extraction, recovery, lifting, stabilization, separation or treating of the hydrocarbon produced. After the separation process there are three main products separated from free-water and solids: crude oil, wet gas (natural gas + natural gas liquids), and condensates.

Wet gas can be found as associated or non-associated gas (see Table 1). Associated dissolved gas is produced in oil fields where natural gas is found either as free gas (associated) or gas in solution with crude oil (dissolved) (EIA, 2016). Non-associated gas produced by gas wells⁶ in gas condensate fields or in gas fields. Gas condensate produced in gas condensate fields consists predominantly of methane (C1) and other short-chain hydrocarbons, but also contains long chain hydrocarbons. An average gas condensate usually contains 70–75 mol% methane and 5–10 mol% C7+ fraction, with the rest distributed between the non-hydrocarbons and the intermediates (Dandekar, 2015). Gas fields produce a more “dry” gas where liquids fractions are less significant. For modelling purposes we will consider a gas condensate commodity for non-associated gas wells of both gas fields and gas condensate fields.

In order to model natural gas production, we divided it in three categories: Conventional Associated Natural Gas, Conventional Non-Associated Natural Gas and Unconventional Natural Gas. Argentina has a detailed database of productions by fields and concessions (Secretaria de Energia, 2015a). To identify associated natural gas fields we considered a gas-to-oil volumetric ratio above 5000 to include from gas-condensate fields (Table 1).

⁶ According to the RRC (2003) is defined as “any well which produces more than 100,000 cubic feet of natural gas to each barrel of crude petroleum oil from the same producing horizon”.

Table 1. Natural gas classification according to gas-to-oil volumetric ratio (v/v)

Classification	Gas-to-Oil Ratio (v/v)
Gas non-associated	>10 000
Gas Condensate	>5.000
Gas dissolved in oil	>1 000
Gas separated from oil	<1 000

Source: (Thomas, 2004)

Associated natural gas production relies on the dynamics of crude oil production, which is assumed as not having either logistics constraints or dependence on the domestic market. Oil production also has a shorter length between discovery and production start, differently than non-associated natural gas projects (Sällh et al., 2015). Furthermore, associated natural gas is considered as a “by-product”, and in the past it was a common practice to flare it, since the project is already paid with the liquid productions, and, additional investments are required to monetize the associated gas (OGJ, 2002). Consequently, in order to project the associated natural gas production, we need to develop an oil production model based on a Multi-Hubbert approach (Chavez-Rodriguez et al., 2015; Laherrere, 1997).

Oil production was modelled only for Argentina, where the production of associated natural gas is relevant. In the case of Chile it was assumed that all the gas produced is non-associated. The oil production projection for Argentina, was based on historical oil production obtained from (IAPG, 2015b). The EUR (Estimated Ultimate Recovery) composed of 3P reserves (Proven + Probable + Possible reserves) and Contingent Resources was used. Once Argentinean oil production curves were obtained, the country’s associated natural gas production was modelled using a natural gas-to-oil ratio of 0.3 MMm3 of natural gas per Mm3 of crude oil (0.036 MMm3/Mbbl), which was estimated based on historical production (Secretaria de Energia, 2015a)

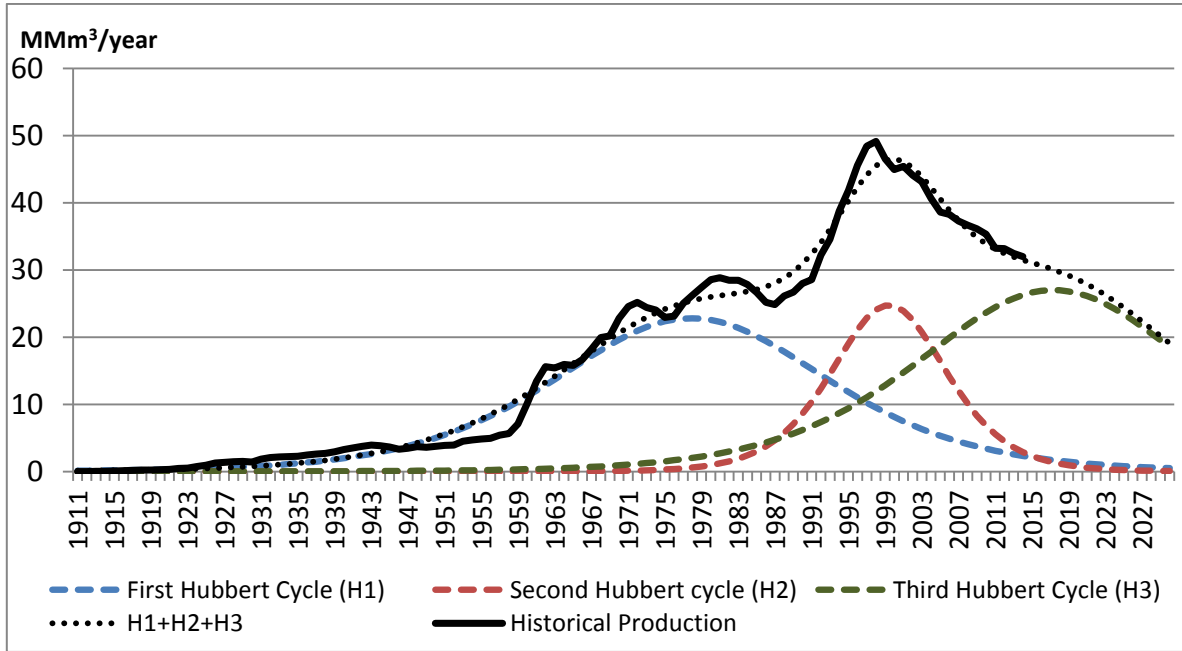


Figure 6. Multi-Hubbert Curve for oil production calculated for Argentina.

Source: Based on (IAPG, 2015b)

As shown in Figure 6, there are three Hubbert cycles that explain the oil production in Argentina. The first one is related to the opening to private oil and gas companies during the 60s and the developments in the Golfo San Jorge Basin (Econlink, 2008; Gadano, 1998); the second cycle is explained by the new cycle of production in the 90s, promoted also by a large amount of concessions to private companies and the market-oriented reforms for the petroleum produced domestically (Vásquez, 2016). Finally, the third cycle reflects the production of EUR of remaining oil.

Both conventional and unconventional non-associated natural gas production were modeled using (Chavez-Rodriguez et al., 2016b) methodology but defining a decline curve for the existing natural gas production capacity. For that, the current production of developed reserves was modelled using an Arps (1945)'s hyperbolic decline curve (Eq. 1).

Eq. 1.

$$q(t) = \frac{q_i}{[1 + b\theta_i t]^{1/b}}$$

Where t is time (years), q_i is the initial surface rate of flow at $t=0$, θ_i is the initial decline rate, b is a constant commonly known as the “Arps” factor. As commented by Adeboye et al. (2011), even for wells that follow exponential decline solutions, the total production decline curve from the reservoir or field is better estimated using a hyperbolic decline model. Values for θ_i of

15% and a b of 0.10 were used based on (Ferioli, 2014)'s production curve for a typical conventional natural gas well of Argentina.

In the case of Argentina, the methodology of Chavez-Rodriguez et al. (2016b) was applied using historical production data of (Secretaria de Energia, 2015a) and reserves data from (Secretaria de Energia, 2015b) for Argentina (Table 2).

In Chile, natural gas is only produced in the far south Magallanes Basin, which has more than 3000 wells drilled since 1945 (Rojas, 2012). In the last years, the state-owned company ENAP in partnership with private companies has increased investments in the region. Nevertheless, the natural gas production is decreasing due to natural declining of the mature plays and disappointing exploration results (ENAP, 2015). In 2013 domestic natural gas production in Chile was 965 MMm³/year (IEA, 2015). However, there are expectations about unconventional gas production. According to a (USGS, 2016)' assessment in Zona Glauconita in the Magallanes Basin there are 2.46 TCF (95% probability). In Arenal block in Magallanes basin, 16 of 24 exploratory wells have had positive results, and in 2014 reached a peak production of 0.5 MMm³/day (ENAP, 2015). Based on unconventional gas production ENAP aims to supply 100% of natural gas consumed in Magallanes region (ENAP, 2014). For the sake of simplicity, current capacity of natural gas production in Chile will be considered as non-associated natural gas and modelled with the Chavez-Rodríguez et al. (2016) approach.

In Chile, there is no official, publicly-available publication listing natural gas reserves. Cedigaz and the Oil and Gas Journal have reported proven reserves of 41 and 98 billion cubic meters for the end of 2013 (IEA, 2015). To be conservative, we have used the values of Cedigaz as the proven reserves and the difference to the Oil and Gas Journal values as probable reserves.

These reserves and resources, along with the F95⁷ undiscovered unconventional resources of (USGS, 2016) (Table 2), and the historical natural gas production in Chile obtained from (IEA, 2015) were inputs for forecasting Conventional Non-Associated natural gas production.

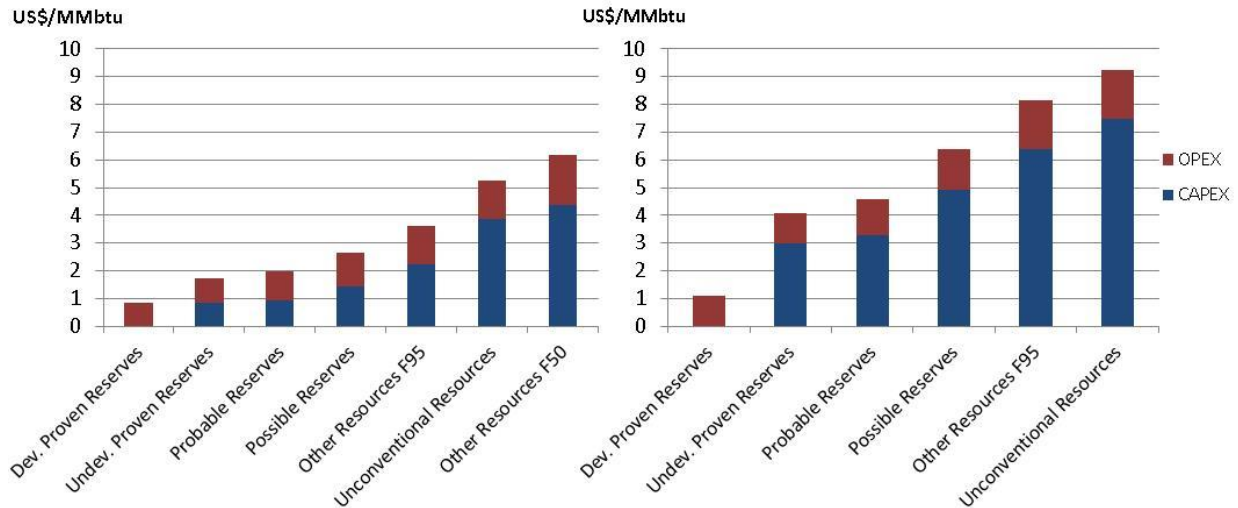
⁷ USGS defines F95 as the fractile of undiscovered resources with at least a 95 percent chance of at least the value estimated.

Table 2. Argentina and Chile natural gas reserves and resources estimated for modeling (MMm3)

Country	Natural gas type	Resources Category					
		Proven	Probable	Possible	Other Resources	Economically Recoverable (Estimated)	Undiscovered F95
Argentina	Associated natural gas	90 874	36 282	24 677	118 291*		
	Conventional Non-associated natural gas	241 297	112 795	120 368	395 675*		
	Unconventional Non-associated natural gas					5 978 256 ⁸	
Chile	Conventional Non-associated natural gas	41 000	57 000	-	42 583*		
	Unconventional Non-associated natural gas						69 458

*Includes Mean Estimates of Undiscovered Conventional Gas of (USGS, 2013)

CAPEX and OPEX for different categories of reserves and resources were made using the same approach of Chavez-Rodríguez et al. (2016). This study also used a “typical field” to estimate CAPEX Development, CAPEX Finding and OPEX costs. However, in order to model it into TIMES, the CAPEX costs were discounted to present value using a discount rate of 10%. Figure 7 shows the break-even costs of the gas divided by CAPEX and OPEX. Costs of associated natural gas have been assumed to be the same as the estimates of developed proven reserves for each country.



⁸ According to (EIA, 2013b) there are 763 TCF of technically recoverable resources of non-associated gas in Argentina . We penalized that estimated value using a correction factor of $\frac{P}{3P+Other\ Resources} = 0.277$, obtained from Argentinian conventional reserves and resources, in order to have a rule-of-thumb economic fraction. The final outcome is 212 TCF (5 978 256 MMm³) that we denominated as Economically Recoverable, which is a more conservative number to work with for unconventional resources.

* Since there are no historical costs available of unconventional gas production in Magallanes Basin, we used those estimated for Argentina but increased Well CAPEX according to the depth⁹.

Figure 7. Nominal natural gas cost estimated for Argentina and Chile according to reserve/resource classification. Source: Own estimations based on Chavez-Rodriguez et al. (2016b); ENAP (2016, 2015), Secretaria de Energia (2015a, 2015c)

A natural gas field, whether non-associated or associated, can have the following hydrocarbons as outputs: crude oil, condensates, natural gas liquids and natural gas. Real cost is made on the facilities and wells themselves, the cost-split into the different products is made artificially ex-post. According to (Smith, 2015) this cost-split should not be made on an energy-basis but on a revenue-basis. Nevertheless, TIMES cost-split relies on shadow prices. As we fixed the condensates, oil and natural gas liquids products prices, the cost attributed to natural gas will be the shadow price to increase the production by a unit.

Due to low costs and high volume of resources and the optimization nature of the TIMES model, preliminary simulations indicate that unconventional natural gas production will satisfy both demand of Chile and Argentina from the first years. This situation does not represent reality, as in the last years despite the unconventional resources exploitation the total output of hydrocarbons in Argentina has been declining, evidencing the real challenge of attracting investments.

In the real world, the capacity to attract investment for CAPEX in the upstream is a constraining factor. OPEX costs do not suffer this challenge as the owners have revenues from production that cover these costs. For instance, in the case of Argentina, oil and gas companies are largely dependent upon economic conditions and the country's institutional framework. CAPEX and OPEX costs are also subject to level of inflation. This does not only constrain the ability to finance and pay the CAPEX planned in foreign currency, but also affects the interest rates because of the risks (Harden, 2014), and companies such as YPF are financing their CAPEX expenses relying on borrowing funds subject to changes in interest rates (YPF, 2016).

Therefore, to address this issue we have elaborated two investment scenarios: A "Low-investment" scenario, and a "High-investment" scenario. The objective of the use of these scenarios is to test how the financial and capital constraints affects the balance of supply and demand in both countries to provide quantitative insights for policy-making in the upstream sector and investment goals.

Investment in CAPEX in upstream worldwide was estimated to have fallen around 40-50% in 2016 when compared to 2014, due mainly to low oil prices (Forbes-Cable, 2016). To capture this fact for Argentina in the model, a decline of 50% was projected in the CAPEX investments for 2016 when compared to 2015 (Secretaria de Energia, 2015c) for both scenarios.

The Low-investment scenario represents a declining in the investments in CAPEX for non-

⁹ For Magallanes Basin we used an average depth of 12000 ft. for "Estratos con Favrella" shale formation (EIA, 2013c), whereas Vaca Muerta shale formation has an average depth of 6500 ft (EIA, 2013b).

associated conventional natural gas projects of 5% from 2016 onwards, and a growth of +10% in non-associated unconventional natural gas projects; this scenario is likely to occur if there is uncertainty for producers about future gas prices rules, continuous conflicts with unions, currency volatility, capital controls, unfulfilled payments to gas producers and lack of upstream industrial capacity. The High-investment scenario represents a recovery of the CAPEX value of 2014 in 2018 and an increase of US\$ 0.5 billion US\$ 2 billion in conventional and unconventional gas resources from 2019 to 2020 and maintaining the same levels of investments in the following years. This scenario attempts to reflect a competitive upstream sector for attracting investments which could be achieved through macroeconomics stability, increases in labour productivity and certainty about gas pricing rules (either market driven or regulated).

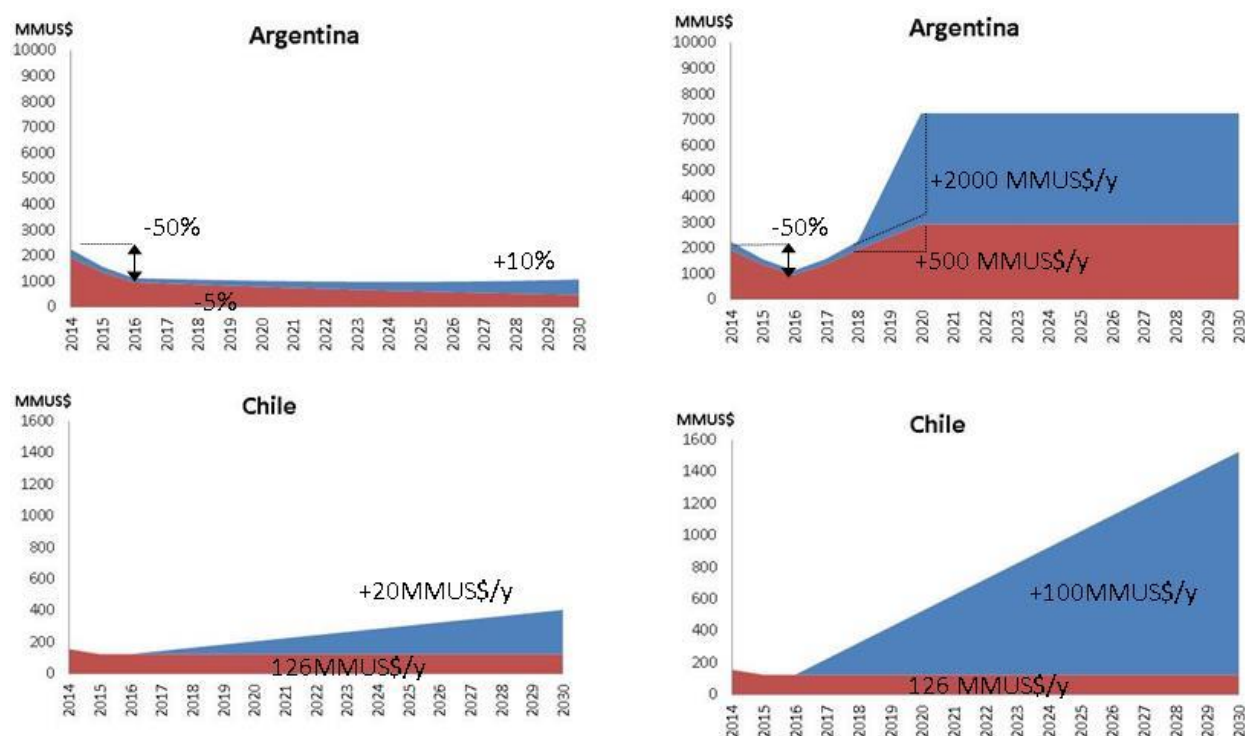


Figure 8. Investments in upstream CAPEX per year in Argentina and Chile: a) Low-Investment Scenario ; b) High- Investment Scenario

2.2.2 Midstream and Trade

Wet gas is transported to the treatment plant containing solid particles (fine sands), liquids (mercury, oil, and natural gas heavy liquids), and harmful gases (CO_2 and H_2S). The objective of a natural gas processing plant (NGPP) is to produce a methane-rich gas and hydrocarbon liquids by removing the acid gases, nitrogen, water, and other impurities (Mazyan et al., 2016). CAPEX of NGPP will depend on the scale, the complexity and location of the plant. As we are not incorporating scale costs we adopted the 27.3 MMUS\$/MMcmd for CAPEX of NGPP. OPEX of NGPP is usually rated on a % of CAPEX costs. It ranges between 1.5% and 4.0% of CAPEX (Petrobras, Santos, 2015). For modelling purposes we adopted an OPEX of 3.0% of total CAPEX.

New NGPP reach a NGL recovery over 99% and ethane recovery over 95% (Costain, n.d.; Huebel and Malsam, 2012; Linde, 2015). For modelling purposes considering the existing installed capacities we adopted an ethane recovery factor of 90% and heavier NGLs of 95%.

Gas trade with other regions was modelled through LNG flows. To model LNG regasification and liquefaction plants, investment costs adopted were 150 US\$/tonne of capacity per year for new regasification projects, 1400 US\$/tonne of capacity per year and 1800 US\$/tonne of capacity per year for onshore and floating liquefaction plants respectively (IGU, 2015). Operating costs were considered to represent 4% of the capital cost per year for both technologies. Based on IEA-ETSAP (2011) losses of 2.5% and 11% were considered for regasification and liquefaction plants, respectively.

Defining LNG prices is a critical issue for the developed model, since it can determine if it is less costly relying on the importation of LNG or tapping the domestic resources to supply the domestic demands. Figure shows the historical average CIF prices of LNG imports in Argentina and Chile from 2010 to the first quarter of 2016. In most of the recent years, Chile benefited from the least average import prices compared to Argentina and Brazil. This is because Chile has long-term “take-or-pay” contracts with its suppliers. As for Chile this is the behaviour expected in the future, the differences of import price values is kept and prices of 2015 are maintained in the future. For liquefaction projects, an export FOB price of 5 US\$/MMBtu is applied over the time horizon.

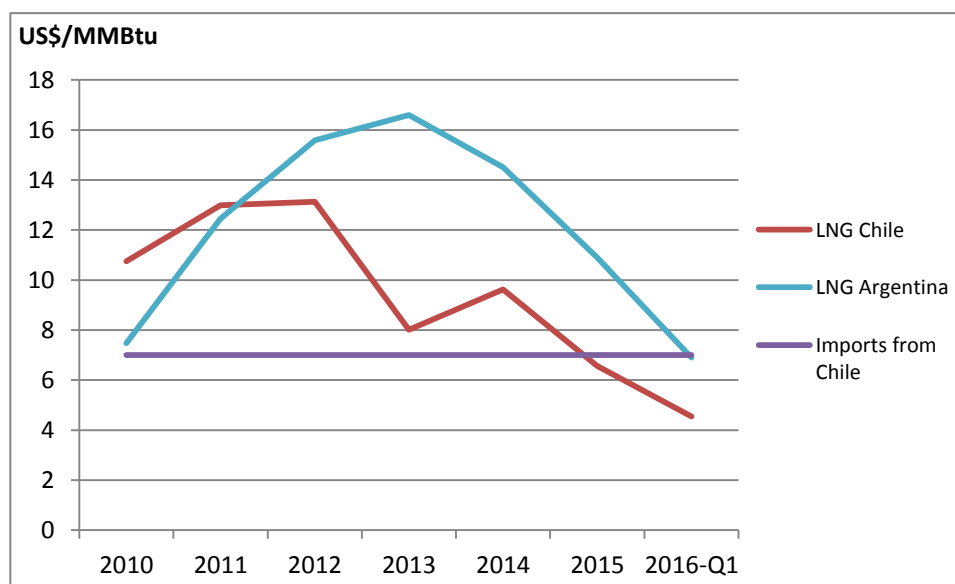


Figure 9. Average prices of LNG imports and Imports from Chile to Argentina through bi-directional pipelines.

Source: CNE (2016); MINEM (2016b)

Gas trade between Chile-Argentina and Bolivia-Argentina were modelled by pipelines. The international gas pipelines constructed in the 90s between Chile and Argentina were modelled using their nominal capacities. Our analysis considers the Gas Andes and Norandino Pipelines reversed but not restricted to their 5.5 MMm³/day contracted in 2016 but to their nominal capacity. A price of 7 US\$/MMBtu was considered for imports from Chile through Gas Andes and Norandino reversed pipelines. The flows between these two countries results of a minimization of the present value cost of the operation and expansion of the energy system in both countries.

Gas flows from Bolivia to Argentina were modelled considering the compliance of the take-or-pay volumes contracted between YPF and ENARSA (YPFB and ENARSA, 2010). For the sake of simplicity we considered an extension of this contract until the end of the horizon of analysis.

2.2.3 Water requirements

In terms of quantity, Argentina has good water availability; however, its distribution is very irregular. WRI (2014) indicates that most of the sedimentary basins are located in areas with semiarid or arid climates, except for the Parana which has more abundant water resources feeding from the Parana River. The most important river systems of Argentina belong to the Atlantic Slope Basin, and most of them are related with the location of the sedimentary basins. The distribution of shale gas is in the Parana Hydrographic System, Colorado Hydrographic System, Patagonicos Hydrographic System (a figure showing the location of the basins can be found in Supplementary Material C).

In order to quantify the water demand for fracking in the production of shale gas in Argentina, the average number of well drilled per month were estimated based on the supply outputs of the TIMES model. We modelled a representative shale gas well using Arps (1945) equation adopting a θ_i of 15% and a b of 1.5 for unconventional gas wells. The water requirements per well is estimated at 1143 m³/day based on a volume required of 8000 m³ for a timeframe of seven days for seven fracking in a period of seven days (see Supplementary Material C for more details). For illustrative purposes this water requirement was converted to a monthly basis to match the temporal resolution of the wells. This approach attempts to highlight the water withdrawal rate instead of the volumes required as the first is more appropriate to assess a possible hydrological stress of the fracking activities. Furthermore, based on WRI (2014), we looked for representative flow gauge stations in the principal rivers of Vaca Muerta and San Jorge plays with the purpose of analyzing the seasonality of the river flow that can be feed the fracking activity (Supplementary Material C).

3. Results

3.1 Domestic production of natural gas

Figure 5 shows the projection of the gross domestic production of natural gas until 2030 on a monthly resolution under the different scenarios analysed. In a Low-Investment Scenario the natural gas production in Argentina declines reaching in 2030 a production of 2700 MMm3/month relying mostly on conventional resources. Current Natural gas 2P reserves (proven+probable) have been compromised already in 2015, and without investment in exploration or economic incentives to producers to turn possible reserves and contingent resources, even developing the Low-Investment Scenario will not be possible. On the other hand, under a High Investment Scenario, unconventional gas is boosted from 2019 onwards representing a production of 2236 MMm3/month in 2030, which means 48% of total gross natural gas production in that year. In this High-Investment Scenario, conventional gas production will start to decline in 2022, and a peak production of total natural gas (including unconventional gas) of 5000 MMm3/month will occur in 2028.

For Chile, both Low-Investment and High-Investment Scenarios result in the same levels of conventional production, namely just tapping the undeveloped proven reserves. The model limited the unconventional resources of natural gas in Chile due to the high-cost considered to tap them and instead preferred to import LNG as the most economic option to supply the natural gas demand.

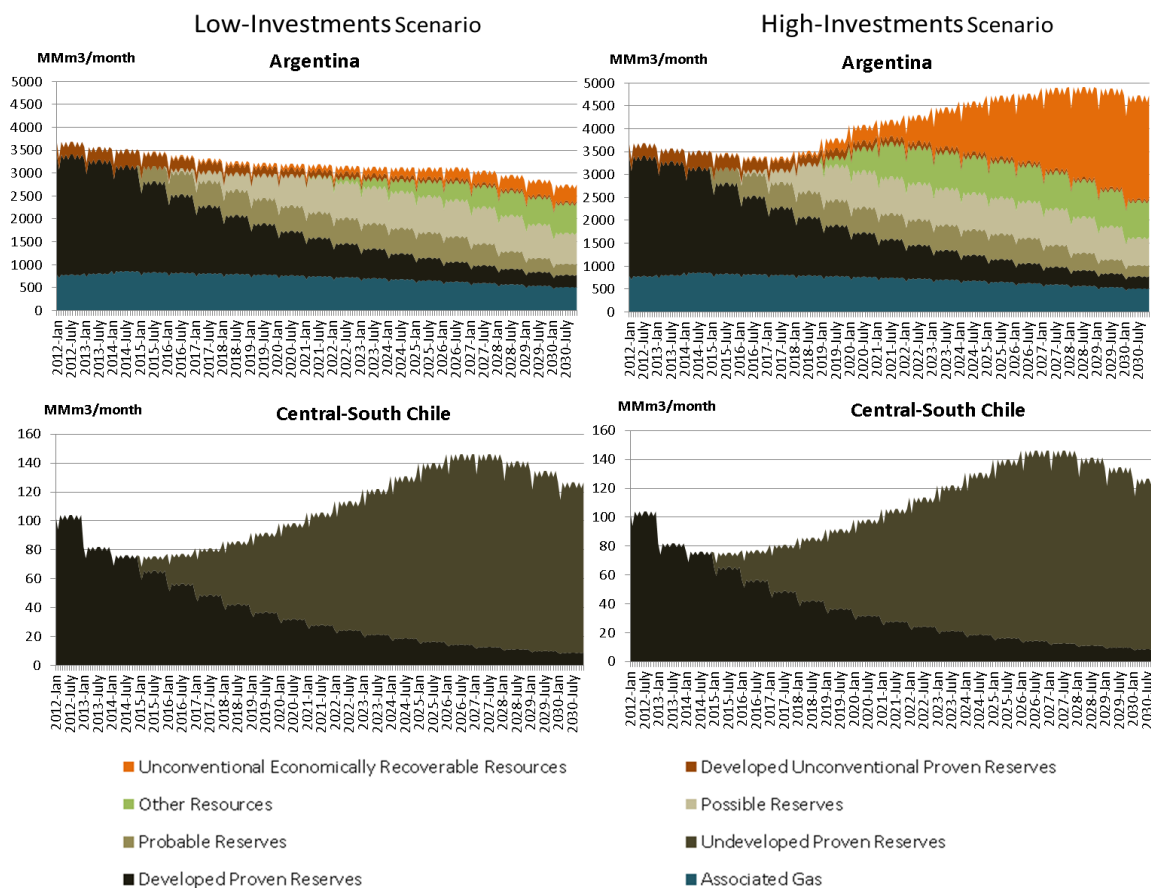


Figure 10. Monthly natural Gas gross indigenous production in Argentina and Chile projected for the different Scenarios analyzed

3.2 Natural gas supply

Figure 11 shows the supply of natural gas to attend the demand either by domestic production, LNG imports or imports through pipelines. In both Scenarios, Argentina will rely on LNG specially to attend winter demands. In a Low-Investment Scenario it will be necessary to increase the regasification capacity in 65 MMm3/d at the end of 2030, which could represent an investment over US\$ 2 billion, whereas in the High-Investment scenario barely 15 MMm3/d of regasification capacity is required.. From an optimal economic point of view, in both scenarios at prices of 7 US\$/MMBtu, natural gas imports from Chile will only be necessary between 2016 to 2019 provided Bolivia could fulfill its exporting commitments, and new regasification plants could be installed from 2019 onwards. Otherwise, imports from Chile will be a contingency solution in the next years. In addition, in the High-investment scenario, natural gas processing capacity is required to expand in 34 MMm3/d, this will represent an investment of around 900 MMUS\$.

For Central-South and North Chile, new regasification units will be necessary in 2022 and 2023 respectively in a Low-Investment Scenario. These expansions of the regasification capacities can be delayed in a High-Investment Scenario where Argentinian exports of natural gas to Chile

substitute LNG imports during summer seasons potentially up to 20 MMm3/d. Despite of this, the regasification capacity required in both scenarios is similar: 18 MMm3/d in Central-South Chile and 2 MMm3/d in North Chile. Interestingly, as extraction costs of Argentinian gas increases over time in our modelling, in the last years of the next decade even in a High-Investment Scenario LNG increases its market share in Chile over imports of Argentinean natural gas.

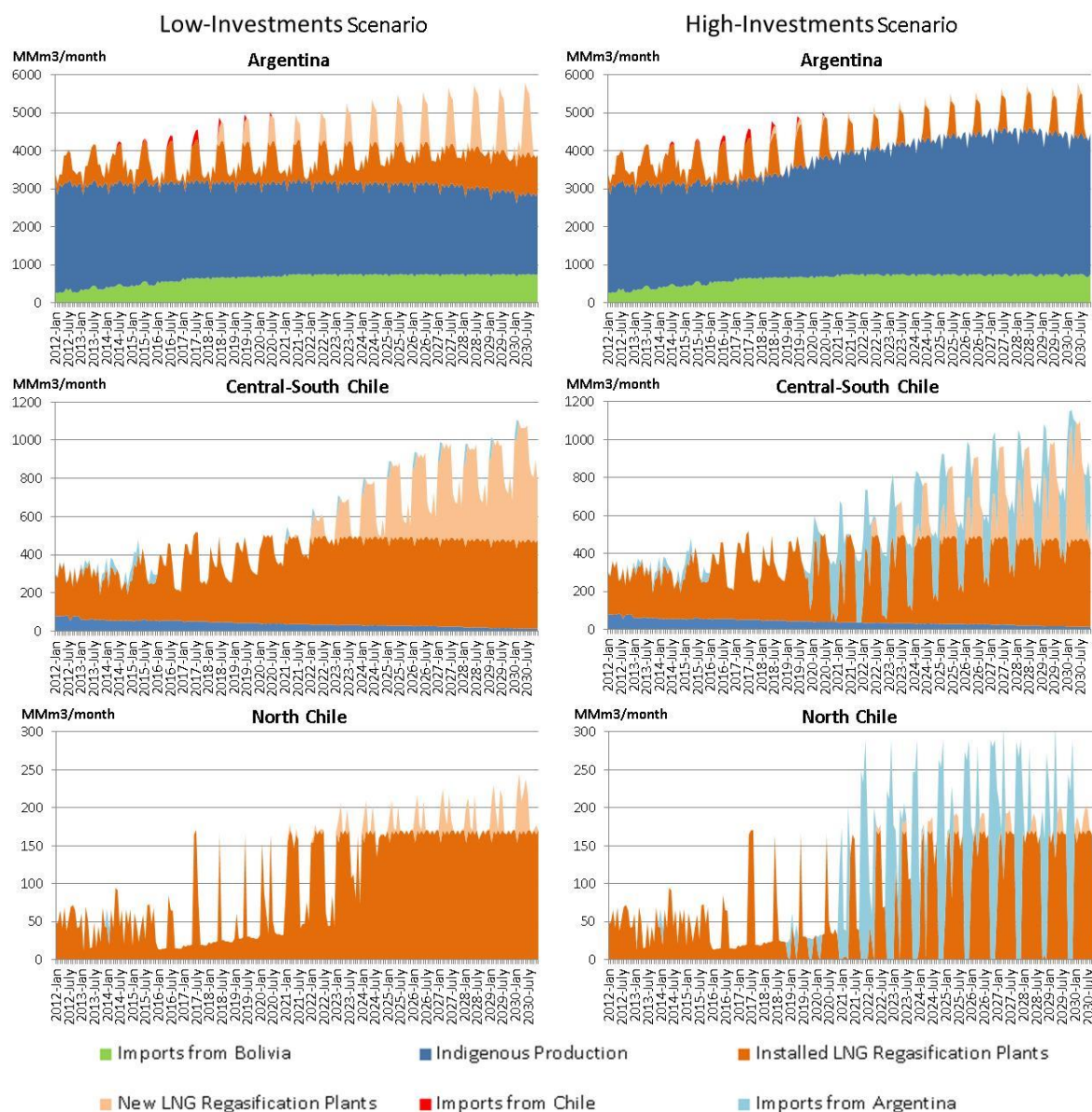


Figure 11. Monthly natural gas supply in Argentina and Chile under the different scenarios

3.3 Natural gas demand

Figure 12 shows the effects of the different impacts of the scenarios assessed on the demand. In

Argentina, in both scenarios the demand of natural gas in power generation remains the same. However, a higher capacity of investments in upstream allows Argentina to retake its exports to Chile and Brazil in the summer season, in order to maintain the indigenous production levels at nominal capacity. In Chile, natural gas consumption in power increases slightly under a high-investment scenario, mostly in the North Chile region, where combined cycle plants based on natural gas operate to send electricity to the Central-South Region (Supplementary Materials A). It is observed also in Figure 12 that 2017 will be the year with the highest exports from Chile to Argentina through the bidirectional pipelines, with shipments of 150 and 250 MMm³/month from North Chile and Central-South Chile to Argentina respectively during winter.

The natural gas seasonality in the consumption of residential and commercial and public services sectors shows that in, in both countries, the industrial sector will lead the consumption of natural gas. In terms of relative growth of total consumption, Chile (Central-South+ North Chile) is projected to have an 11.5% of growth rate per year, from 4 MMm³/d in 2012 to 27 MMm³/d in 2030, and Argentina 2.0%, from 90 MMm³/d to 222 MMm³/d for the same period.

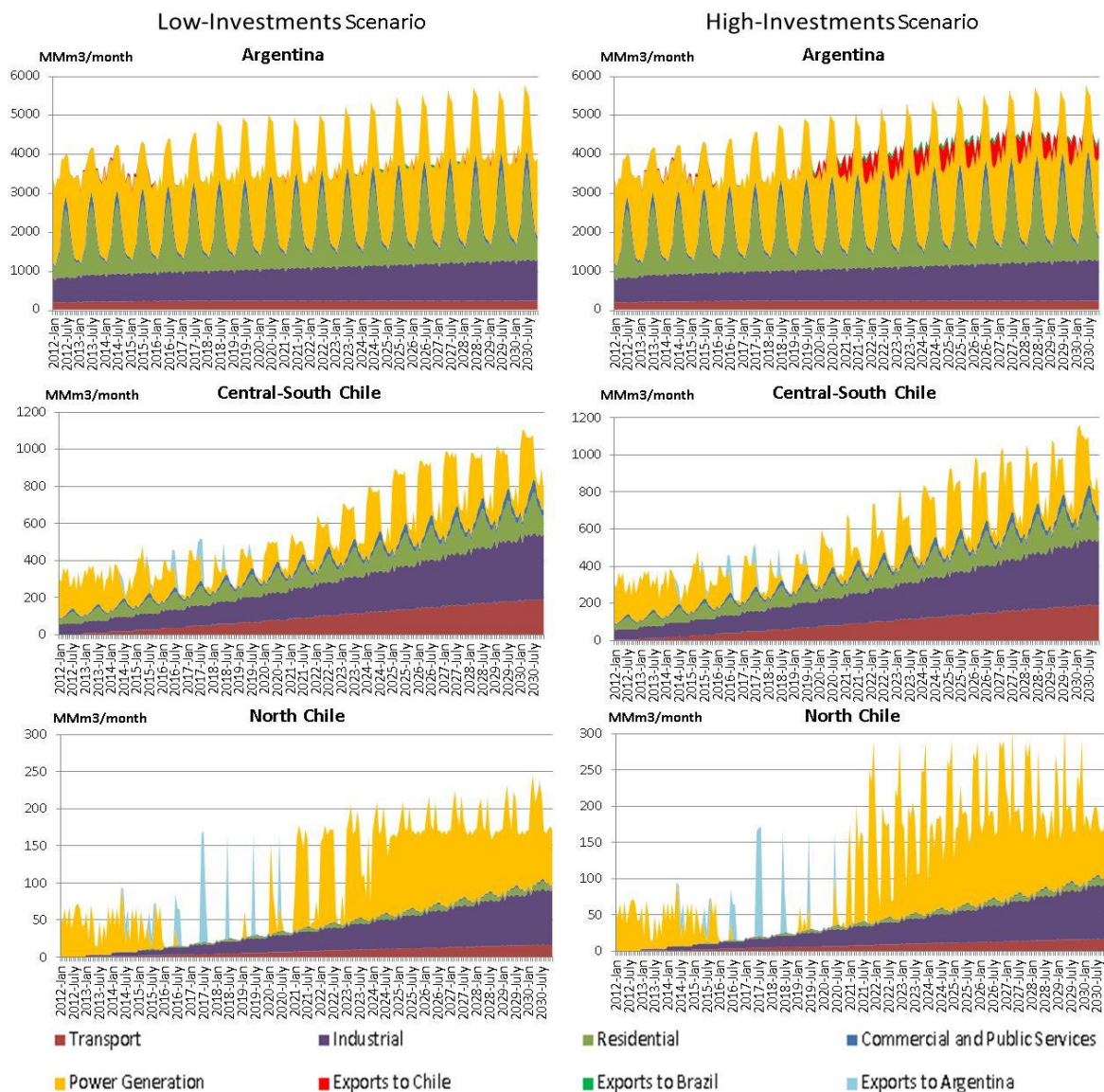


Figure 12. Monthly natural gas Demand in Argentina and Chile under the different Scenarios

3.4 Water constraints for unconventional gas production in Argentina.

The numbers of drilled wells per month and the average rate of water consumed for fracking activities were projected in Figure 13 for each investment scenario. As observed, a High-investment scenario would result in a drilling rate of around 17 wells per months in the last years of the next decade. This results in an average water consumption rate of 0.6 million m³ per month (nearly 0.2 m³/s). Neuquen River is one of the main source of water for fracking activities in Vaca Muerta play. March is the month with lower flows of this river, and the minimum historical flow registered¹⁰ is 64 m³/s. This means that fracking activities in the high-investment scenario, assuming all drilling

¹⁰ Considering the “Paso de Indios” and “Senguerr” flow gauge station for Vaca Muerta and San Jorge respectively (SRH, 2016) (See supplementary material C).

activities are concentrated in Vaca Muerta, would represent 0.3% of the water available in the driest month.

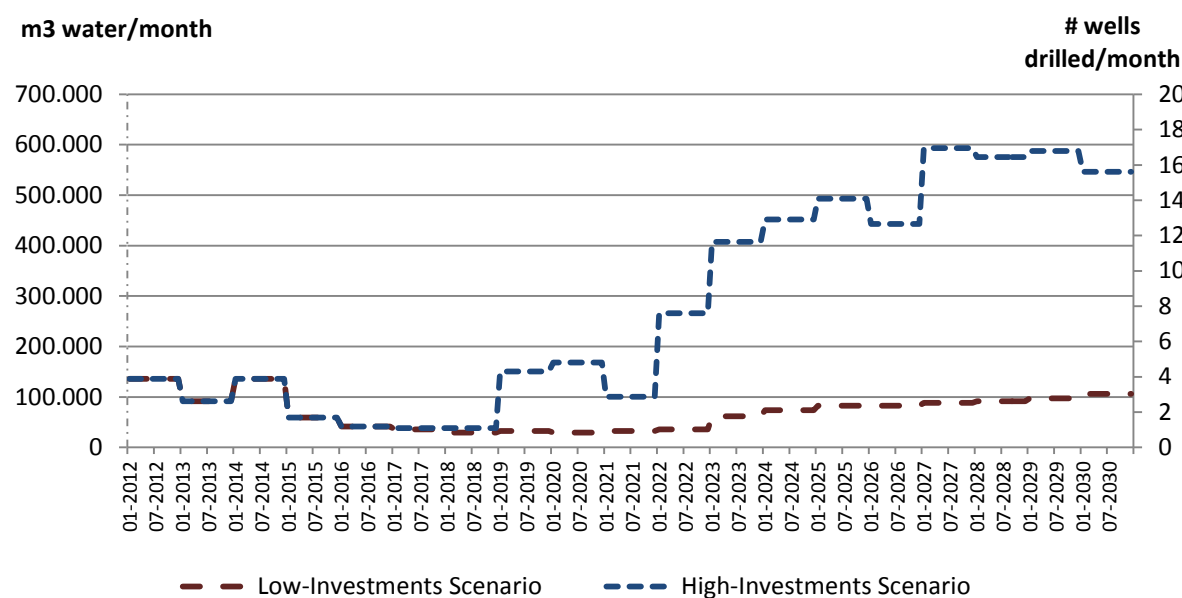


Figure 13. Average wells drilled per month according the investment scenarios and water demands for fracking.

With the methodology used it is not possible to estimate the distribution of wells shown in Figure 13 among the sedimentary basins of Argentina. Nevertheless, it is unlikely that San Jorge shale formation will have the same drilling rates as Vaca Muerta, where most of the planned investments are focused. However, if 17 wells per month are drilled in San Jorge, this would demand around 2% of the minimum water available registered¹⁰ in March (the driest month) of the Senguer River, the nearest river to the San Jorge shale formation. This comparison is just to have an order of magnitude of the possible water demand of shale gas activity in Argentina. To determinate potential water stress, a more robust study is necessary, one using a water balance methodology that includes other water uses into the equation.

The analysis of water seasonality indicates the most favorable seasons for fracking activity during a year, to minimize water use conflict, and to avoid possible water stress. In Vaca Muerta play, more water is available during the summer and spring seasons in the area of Rio Colorado watershed. In the watershed of Rio Neuquén, winter and spring seasons have more water available. The San Jorge play shows small observed flows. It could have more water stress problems during the summer and fall seasons. Furthermore, it could face increasing costs because of the necessity of water supply from other areas. A detailed description and results of the seasonality of each flow gauge station can be found in Supplementary Material C.

In terms of quality, onshore oil and gas resources in Argentina are governed by provincial

governments in their own territory; also, water is primarily regulated by the provincial government. Neuquén government established a regulation (Decreto 1483/12) related to the obligation of the wastewater discharge treatment (fracking flowback) and the prohibition of the use of the groundwater intended for water supply and irrigation uses. In addition, Neuquén sedimentary basin covers the provinces of Neuquén and parts of Mendoza, Rio Negro and La Pampa (Vaca Muerta play is located in the provinces of Neuquén and Mendoza). Not mentioning the location of the other sedimentary basins in each province suggests a loophole, indicating the need for more robust regulations for protecting water quality.

4. Conclusions

The analysis performed in the previous sections shows that for Argentina there are great benefits waiting to be materialized from the development of its large unconventional natural gas resources, which according to our estimates could represent half of Argentinian gas production in 2030. If the country succeeds in creating and enabling business environment which allows for the needed investments in natural gas exploration, production and infrastructure to happen, unconventional natural gas resources will substitute LNG imports at a lower cost. In a high investment scenario in Argentina, Argentina will rely on natural gas imports from Chilean LNG terminal only to cope with short term deficits, during the periods of peak demand and only up to 2020, and from 2020 on LNG will be used only to satisfy that extra demand from peak period. However, if a low investment scenario to develop unconventional resources in Argentina prevails, from 2020 on, domestic natural gas resources in Argentina will be substituted with additional LNG imports, using its current and new LNG infrastructure facilities.

In Chile, LNG is expected to keep playing a key role in the natural gas market, where, in a low investment scenario in Argentina, minor natural gas imports from Argentina are used to cope with peak natural gas demand in the Central South part of the country. However, in a high investment scenario, Argentinean gas from unconventional sources will displace LNG imports from current and new LNG plants in Chile in the summer season, and that will happen in the Central-South part as well as in the North part of the country, and these will take advantage of the current infrastructure of pipelines that exists between Argentina and Chile. In this sense, it is pivotal to establish a regulatory framework that enables this bilateral trade.

As the modelling exercise performed in this study shows, natural gas consumption is expected to increase in both Argentina and Chile. In Argentina, local gas supply from unconventional sources, can play an important role. How big that will be will depend on how successful the Argentinean economy is in creating an enabling investment scenario that brings the large investments for CAPEX needed to develop its unconventional natural gas resources, estimated to be in over US\$ 50 billion accumulated from 2017 to 2030 according to the high-investment scenario simulated. If Argentina succeeds, LNG will be a complement to satisfy spikes during peak demand periods. If Argentina does not succeed in attracting the needed investments to develop its rich unconventional natural gas resources, imported LNG can represent up to 45% of natural gas consumption in the country during the peak demand period, requiring 65 MMm³/d of additional

regasification capacity by 2030. . The high-investment scenario will result in 17 new wells per month in the last years of the next decade. This drilling rate will require a water offtake rate of around 0.6 million cubic meters per month. This amount represents only 0.3% and 2% of the main rivers' flow in the driest month of the year for Vaca Muerta and San Jorge shale formation, suggesting no water constraints in terms of volumes. However, further robust studies to assess hydrological stress using a water balance methodology are suggested, which could take the water demand for fracking activities estimated in this paper as an input.

In Chile, imported natural gas as LNG is expected to be the base source of natural gas to cope with the country needs, and where natural gas imported by pipes from Argentina will be an efficient energy source during summer with potential imports up to 20 MMm³/d. However, Argentinian gas flows to Chile will play a complement role to LNG imports.

For Argentina and Chile is expected a brilliant future for the use of natural gas in the region, from different sources but with complementary solutions, in an environment of increasing demand of gas for both countries. In a high investment scenario in Argentina, which is possible given today's economic and political situation of the country, Chile re-emerges as a net importer of Argentinian gas. But, Chile is likely to not compromising its energy security, as is expected that the country will expand even further its imports capacity of LNG. The existent pipelines infrastructure between Argentina and Chile enables complementarities between the energy systems of both countries to have a more optimized use of Argentinean unconventional gas and LNG facilities and Chilean LNG facilities, with a more efficient energy system which can benefit them.

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