UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE
ELECTRIC POWER INDUSTRY

Master's Thesis

LNG TO POWER: LNG AS A KEY DRIVER FOR NEW POWER GENERATION PROJECTS IN DEVELOPING MARKETS

Author: **Milena Plazinić**

Supervisor: **Pablo García Arruga**

Madrid, July 2015

INSERT: AUTHORISATION OF THE SUPERVISOR

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Summary

Global gas companies have commercial departments specialized in finding new markets suitable for future sales of Liquefied Natural Gas. The process of creating a contract for a potential counterparty asks for thorough examination of the country, regulation, and its gas and power system and estimation of the potential demand. After the decision has been made that the counterparty is a country reliable for this kind of business and that the demand is sufficient, gas companies struggle with defining the price of LNG that would be competitive for this market. They need to make series of decisions, including the supplying region which will be used. This is a crucial factor for determining analyzing the costs of providing LNG to a particular region and the final price that will be offered.

This master thesis firstly introduces the reader with Power, Natural Gas and LNG industry and their interconnections. It provides current and historical overview as well as future projections. The main focus of this part is LNG Industry, precisely LNG Value Chain, it's theoretical explanation as well as global market overview that include current trends, graphical representations that are the best way for a reader to understand that LNG plays a significant role in global gas supply as well as in power generation projects and that this role will be strengthen in following years due to the innovations in the sector. Second part is focused on the analysis of three countries which are considered to be suitable markets for LNG-to-Power projects. These countries were analysed in the following way: firstly country overview is given, followed by power sector analysis with focus on thermal generation and current fuel supply. An estimation of demand for LNG was made and the regulatory framework closely related to LNG was done. Ending refers to estimation of costs and analysis of costs vs. electricity or competing fuel prices. This has an aim of helping LNG suppliers when deciding on the proposed price for which they would offer LNG to a potential buyer.

This framework is an original work and it can be used for analysing other markets for the sales of LNG.

Abbreviations

Bbl – Barrel
Bcm- Billion cubic metres
Btu – British Thermal Units
FSRU – Floating Storage and Regasification Unit
GWh – Gigawatt-hour
LNG – Liquefied Natural Gas
kWh – Kilowatt Hour
MMBtu – Million British Thermal Units
MMSCFD – Million Metric Standard Cubic Feet per Day
Mtpa- Million tons per annum
MWh – Megawatt hour
Tcm – Trillion cubic metres

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1. Introduction

1.1. Motivation and Objectives

This master thesis is the final work produced as a result of both two-year Erasmus Mundus Joint Master of Economics and Management of Network Industries (EMIN) under the supervision of Dr. Javier García González, associate professor at Instituto de Investigación Tecnológica (IIT) and five-month long internship in company Gas Natural Fenosa, in the department of Global Gas and LNG under the mentorship of Pablo García Arruga, a Senior Marketing Manager in charge of Iberia & Mediterranean region in the department of Global Gas and LNG.

The focus of the Master during both years and especially the second one which took place at Universidad Pontificia Comillas, Escuela Técnica Superior de Ingeniería (ICAI), was on the Electric Power Industry. Among all the courses we had that covered technical, economical and strategic aspects of the industry, I got particularly interested in topics related to how the electricity markets in different countries are organised. First practical encounter where I needed to analyse power system of one country, was during the course of regulation, for which I have chosen power system of Russian Federation. When choosing the topic for my master thesis, I wanted to do something similar. Thus, the idea proposed by the company Gas Natural Fenosa and my mentor, sounded tempting.

It required knowledge of power generation, as well as general market research and strategic planning skills, which are also part of my bachelor studies (Management at Faculty of Organizational Science, University of Belgrade) as well as the first year of master at the Université Paris-Sud XI. The additional knowledge that was obtained in the company was related to natural gas as a product, and in particular – liquefied natural gas. All of this was afterwards used in the analysis of developing markets, possible importers of LNG.

Why natural gas?

Natural gas has been a significant impulse for the development of the Electric Power Industry.

Firstly, natural gas is a hydrocarbon with the greatest amount of reserves, guaranteeing sustainability of energy projects associated with this fossil fuel. Secondly, it is a fossil fuel with lowest emissions of greenhouse gasses (GHG), which makes it a non-renewable technology most respectful to the environment. Furthermore, natural gas is cheaper than the rest of the liquefied petroleum gasses (LPGs) and due to this its efficiency when compared to other fossil fuels is higher and it is the quintessential substitute. Last, but not least and as a conclusion of everything previously mentioned, the simplicity of the operation and maintenance of natural gas make this fuel ideal for substitution of other fossil fuels like coal, fuel oil and gasoil.

The development of developing (emerging) countries is followed by the increase in the electricity demand, which as a consequence has introduction of new projects for power generation. In these projects of origination or expansion various technologies are contemplated (gas, coal, renewables and to a lower extent hydro and nuclear). Apart from building new plants, it is also considered converting existing plants which are using as fuels fuel oil and diesel. In this case, natural gas plays a significant role.

In order to access natural gas, some countries are constructing immense pipeline infrastructures which would connect them to countries that are producing gas. Yet, in many cases, these kinds of projects encounter difficulties for many reasons. Firstly, the location of supply could be very distant from the importing country. Secondly, if the pipeline crosses over various countries, there has to be an agreement with all of them for the necessary transit. Another important issue are the funds; these projects can be very expensive. Also, other obstacles might occur, including different geopolitical tensions that make the project impossible.

In these cases, liquefied natural gas (LNG) represents a reliable, secure and economic alternative for the development of gas supply projects. Evolution of LNG has come to the stage where since more than a decade, a great number of power generation projects have been designed and constructed together with a terminal for regasification and more recently often with a so-called “Floating Storage and Regasification Unit” – FSRU.

Main objective of this master thesis that was done in company Gas Natural Fenosa, using their resources is examining the importance of Liquefied Natural Gas for emerging markets. In these markets, the focus is on Power Generation projects. The analysis is not strictly company-oriented; it represents an analysis for any LNG supplier. This main objective is organized around three smaller objectives:

1. Update of databases in Gas Natural Fenosa with current LNG market trends
2. Development of a report of LNG-to-Power contracts/prices in the mid/long term in the chosen developing markets
3. Building a framework for LNG-to-Power projects analysis of other potential developing markets.

1.2. Scope of the Problem

This master thesis will deal with the most important features of LNG industry as well as the current trends, especially the ones that are supply/demand or market-oriented. This part provides market guidelines for global gas companies in LNG business. A suggested framework for the analysis of developing markets was provided and three different countries were analysed using this methodology.

1.3. Company Overview

Gas Natural Fenosa (GNF)

Industry: Natural gas utility
Founded: 1991
Headquarters: Barcelona, Spain
Chairman: Salvador Gabarró Serra
CEO: Rafael Villaseca
Products: Supply, distribution and commercialisation of natural gas, electricity generation and distribution.
Website: www.gasnatural.com

“Gas Natural Fenosa is a leading group in the energy sector, pioneering in gas and electricity integration. It is currently present in more than 25 countries, where it offers service to more than 20 million customers on the five contents, with 15,4 GW installed power and a diversified mix of electricity generation. Following the acquisition of the electricity company Unión Fenosa, the third largest in the Spanish market, Gas Natural Fenosa has achieved its objective of integrating the gas and electricity businesses in a single company with extensive experience in the energy sector, capable of competing efficiently in markets subject to a process of increasing integration, globalisation and levels of competition.” (Gas Natural Fenosa, 2015)

Facts about the company:

- The first and largest integrated gas and Electricity Company in Spain and Latin America.
- The third largest utilities company in the Iberian Peninsula.
- Leader in gas commercialization in the Iberian Peninsula.
- Leading natural gas distribution group in Latin America.
- One of the leading liquefied natural gas operators worldwide and a key operator in the Atlantic and Mediterranean basins.

GNF began its activity in Barcelona in 1843 bringing public lighting to the city streets for the first time. Today, more than 170 years later, almost two centuries later, and after more than a half century in the LNG business, this same innovative spirit continue to drive the company towards new opportunities.

In the early 90s, GN began expanding abroad staring with Latin America, which was then further developed by an increased presence in the power sector in 2000.

The company as it is known today was created in 2009 following the merger between the third largest electricity company in the Spanish market, GN, and one of the four largest electric company, Union Fenosa.

Following this acquisition, Gas Natural Fenosa has achieved its objective of integrating the gas and electricity businesses in a single company with extensive experience in the energy sector, capable of competing efficiently in markets subject to a process of increasing integration, globalization and levels of competition.

In more recent years, GNF has continued to be active in the LNG and NG market, increasing the volume and diversity of its portfolio. GNF has signed agreements with Chenier for the off take of 3.5 mtpa from Sabine Pass Train 2 and 1.7 mtpa from Corpus Christi Train 2. It also signed a supply contract with Medgas, Sahah Deniz and Yamal. GNF is now also operating in the Chilean energy market after successfully concluding a takeover bid for Compañía de Generación de Electricidad, SA, the leading power company in the country.

GNF has transformed the energy sector in Spain and diversified its business portfolio to become the leading integrated gas and electricity group, and has expanded its activity throughout the world. This international expansion process has been unstoppable up to the point of reaching more than 25 countries worldwide, including Australia, South Africa, Oman, the Dominican Republic, Guatemala, Belgium and Germany. Today, Gas Natural Fenosa provides service to more than 20 million customers on the five continents, with 15,4 GW installed power capacity and a diversified mix of electricity generation. GNF is a leading company in the gas and electricity sector in Spain and Latin America and is the main supplier of liquid natural gas in the Mediterranean and Atlantic basins. GNF’s rich history and diverse experience allows it to be both a reference player in the global LNG trading space and to understand the needs of our customers as end users and at the same time, to manage an integrated gas & LNG platform to compete globally. GNF has expertise in power generation, electricity and gas distribution, NG and LNG infrastructure and sales, regasification capacity, and coal mining.

GNF operates in 10 European countries (including Spain), 12 countries in The Americas, 7 in Africa and 7 in Asia & Oceania. In Asia, GNF has established itself as a stable and reliable player through its term contracts in Japan, Korea and India.

1.4. Methodology and References

The methodology that was used in the thesis consists of:

- Corporate learning about the natural gas sector as a product and its use for power generation
- Corporate learning about the international markets of natural gas/LNG
- Access to corporate documentation and analysis of upcoming global LNG to power projects
- Power generation production costs analysis in order to get a netback price of LNG
- Searching for the indicators of electricity prices that would enable setting an LNG reference price

The references (bibliography) that was used in the thesis is:

- Training provided by the mentor
- Company information and publications
- Publications on markets of energy/gas sector (Platts, Argus, etc.)

2. State of the Art

In order to approach writing of my master thesis, first step was to do investigation of the examples and cases studies on how some European countries did implementation of the LNG in their power systems. Best example that had have influence on my work is the Spanish experience, explained in the paper “Power and Gas integration” written by assisting professor Ernesto Parrilla, from Universidad Pontificia Comillas (ICAI). Due the high demand and isolated geographical position, and taken into account that at that moment there were significant investments in CCGT plants, the best solution for Spain was building a large number of regasification plants and introducing LNG. Regasification terminals that were built worked on principal “Just-in-Time” and “Just in place” To build this kind of regasification terminal was really expensive and required good contracting and extensive planning. “Just-In-Time” means that consumption of the LNG by customers was happening immediately after LNG are loaded in regasification terminals. Due the fact that Spain didn’t have so much gas storages developed this meant that regasification terminal can’t have full stocks in regasification plant. If shipper can deliver his LNG he could clam penalties. “Just-in-place” was happening because of infrastructure problem that was described in section II D of this paper. The problem was that some power generation companies could only consume gas by one entrance. As a final remark of his work, assistant professor Ernesto Parrilla concluded that LNG enables Spanish shippers and companies to play an international role in Gas Delivery and to sell it on international market. In this Master Thesis we will read about this, and how to approach emerging markets by using new solution for regasification process which will not have such high starting infrastructural cost, like traditional regasification plants that exist in Spain.

In the paper “Technology options for securing markets for remote gas” that was published in “Proceedings of 87th Annual Convention of the Gas Processors Association (GPA) 2008 (November).” by Davide Wood, Seid Mokhtab and Michel J. Economides they were mentioning that only on close distance we should have pipeline as transport option for LNG. For long distance we should use LNG option, transported in LNG vessels. In order to avoid “Just-in-Time” and “Just-in-place” that Ernesto Parrilla described in his work they propose that regasification station is built on the boat that will receive transporting gas and do regasification on the boat. This will not have high infrastructural cost for building regasification station in country where infrastructure exists. In the beginning price for building this kind of solution was $250 million, according to this paper. However six year later technology advanced and cost for building these solutions are much lower. In this work we will exactly focus on specific emerging markets for which we should use this kind of solution.

Name of this solution if FSRU (Floating Storage and Regasification Unit). ‘’FSRU is a monohull floating terminal where the LNG is received, stored, vaporized and exported to the onshore gas distribution network. Use of such a unit avoids dredging and construction of port facilities and allows shuttle tanker operations to be kept away from congested waters.’’ (Giovanni Scarpa, Mario Dogliani, Andr Ducert). In the paper “LNG Receiving Terminal: The floating alternative” Giovanni Scarpa, Mario Dogliani, Andr Ducert we can find detailed technical description of the solution with different kind of analysis. At the end paper emphasizes that The FSRU concept is therefore shown to be an attractive alternative to conventional onshore terminals:

- when it is difficult to locate the plant in environmentally sensitive shore areas

- for an early start of a new market, where FSRU could be relocated once the permanent facilities have been constructed and come on stream.

In Paper "LNG in South America: the Markets, the Prices and the Security of Supply" written by Luiz Augusto Barroso, Senior Member, IEEE, Hugh Rudnick, Fellow, IEEE, Sebastian

Mocarquer, Member, IEEE, Rafael Kelman and Bernardo Bezerra they described why South America should use LNG, also they described the markets, new prices and their implication on the gas and electric power market and security of supplies. In this master thesis we also cover all of these topics starting from the high level explaining why we should use LNG in the first place for new power projects to concrete description of specific markets and the integration of LNG in them. They also analyse Brazil and Chile separately by presenting facts about LNG market in those countries presenting business model for LNG, analyzing challenges from price and infrastructural point of view and. This was foundation to prepare analysis for emerging markets in this paper and enhancing it with Regulatory framework for each country and adding model for completive LNG price suggestion.

Each literature had impact on this master thesis. As it is mentioned starting from case study how LNG was implement, going to possible technical solution which will optimize the cost and providing model how to analyze each market.

3. Power Generation

3.1. Fossil Fuels for Power Generation

Fossil fuels are formed by natural processes, remains of plants and animals, including phytoplankton and zooplankton buried deep inside sedimentary rocks for millions of years. (Drbal, 1996) Term fossil fuel also includes natural resources that contain hydrocarbon but are not acquired from animals or plants. All the fossil fuels are of an extreme importance to the mankind due to their characteristic to produce significant amount of energy when burned. They are resources that are considered to be non-renewable since with the rate of current exploitation and constant increase in the demand, the available reserves are decreasing and the reserves will be exhausted very soon. This is one of the main reasons why other, renewable sources of energy have to be analysed and considered.

The other reason is the fact that during the process of energy production, these fuels are emitting so-called greenhouse-gasses (GHG). Greenhouse-gasses (GHG) have an influence on increasing the temperature on the Earth due to the reflection of radiation that the Earth emits. Further, this has the influence on the weather, causing irregular patterns in the weather changes, so called "climate changes''. GHG also have negative effect on the health of the population. The most important GHG gas, emitted when burning fossil fuels is carbon dioxide (CO2). Apart from it, there are Sulphur dioxide (SO2) and Methane (CH4). Power generation companies are charged for the emissions of GHG.

Classification of fossil fuels is:

- Petroleum (Oil)
- Coal
- Natural gas

Petroleum (Oil) is the primary energy source in the world.

"Petroleum, from Medieval Latin petroleum is a naturally occurring, yellow-to-black liquid found in geological formations beneath the Earth's surface, which is commonly refined into various types of fuels. It consists of hydrocarbons of various molecular weights and other organic compounds. The name petroleum covers both naturally occurring unprocessed crude oil and petroleum products that are made up of refined crude oil. A fossil fuel, petroleum is formed when large quantities of dead organisms, usually zooplankton and algae, are buried underneath sedimentary rock and subjected to intense heat and pressure." (Wikipedia, 2015)

The process of recovering oil starts with geological study of the area in which it is assumed to contain reserves. Apart from this, there are studies of the basin, reservoir characterisation. After this, the extraction through oil drilling takes place. Large number of products is produced from petroleum by refining processes. Petroleum products are: gasoline, kerosene, asphalt, chemical reagents. Products that are most common are fuels. Common fraction of petroleum as fuels:

- Liquefied petroleum gas (LPG)
- Butane
- Gasoline
- Jet fuel
- Kerosine
- Fuel oil

- Diesel fuel

In this master thesis special attention will be given to diesel and fuel oil since they are petroleum products used for power generation and could be substituted with natural gas in some of the cases.

“**Coal** is a combustible black or brownish-black sedimentary rock usually occurring in rock strata in layers or veins called coal beds or coal seams. Coal is composed primarily of carbon along with variable quantities of other elements, chiefly hydrogen, sulfur, oxygen, and nitrogen.” (Blander, 2014) It provides 40% of global electricity needs. It is primary and the source of power generation and the fastest-growing source of energy. Between 2000 and 2012 its global consumption had 60% growth. This growth is especially notable in OECD countries. Projections by International Energy Agency are that it will have a downward trend in the following years, due to the exhaustion.

“Natural gas is a fossil fuel formed when layers of buried plants and gases are exposed to intense heat and pressure over thousands of years. The energy that the plants originally obtained from the sun is stored in the form of chemical bonds in natural gas. Natural gas is a non-renewable resource because it cannot be replenished on a human time frame. Natural gas is a hydrocarbon gas mixture consisting primarily of methane, but commonly includes varying amounts of other higher alkanes and sometimes a usually lesser percentage of carbon dioxide, nitrogen, and/or hydrogen sulfide. Natural gas is an energy source often used for heating, cooking, and electricity generation. It is also used as fuel for vehicles and as a chemical feedstock in the manufacture of plastics and other commercially important organic chemicals.” (Wikipedia, 2015)

Natural gas represents a transition fuel from carbon intensive fossil fuels. For the power industry, it is certainly a cleaner way of producing electricity for numerous economic, operational and environmental reasons. Significant amount of fossil fuels is used for electricity generation, with expected growth of usage of natural gas in following years.

Apart from scarcity, on-going concerns when it comes to fossil fuels are carbon dioxide (CO2) emissions and the influence these gasses have on the climate. Carbon intensive fossil fuels are coal and oil. Natural gas emits significantly lower amount of CO2.

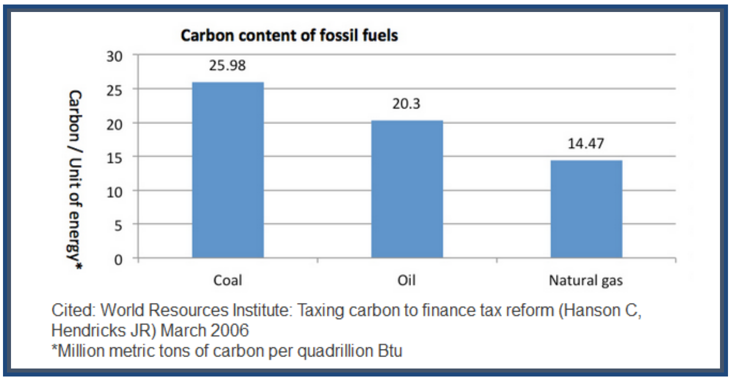


Chart 1: Carbon Dioxide Emissions from Electricity Generation from Fuel Type, (EIA, 2010)

Analysing power sector generally, we can see that the share of power generation in the primary energy usage is increasing constantly, and according to the projections made by British Petroleum, it will continue to grow. Looking precisely at the share of fossil fuels in the global generation mix was we can see that it has a significant share which in 2013 amounted for 68,5%.

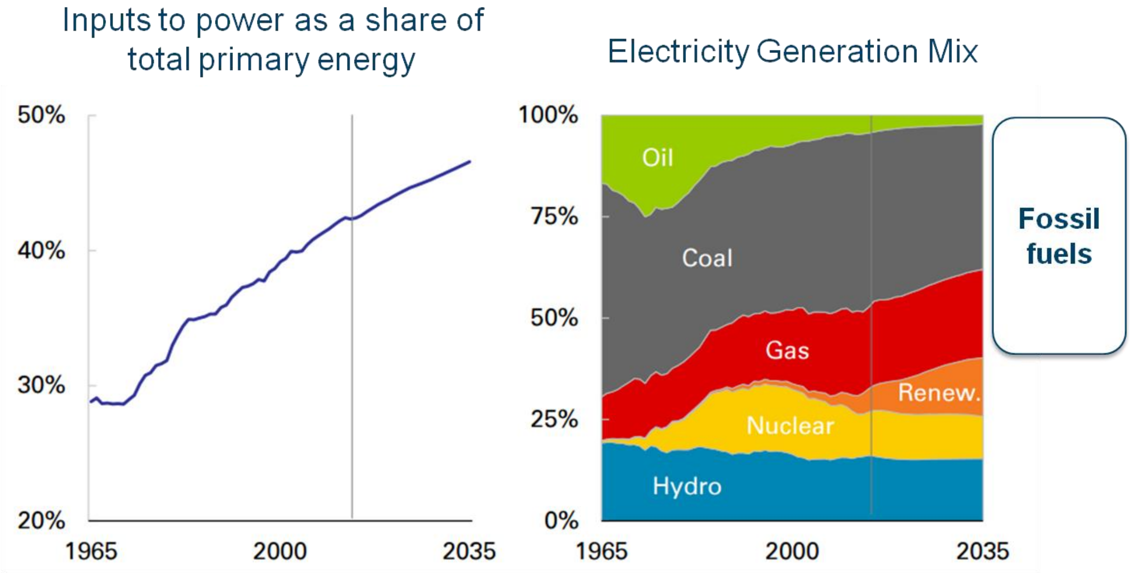


Chart 2: Outlook: Inputs to power as a share of total primary energy; Electricity generation by different fuels (Compiled based on data from British Petroleum Energy Outlook Database, 2015)

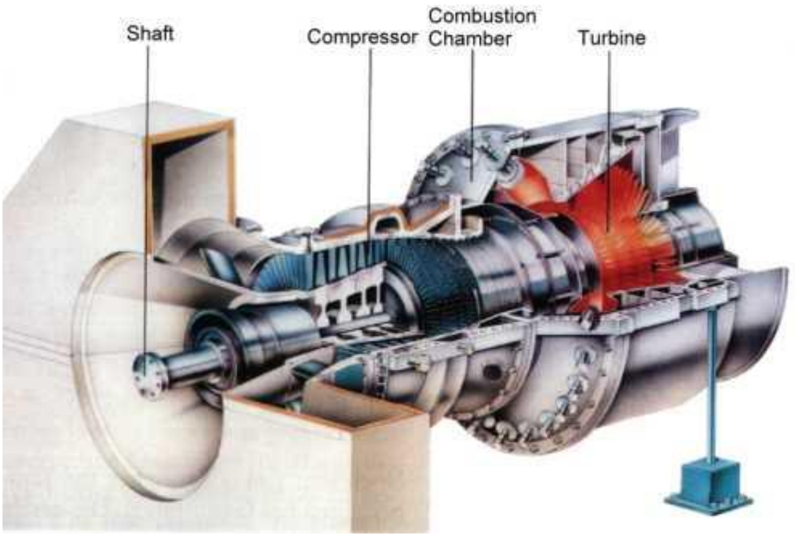
If we analyse the global generation mix and compare situation from 1990, current situation, and the projections up to 2035, we can see significant changes. Looking globally at all the fossil fuels, it can be noticed that the share in the following 20 years will decrease for around 10%. Most of this decrease will be seen in the share of oil. Natural gas is projected to be the only fossil fuel with a stable future growth. On the other hand, exponential growth is projected for the renewable sources.

3.2. Gas-Fired Power Generation

There are two types of gas-powered power plants (Gas Natural Fenosa Knowledge Base, 2015):

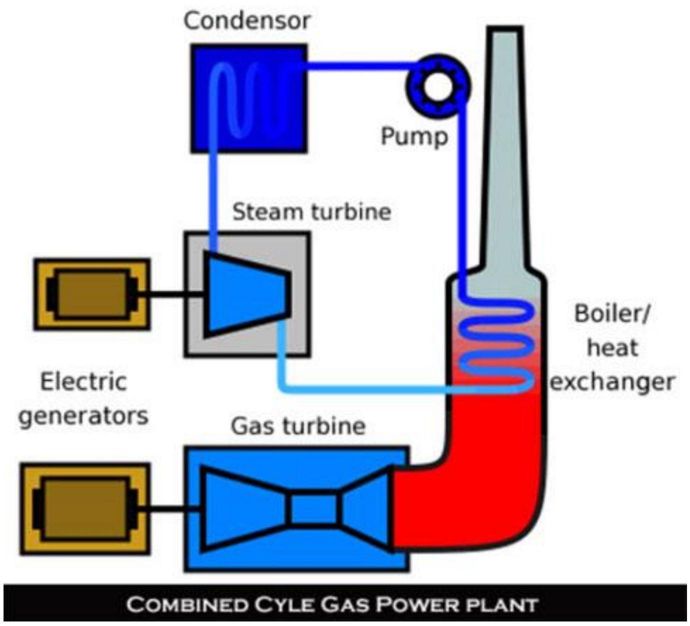
1. Gas turbines
2. Combined-cycle turbines

Gas turbines are type of gas-powered power plants that are using the same technology as jet engines, but unlike jet engines, they are creating power in this way. Gas turbine is different from a steam turbine because of the fact that in a combustion turbine the fuel is combusted and the hot combustion gases are being sent through the turbine at high speed and temperature. As a consequence, turbine blades are spinning and the electricity is generated. In a gas turbine, air compressor and a gas turbine aligned on a single shaft on a single shaft are connected to an electricity generator. Compressed air fires natural gas that drives the compressor and electricity generator. From the whole output of the turbine, greater part is used to compress the air. The rest of it drives the electricity generator. The efficiency of a combustion turbine is around 30-34% up to 42%. Generally, gas turbines can burn liquid fuels such as crude oil, fuel oil or diesel, not only natural gas. Due to their flexibility, speed in which they can reach full production, they are often chosen in cases of volatile power requirements. They are considered to be cheap and fairly modular technology. Setting up a gas turbine takes from 18 to 24 months, which is far less comparing to steam turbines, which normally need 3-5 years. Following the current global prices of natural gas and diesel, the perception of this technology as being an expensive solution has changed.



Picture 1:Gas Turbine (USudy, 2015)

Combined Cycle Gas Turbine (CCGT) is a mature technology, one of the triggers and a main technology for Independent Power Producers (IPPs). They are used both for intermediate as well as a base load power generation. It is a combination of a steam turbine and a gas turbine.



Picture 2 : Combined Cycle Gas Power Plant (Global Greenhouse Warming, 2010)

Combined cycle makes use of the energy that is contained in the combusted gas that is released on the other side of the gas turbine. These gases are sent into the Heat Recovery Steam Generator (HRSG). This set of pipes turns the water in the pipes to steam using the hot gasses. The steam is driving the steam turbine.

The cost of a CCGT turbine is normally more than a Gas Turbine, but this cost difference is not that significant comparing to the efficiency difference which is in case of a CCGT Turbine way higher and can reach up to 61%. This is usually not the case and normally the efficiency of a steam turbine is around 50-55%. Due to the fact that they include two types of turbines, they cannot reach full production as rapidly as a simple Gas Turbine. This drawback is something engineers were working on recent years, thus improvements can be seen in this area as well.

Key differences between a Gas Turbine and a CCGT can be seen in the table below.

Technical Performance	**Typical current international values and ranges**					
Energy input	Natural gas					
Output	Electricity					
Technologies	**GT**			**CCGT**		
Efficiency, %	35–42%			52–60%		
Construction time, months	Minimum 24; Typical 27; Maximum 30					
Technical lifetime, yr	30					
Load (capacity) factor, %	10–20			20–60		
Max. (plant) availability, %	92					
Typical (capacity) size, MWe	10–300			60–430		
Installed (existing) capacity, GWe	1168 (end of 2007)					
Average capacity aging	Differs from country to country. CCGT construction started end of 1980s.					
Environmental Impact						
CO2 and other GHG emissions, kg/MWh	480–575			340–400		
NOx, g/MWh	50			30		
Projections	**2010**		**2020**		**2030**	
Technology	GT	CCGT	GT	CCGT	GT	CCGT
Net Efficiency (LHV), %	35-42	52-60	≤ 45	≤ 64	≤ 45	≤ 64

Table 1: Key Data and Figures for Natural Gas based Power Technologies (IEA, 2015)

4. Natural Gas

4.1. Natural Gas Overview

“Natural gas is composed primarily of methane, but may also contain ethane, propane and heavier hydrocarbons. Small quantities of nitrogen, oxygen, carbon dioxide, sulphur compounds, and water may also be found in natural gas.” (Centre for Energy Economics, 2015)

Composition of gas depends on gas field, but some of the typical values are given in the table below:

Typical Composition of Natural Gas		
Compound	**Minimum**	**Maximum**
Methane (CH_4)	79%	97%
Ethane (C_2H_6)	0,1%	11,4%
Heavier hydrocarbons (Propane, butane and pentane)	0,12%	5%
Nitrogen (N_2)	0,5%	6,5%
Carbon dioxide (CO_2)	0,0%	1,5%

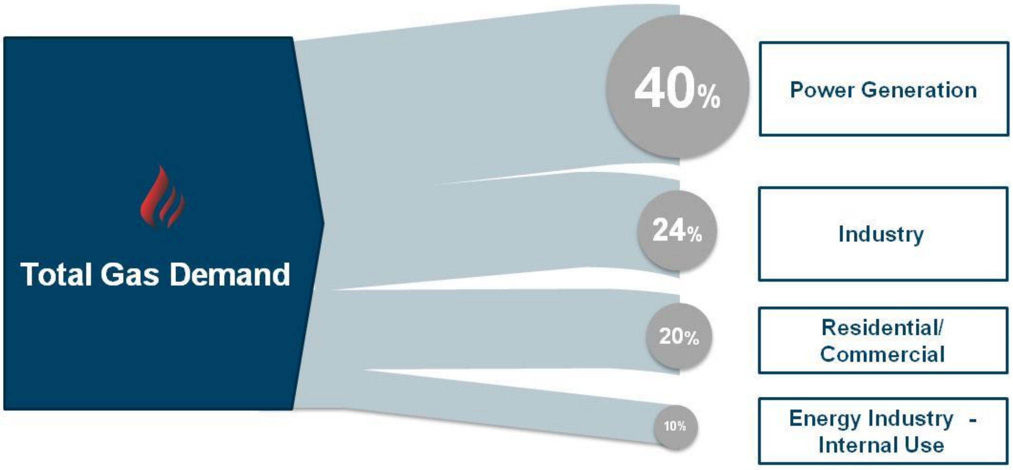
Table 2: Typical Composition of Natural Gas(Universidad Pontificia Comillas Material, 2015)

Natural gas does not require any transformation for its utilization. It is used as a fossil fuel as well as a primary substance in the chemical and petrochemical industry.

According to the type of transformation from the different organic substances, natural gas can be:
1. Thermogenic
2. Biogenic

Apart from this, the mixture of hydrocarbons differentiates different types of gas:
1. Dry gas
2. Gas associated with the production of petroleum
3. Wet gas

The uses of natural gas are numerous. Nowadays its main usage is for power generation (40%), which will be elaborated further in this paper. Historically, natural gas was used mostly for bringing lights to the streets. Due to this fact, it was also known as gaslight. With the development of gas distribution systems, the usage of natural gas has widened and it is possible to use it in power plants, houses and for different industrial uses, as well as in fertilizer production. In houses it is used for space and water heating. One of the gas uses that is developing but has a significant perspective is transportation sector.



Picture 3: Natural Gas Use (BP, 2015)

The phases in the natural gas value chain are following:

1. Exploration

First phase is exploration. This phase lasts for around 5 years in which investigation of new gas fields is done by means of geologic and geophysics studies.

2. Evaluation

The following phase is the evaluation of the fields in order to determine its commercial viability and also measure the amount of reserves. It lasts around 3 years.

3. Market development

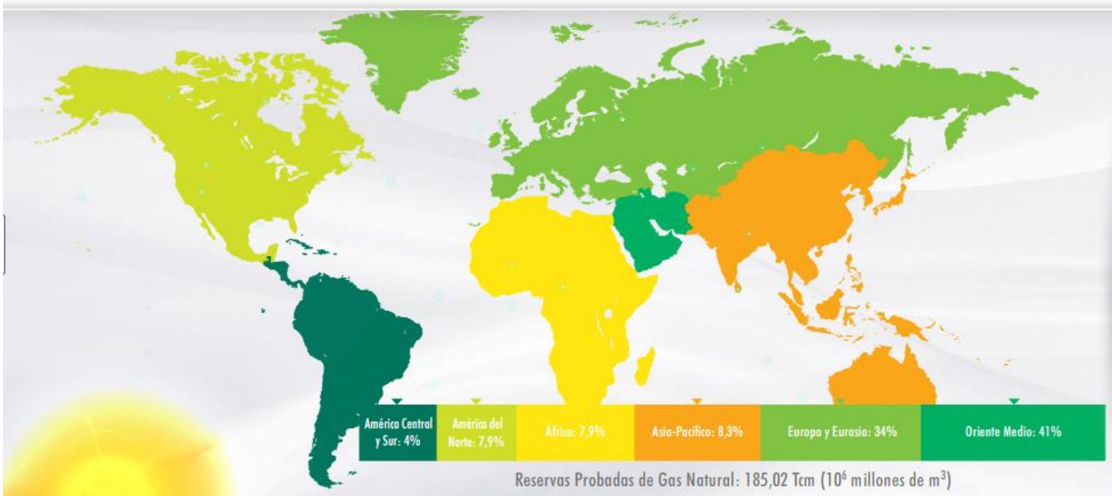
Market development is the next step, lasting around 4 years. It includes the design of the wells, installations, pipelines and the rest of the equipment necessary for the extraction of gas.

4. Production

In between 10th and 30th year the phase of production takes place. Sometimes it extends up to 20 or 30 years. The life cycle finishes with closing down the business and the restoration of the exploited terrain.

There are proven reserves of natural gas all over the world. In the following picture, the map of proven reserves in different regions is given:

1. Central and South America - 4%
2. North America – 7,9%
3. Africa – 7%
4. Asia- Pacific - 8,3%
5. Europe and Eurasia – 34%
6. Middle East – 41%



Picture 5: Proven Reserves of Natural Gas Worldwide (GNF Knowledge Base, 2015)

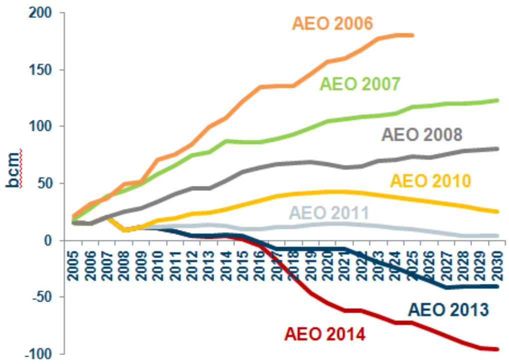
Even though by its size, Middle East is one of the smallest regions, it has the largest proven reserves of gas (41%). Second region is Eurasia. If we focus on countries in particular we can see that the country which has the greatest amount of natural gas is Russia, with its 47,8 tcm of proven reserves. It is followed by Middle East countries, Quatar and Iran and with a new player since couple of years ago in Natural Gas industry, with a role of a global supplier – USA.

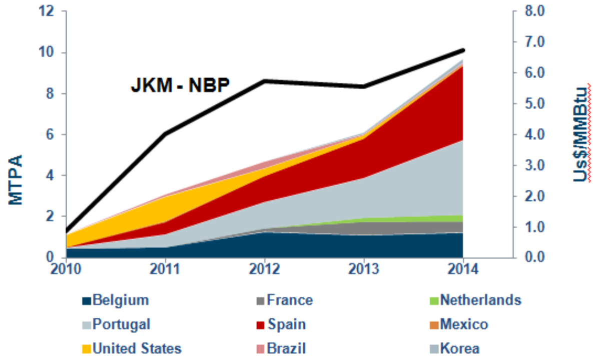
Rank	Country	Gas reserves in cubic metres
1.	Russia	47.800.000.000.000
2.	Iran	33.800.000.000.000
3.	Qatar	25.070.000.000.000
4.	USA	8.734.000.000.000
5.	Saudi Arabia	8.235.000.000.000
6.	Turkmenistan	7.504.000.000.000
7.	United Arab Emirates	6.089.000.000.000
8.	Venezuela	5.562.000.000.000
9.	Nigeria	5.118.000.000.000
10.	Algeria	4.505.000.000.000

Table 3: Proven Reserves of Natural Gas (CIA Factbook, 2015)

If we take a look at historical projections of International Energy Agency about future imports of Liquefied Natural Gas for the United States of America, we can see a significant difference. In the chart below, it can be seen that until couple of years ago it was projected that the USA will be a net importer of gas, in form of LNG. The situation completely changed with the discovery of shale gas, especially after the year 2008 in which the proven reserves of gas amounted for 35% more than in the year of 2006. The current situation is that USA is a net exporter of natural gas, and this is also projected for the future.

When there is a problem of significant change in the demand or supply in a specific country which has long term agreements (usually Take or Pay), one of the solutions is certainly reexport. In this way importing countries can adjust excess of supply, by reexporting it to other countries with unsatisfied demand.





Evolution of Projections for Net Imports of LNG for USA (Compiled based on IEA - Annual Energy Outlook)

Evolution of Reexports (Compiled based on IEA - Annual Energy Outlook)

4.1.2. Natural Gas Demand

According to Woodmackenzie, in the past 15 years overall gas demand had an increasing trend. What is interesting to notice, are the projections for the future. We have seen that natural gas is the only fossil fuel for which the demand is expected to be increasing in the following years. If we go deeper and analyze share that Liquefied Natural Gas has in the Total Gas Demand, we can see that this share is going to increase by 2035 for 6%.

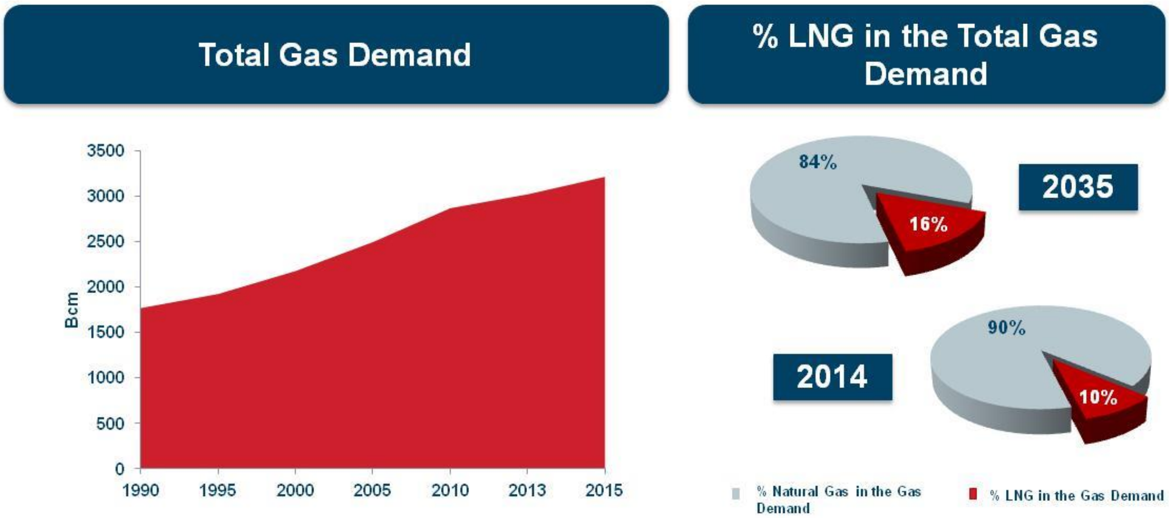
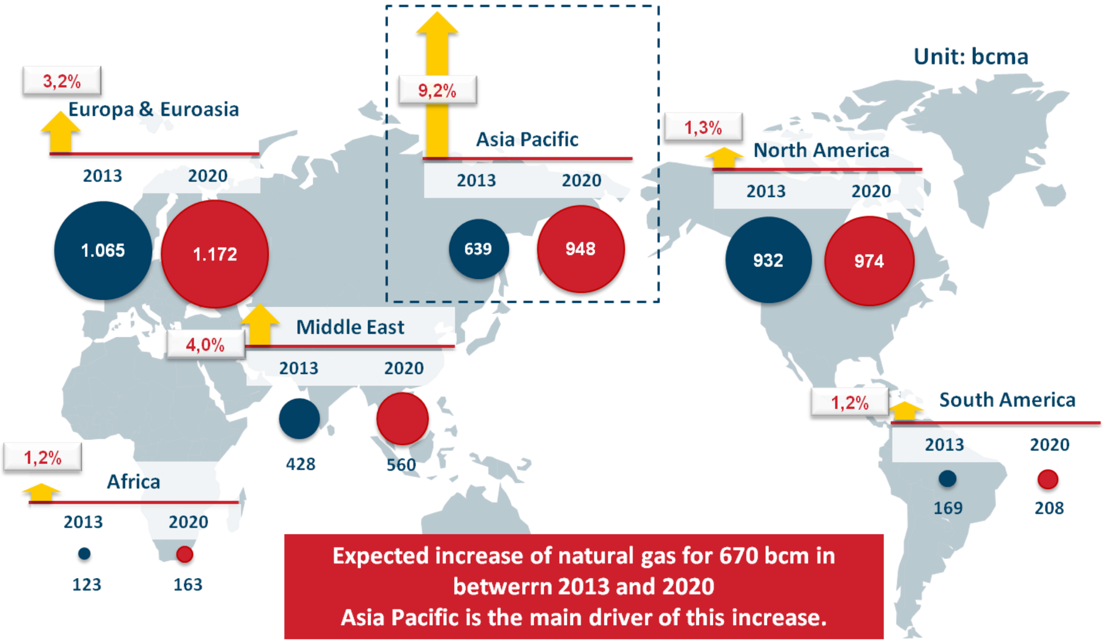


Chart 3: Natural Gas Demand; Share of LNG in the Total Natural Gas Demand (Compiled based on data from Woodmackenzie, 2015)

It's globally accepted that non OECD countries lead the growth in natural gas demand, primarily contributed to increasing power and industrial sectors. Of all fossil fuels, natural gas will have the fastest demand growth. In one of the fastest-growing markets in the world - China coal demand growth will not be as strong due to moderating and less intensive growth for coal in China, and the impact of regulation and police on the use of coal both in US and China. Furthermore plentiful supplies of gas are helping to squeeze coal out from power generation. Over the longer term, the forecasts show that an additional 670 billion cubic metres will be needed by 2020, which is equivalent to today's US gas production. (Woodmackenzie – GNF materials, 2015)



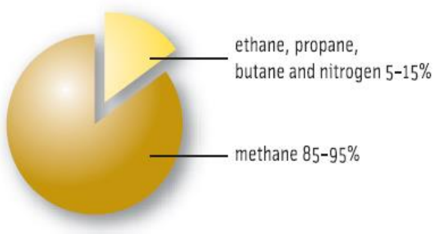
Picture 7: Regional Natural Gas Demand 2013-2020, (Compiled based on data from Woodmackenzie, 2015)

The region with greatest projected growth by the year of 2020 is Asia Pacific. With it projected growth of 9,2 % in following 7 years, it represents a significant driver in building strategies for gas companies all around the globe. With current and upcoming projects of building infrastructures, and with LNG trade becoming easier and competitive, this market will be under the spotlights in the upcoming years.

4.2. Liquefied Natural Gas (LNG)

Liquefied natural gas (LNG) is natural gas that has gone through the process of cooling in the conditions of the temperature of -160ºC. In this process, natural gas which is usually difficult to transport and requires adequate expensive infrastructure, turns into liquid state and becomes suitable for shipping to different locations efficiently (liquefaction) or storage. It is non-toxic, colourless liquid of a volume 600 times lesser than before the liquefaction process. After reaching the desired destination, LNG can be turned again to gaseous state in different regasification plants after which it is handled like classic natural gas, transported by pipelines to power plants, houses, industries.

LNG is consisted of methane with few percents of ethane, less propane and butane than natural gas and slight amount of nitrogen.



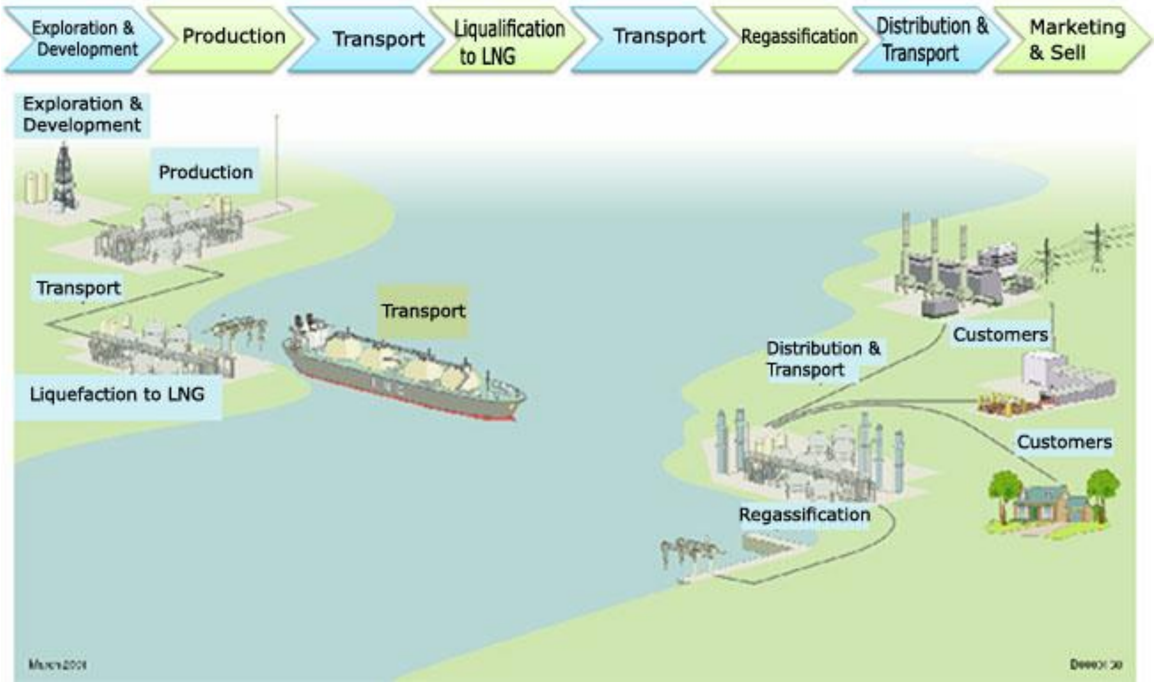
Picture 8: LNG Composition (US Department of Energy, Office of Fossil Energy, 2005)

Liquefied natural gas has its roots in the early 1900s. In the beginning, its usage was limited to storage purposes. Its commercial era started later. In the 1950s the first cargo carrying LNG was shipped from Louisiana to United Kingdom. The first importer was UK and the first exporting country was Algeria. In the 1960s other destinations stared with similar kind of projects followed by the example of UK.

4.2.1. LNG Value Chain

LNG Value Chain has following phases (Gas Natural Fenosa Knowlegde Base, 2015):

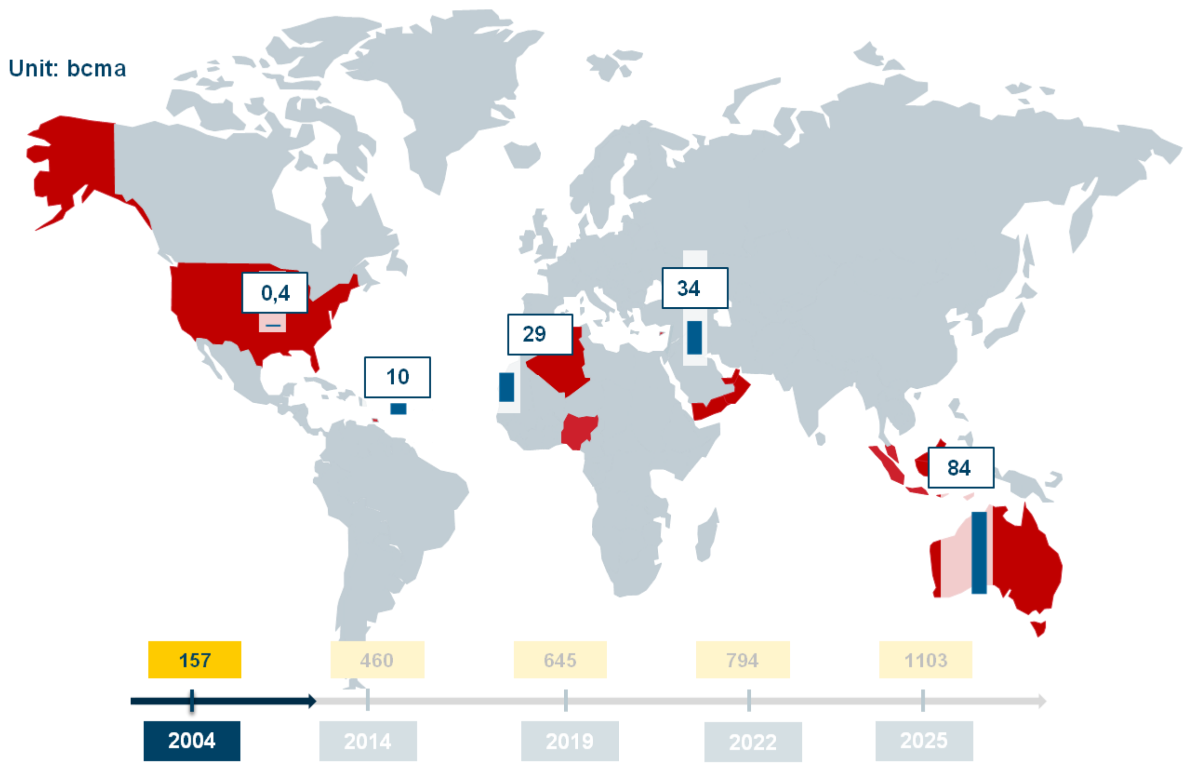
1. Exploration and development
2. Production
3. Transport
4. Liquefaction
5. Transport -Shipping
6. Regasification
7. Distribution
8. Marketing and Sales



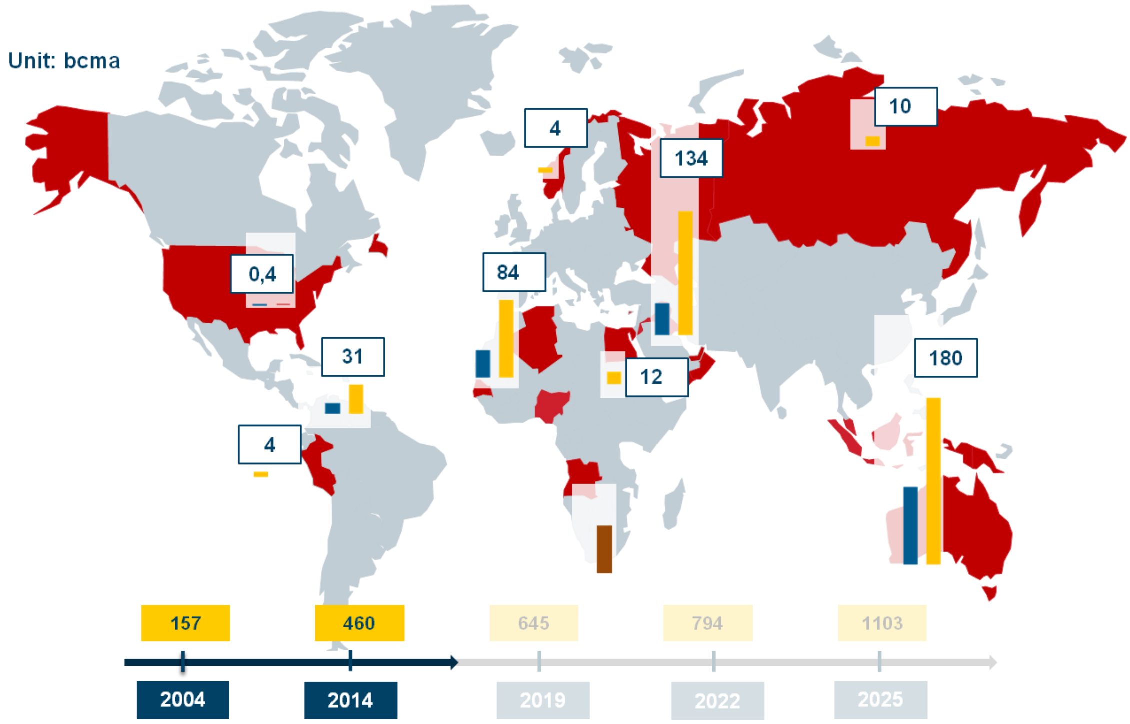
Picture 9: (ICAI - Universidad Pontificia Comillas Material, 2015)

Usual LNG chain starts at the producer's gas fields – the **exploration** and **production** process. Exploration consists of a search for gas by the geologists and geophysicists beneath the surface of the Earth. After a gas field has been found, production can begin. In this process, gas that is extracted is cleaned from the impurities, and non-methane hydrocarbons. After this, natural gas becomes "pipeline quality dry natural gas". The composition of gas that is turned into LNG needs to be fairly precise. Two types of LNG exist thus: "lean" and "rich" LNG. Lean LNG contains liquid methane and ethane and very low amount of heavy gasses. It has lover heating value. On the other hand, rich LNG has higher amount of ethane and some LPG (Liquefied Petroleum Gas). Some users can only use lean LNG.

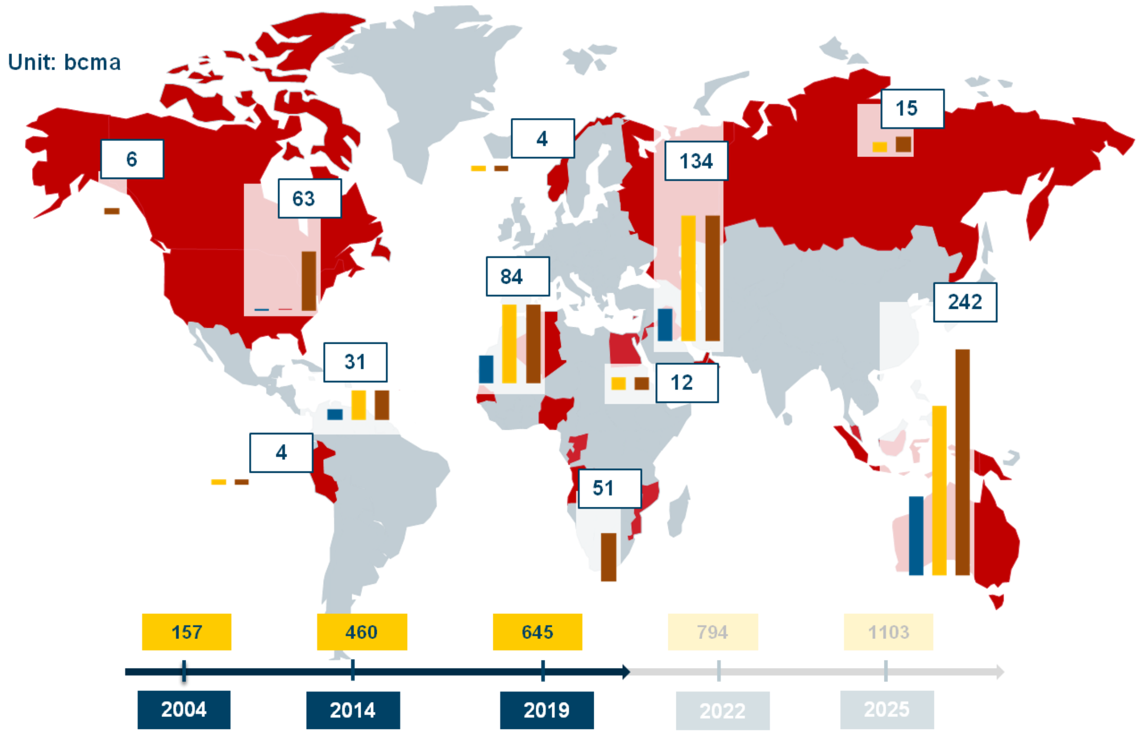
The **liquefaction** process includes the removal of water, carbon-dioxide as well as some other non-methane components from gas. It is done by cooling the gas in the temperature of -256° F (-160 °C). This process is also known as liquefaction train due to the fact it consists of steps in which the temperature is reduced. Liquefaction is one of the most critical links. Generally, they are one of the most capital intensive projects and in the natural gas/LNG industry are the most time-consuming ones. The time necessary to build a liquefaction plant is usually around 4-5 years, taking only construction part into account, and excluding previous analysis, negotiations etc. The development of liquefaction plants is one of the most crucial factors for future projects in LNG industry. Evolution of liquefaction capacities is given in the graphs below.



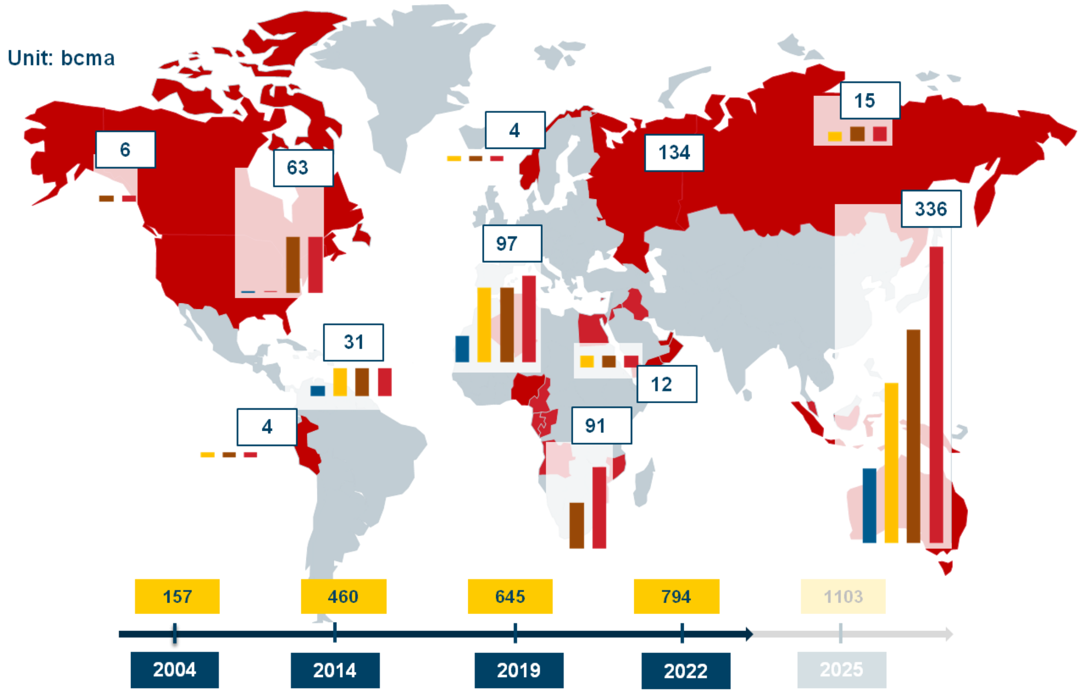
Picture 10: Global Liquefaction Capacity in 2004 (Compiled based on Woodmackenzie and IGU, 2015)



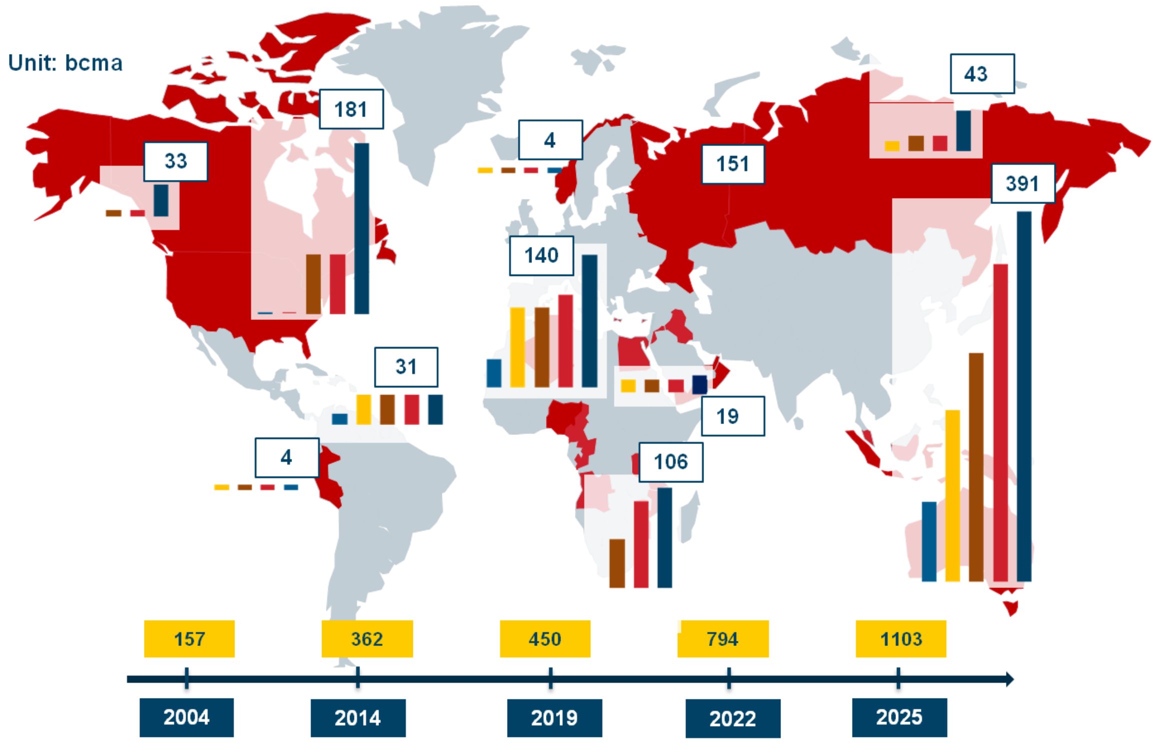
Picture 11: Global Liquefaction Capacity in 2014 (Compiled based on Woodmackenzie and IGU, 2015)



Picture 12: Global Liquefaction Capacity – Projects up to 2019 (Compiled based on Woodmackenzie and IGU, 2015)



Picture 13: Global Liquefaction Capacity – Projects up to 2022 (Compiled based on Woodmackenzie and IGU, 2015)



Picture 14: Global Liquefaction Capacity – Projects up to 2025 (Compiled based on Woodmackenzie and IGU, 2015)

It can be noticed in the previous pictures that the development of liquefaction plants and growth of global liquefaction capacity has been substantial throughout years. Between 2014 and 2019, according to the existing projects that can be seen on Woodmackenzie, the leading countries are Australia and the United States. In between 2019 and 2025, the global liquefaction capacity will be increased for around 650 bcm.

After the phase of liquefaction, natural gas, now LNG is **transported** by sea transport in LNG vessels (LNG carriers) with special conditions for transport of this kind of load up to the terminal in which LNG will be brought back to gaseous state (Regasification plant) and afterwards distributed to the consumers. It can be also stored in insulated storage tanks, before the transport.

The vessels used for the transport use turbines instead of motors. In order for LNG to be successfully transported, the temperature inside of the vessel has to be constantly -163 degrees as well as with atmospheric pressure. For this reason, the material used for building the ships needs to be solid and persistent. It is very costly to build, operate, maintain and ensure security of these ships. Prior to building any new LNG vessels, the cost-benefit analysis needs to be performed. In the last decade the number of LNG vessels has grown exponentially. Also the fact that current global LNG fleet consists of more than 90 percent of "young" LNG vessels that are no more than 25 years old. This implies increase of efficiency and security.

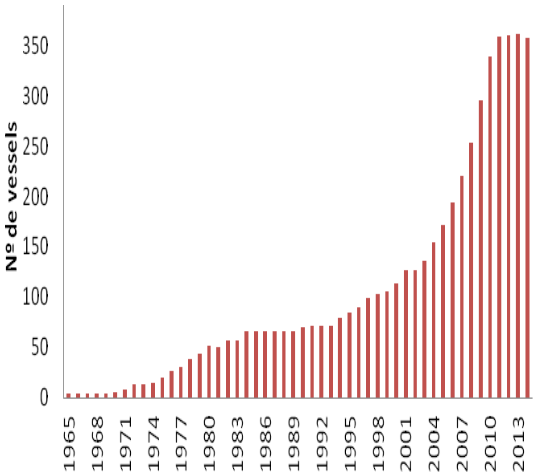


Chart 4: Evolution of number of LNG vessels (IHS, 2014)

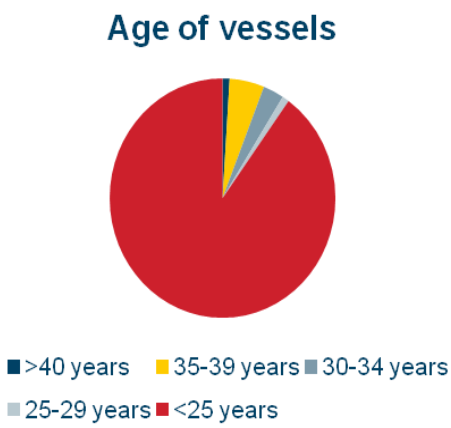


Chart 5: Age of vessels (IHS, 2014)

At the import terminal, LNG is pumped into storage tanks and later inserted into regasification plant according to the needs.

Regasification

After LNG tankers have reached the shore, LNG goes through the process of going back to the initial, gaseous state. Firstly, it is discharged from the vessels, after which they are stored in special tanks. What follows is the evaporation of liquefied natural gas and injection into the gas pipelines or storage after which it is distributed and marketed.

"Regasification involves gradually re-warming the liquefied gas until its temperature rises above 0 °C. The process takes place at high pressure (60 to 100 bar), through a series of seawater trickle-type heat exchangers, the most energy-efficient technique when the right water quality is available. In other cases, some of the gas is burned to provide the necessary heat." (Total, 2015)

There are several types of LNG terminals (Gas Natural Fenosa Knowledge Base, 2015):

- On-Shore
- Off shore
- Deepwater

In the following table, the advantages and disadvantages of all these different types of terminals is given.

Type of Terminal	Advantages	Disadvantages
Deepwater Port	Visual impact No need for removing the sand from the coast Less maritime traffic Less investment, since there is no storage	Discontinuous service It is necessary having an underground pipeline as a connection It is necessary being connected to a very big pipeline network, where a great input into system will not represent a problem and cause instability to the system
Off-Shore	Visual Impact No need for removing the sand from the coast Less maritime traffic	Pioneer in LNG industry It is necessary having an underground pipeline as a connection
On-Shore	Economy Space Mature technology High availability of berths since it is in sheltered ports	Visual Impact Possible necessity of removing the sand from the cost

Table 4: The advantages and disadvantages of different types of terminals (Gas Natural Fenosa Knowledge Base, 2015)

4.2.2. Technological Innovations

The developments in the LNG industry mainly refer to technological advances which had an influence of making LNG trade easier and more cost-effective. One of the most recent innovations that will certainly shape the future of LNG industry and be a prerequisite for most of the future projects are certainly Floating Storage and Regasification Units.

Floating Storage and Regasification Units – FSRU represent an innovation in the LNG industry. It is an offshore solution for reception, storage, vaporisation and export to onshore gas pipeline network. Comparing to traditional onshore solution, it costs less and the necessary time for its construction is lesser. Onshore regasification plants include a long planning process. On the other hand, FSRU are flexible solution. This flexibility provides mitigation of fluctuations from seasonal demands.

Main advantages of FSRU (Indomigas, 2015):

- Shorter time of construction
- Economic solution
- Faster return on capital
- Environmentally friendly
- Easier process of obtaining permission from the authorities
- Flexibility, possible to be reallocated

- Ideal for areas with uncertain economic growth

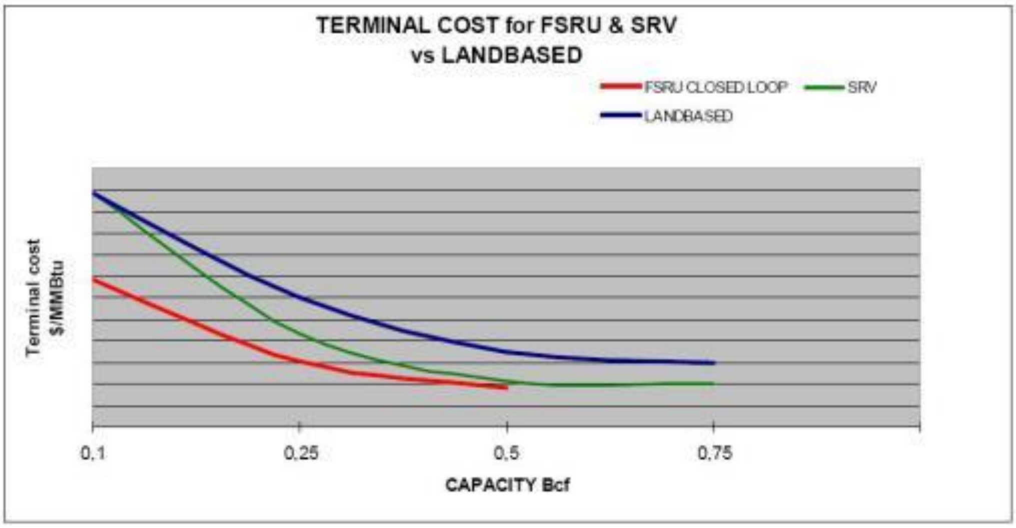
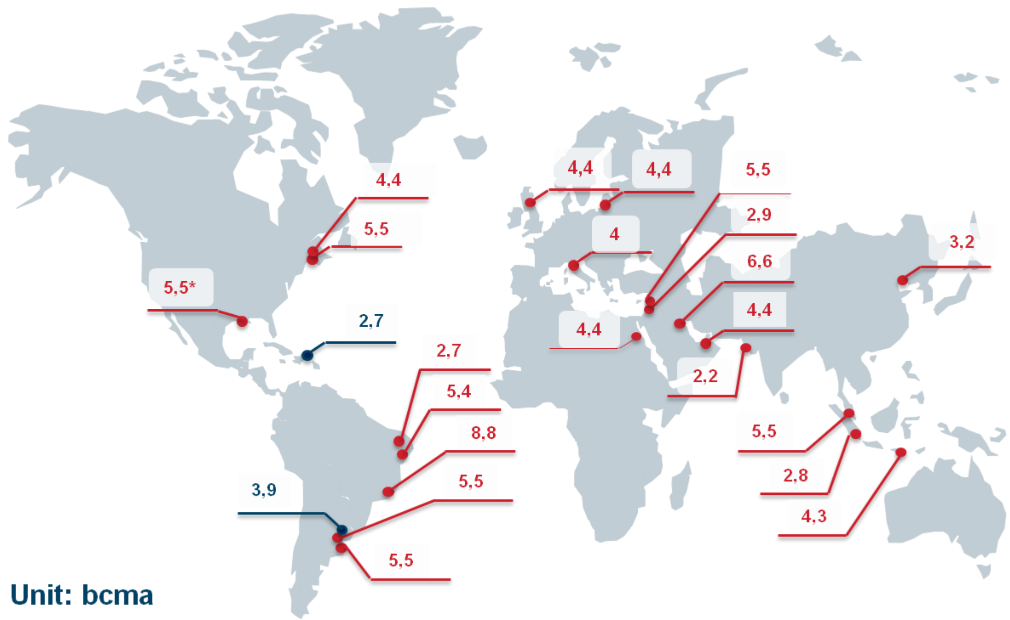


Chart 6: Terminal Cost for FSRU and SRV vs. Landbased (Indomigas, 2009)

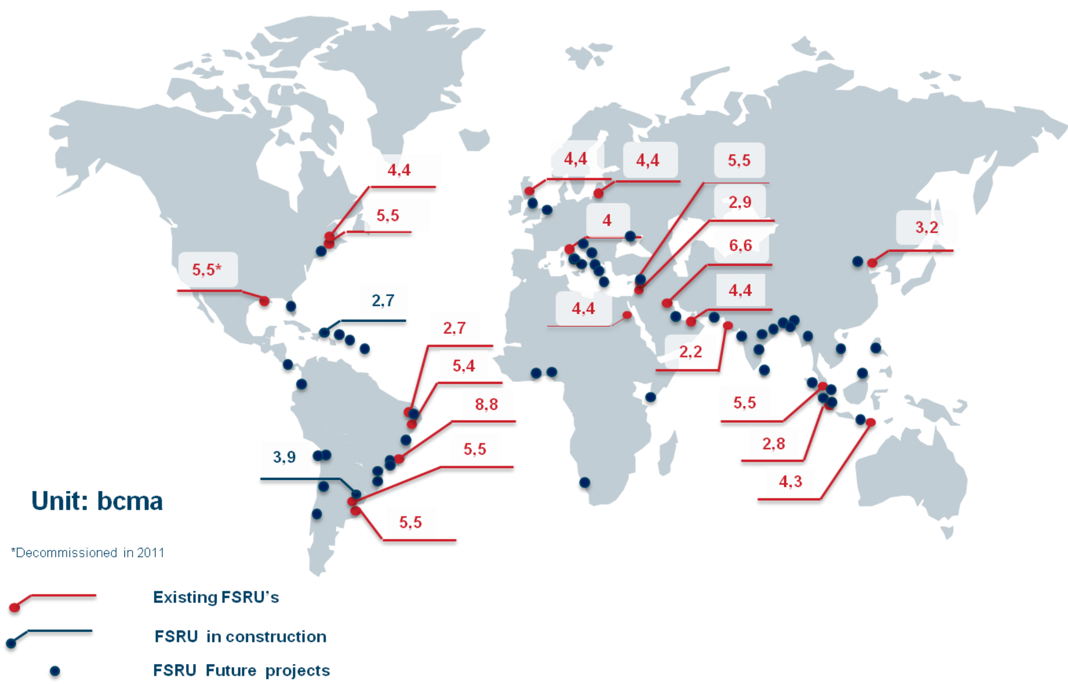
SRV represents one type of LNG carriers which could be used as regular vessels but also have a possibility of regasification onboard.

Picture 15: Floating Storage and Regasification Units – FSRU (Gas Natural Fenosa Materials, 2015)

Current global map of FSRU's is given in the following chart.



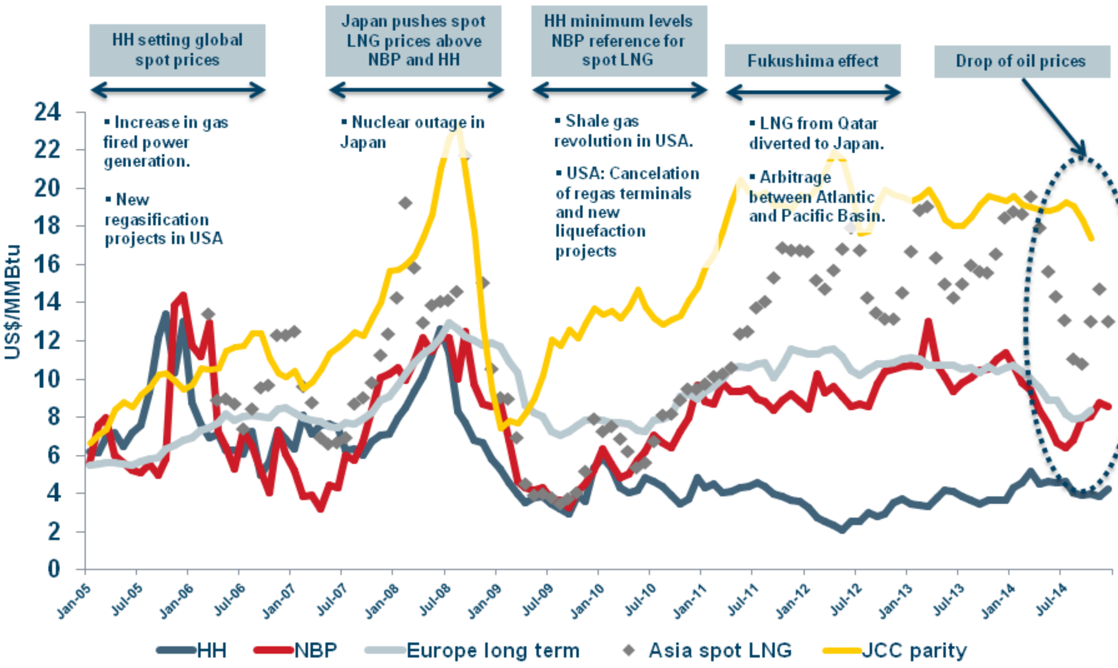
Picture 16: FSRU – Existing (red) and in construction (blue) with corresponding capacities (Compiled based on Woodmackenzie data)



Picture 17: FSRU – Existing (red) and in construction (blue) with corresponding capacities (Compiled based on Woodmackenzie data)

4.3. Natural Gas/LNG Prices

One of the important characteristics of natural gas is that its price is regionally diversified. In 2013, average price in Europe was around 11$/MMBtu, whereas this price in Japan was 16$/MMBtu. In US, in the past years, the price was fluctuating between 2 and 5 $/MMBtu. Development of natural gas trade and especially one of LNG, mainly aimed at Asian Markets, are expected to decrease the gap that existed in between these markets, leading to an integrated and more globalised market due to the increased trades among them.



Picture 18: Natural Gas/LNG and crude oil price evolution regionally throughout years (Compiled based on IHS Cera data, 2014)

On the above chart, evolution of natural gas/LNG and crude oil prices in different regions throughout years is given.

From 2005-2007, the expectation was that major growth for gas - LNG imports would be in the United States. There, local conventional production had reached a plateau and would start to decline gently; meanwhile, gas demand was set to continue to rise on the back of gas-fired power generation. LNG would fill the gap between flat domestic supply and climbing demand. Analyst expected that the United States would overtake Japan as the world's largest importer early in the next decade. In Japan and Korea, most gas was procured under long-term contracts—often 20 to 25 years in duration—with prices specifically set as a percentage or ratio of oil prices, indexed to JCC. But with expectations of growing US demand, HH began to emerge as a new benchmark for global spot prices.

Continental Europe was caught somewhere in the middle, with most gas sold under bilateral contracts linked to oil product prices, but spot prices being referenced to NBP and TTF began emerging.

By 2020, US LNG imports were expected to be as high as 137 MTPA and account for 28 percent of global LNG demand. LNG would therefore bring the world's largest gas market—

and the most deeply liquid traded market—into contact and competition with Asia, Europe, and Latin America as each sought to acquire, for the first time, gas from the same sources.

Things changed between 2007 and mid 2009. The LNG available for spot markets was much lower than anticipated for several reasons. Construction issues had delayed large volumes of LNG from supply facilities under construction, while the plants that had commissioned in those days were failing to produce:

- Delays in the anticipated start-up of the first Qatargas II train had led to a great shortfall in Qatari output. The new train, which would be the largest in the world when commissioned, will account for almost 4 percent of total global capacity.

- The Snøhvit plant in Hammerfest, Norway, had been experiencing operational difficulties since the 4 mt train shipped its first cargo. Although a slow-ramp-up was expected, the persistence of technical issues had drastically decreased output.

- Strikes and civil unrest in Nigeria had led to the continued shut-in of approximately one third of Nigerian oil production and associated feedgas, which affected adversely to the LNG output.

Meanwhile strong Asian demand was pulling both non contracted and contracted volumes to the region and away from the Atlantic and Spain imported more LNG during the first half of the year than expected.

- Increased Indian marginal demand had been driven mostly by fuel substitution for expensive petroleum products in growing markets served by an enlarged natural gas pipeline network connected to both the Hazira and Dahej import terminals.

- Japanese LNG demand grew in 1.2 mt more than previously expected. The additional increase was explained by unforeseen short-term events such as cold weather and by structural changes such as new customers and fuel switching. Nuclear generation decreased dramatically due to the shutdown of seven reactors at Kashiwazaki Kariwa that account for nearly 17 percent of Japanese nuclear capacity.

- Spanish power issues related to a severe drought and high coal prices attracted additional LNG to Iberian shores. The decrease in overall supply coupled with the pull of demand in other regions has left little LNG for the traded markets.

The fuel switching forced JCC prices to peak at historical maximum. In addition to that, the unforeseen demand made Japanese market as premium market with arbitrage between Atlantic and Pacific and spot prices as a discount of JCC. Meanwhile, NBP and HH prices quotations were a netback from premium markets.

For close to two years starting in mid 2009, the global natural gas industry experienced the triple whammy of reduced global gas demand, growth in unconventional gas in North America, and the long-anticipated surge in global liquefied natural gas (LNG) supply. In those days a global gas supply bubble emerged:

The consensus among LNG market watchers was that the surplus would be temporary. Reflecting that, even as contracts were being renegotiated, signs were emerging that foreshadow a tightening market, raising the question of the durability of the surplus.

- Contract renegotiations included spot-price linkages: A handful of new deals signed lately point toward more spot linkage in long-term LNG and pipeline supply contracts.
- Pressures exist on both sides of the market: Delays in final investment decisions, North American reexports, and another Qatari commissioning were symptoms of a loosening market.

At the same time, a faster-than-anticipated economic recovery in Japan and Korea, the eventual removal of Indonesian spot cargoes, and the rapid establishment of smaller niche markets was helping to absorb excess supply.

- Expectations for North American imports declined: As the price projection at Henry Hub deteriorates further, LNG suppliers looked farther afield to place their cargoes anywhere they can. The lower price incentivized additional sales into existing markets and new sales into new markets. North America was also facing a recession-induced decline in gas demand, but was also experiencing the unconventional gas revolution. High drilling levels had led to stronger North American unconventional gas production has the potential to turn the North American import tsunami into a small wave.

After the earthquake and the nuclear outage in Japan Natural gas prices were on the rise across the main consumer regions, with the notable exception of the North American market. High oil prices translate into rising prices for natural gas and LNG delivered under long-term contracts in Europe and Asia. Japan became a premium LNG market.

Between 2011 and 2014, global supply averaged 240 million metric tons per annum (MMtpa), while liquefied natural gas (LNG) demand growth, by contrast, shifted regionally. Marketers responded by pushing more destination-flexible supply produced in the Middle East and the Atlantic Basin toward demand markets located in Asia Pacific, facilitating a 12% increase in Asia Pacific's share of global imports between 2011 and 2014.

- Price divergence growing stronger. Asian short-term prices climbed between 13 and 17 US$/MMBtu, while the UK National Balancing Point (NBP) declined around 8-9 US$/MMBtu and US prices hovere around 4 US$/MMBtu. Asian price increases outpaced the stagnant NBP, leading to a growing price divergence among the three major gas markets (Asia/America/Europe).
- The strengthening of the price divergence amid growth in the volume of flexible cargoes highlights the difference between flexible and available. The price disconnect implied that—although the flexible market had grown considerably—there was still not enough available LNG to satiate short-term Pacific demand, leading buyers to bid up Asian prices.

Slowing demand in Northeast Asia, lower oil prices, and a projected 10 million metric tons (MMt) of incremental global supply growth headlined by Australia will pose greater challenges to the short-term interregional LNG marketing. Japan, South Korea, and China—the world's top three importers—recorded negative year-on-year import growth in fourth quarter 2014.
Several key sources of short-term, marginal supply—such as Qatar, Nigeria, and European reexports—sent less LNG into Asia Pacific in the second half compared with the first half of 2014.

It is expected that China to reclaim the global incremental annual growth title in 2015. But China will do so based on imports under new long-term supply contracts rather than spot imports, which have supported import growth in past years. New contracted supply will back out spot demand not just in China but also in Japan, where the possibility of nuclear restarts is expected to lower total import demand in these second half of 2015. Moreover, oil price declines in fourth quarter 2014 will likely lower Northeast Asian spot prices below $9/MMBtu during the second quarter 2015 shoulder season. As marketers scramble to win the marketing battle for unmet short-term demand, the changes in cross-regional trade flows and marketing in fourth quarter 2014 will expand over the course of 2015.

Markets such as Brazil and India will continue to function as opportunistic buyers. Potential new importers such as Egypt and Jordan could also join their ranks, although both are expected to import a much lower volume of spot supply. For marketers, comparative cost advantages not just for supply but also for shipping and LNG storage (onshore and floating) will prove critical in determining trading margins given declining prices.

Based on the oil price decline in the fourth quarter, the Japan average import contract is projected to slip below $10/MMBtu in second quarter 2015 and could head below $9/MMBtu during the summer. Assuming normal weather and no unexpected supply disruptions, it is expected Northeast Asia spot prices to trade below $9/MMBtu during the second quarter 2015 shoulder season.

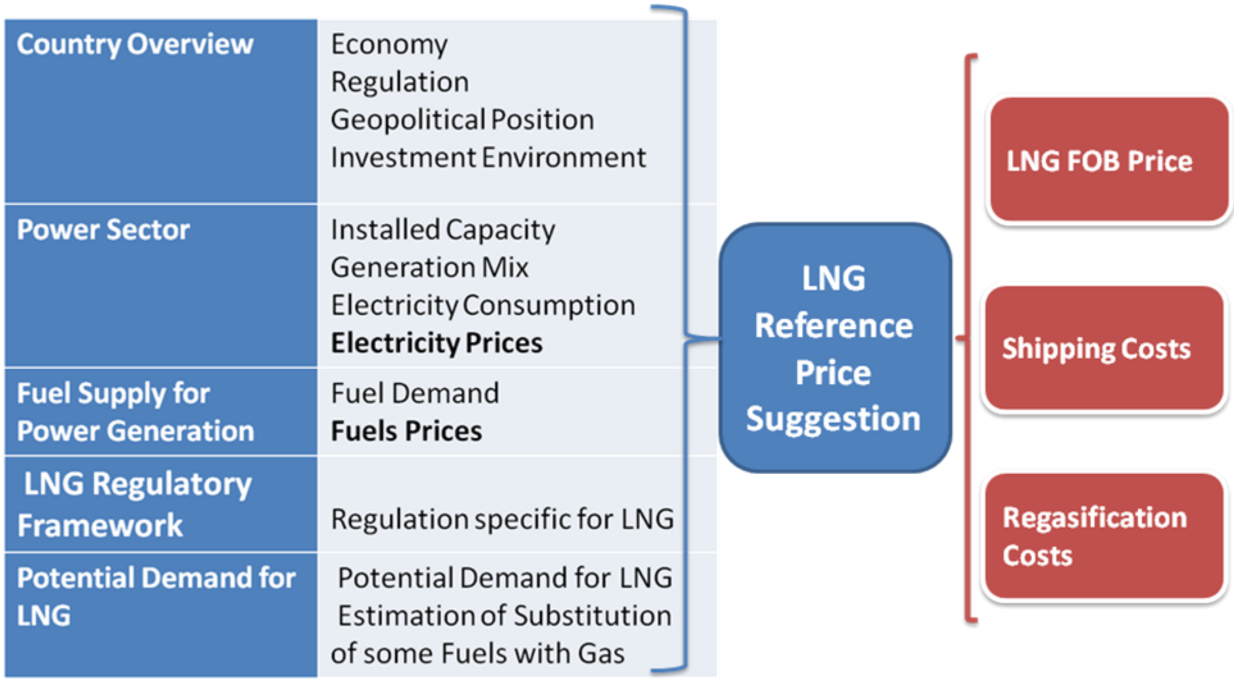
In Europe, NBP outlook to reflects the lingering influence of oil-indexed pipeline contracts on gas price fundamentals. Specifically, it is expected legacy pipeline contracts not yet linked to the European spot markets to act as a cap on the traded gas price.

As it can be seen, the spread between markets and the movements in price have always come as a response of the market forces. Price fluctuations, although inevitable, stabilized themselves over time. In the case of the current downturn, market forces have affected the fundamental, underlying composition of LNG and gas prices.

5. LNG Developing Markets Analysis Framework

Suggested framework for analysing developing markets for the sales of Liquefied Natural Gas, for power generation projects is following:

1. Country Overview
2. Power Sector Analysis
3. Fuel Supply for Power Generation
4. Potential Demand for LNG
5. Regulatory Analysis
6. LNG Reference Price Suggestion



Picture 19: LNG Developing Markets Analysis Framework

All the following sections have a purpose of analyzing a particular country. Some of them are used to tell whether a specific LNG to Power Project is possible, and some to indicate which suggested price would be competitive. For setting a particular price what we in particular need to analyse are the electricity prices and the fuels prices used in electricity generation on the one hand and on the other, the costs related to LNG free on board price (FOB), regasification and shipping. In some of the cases, additional cost for transportation via pipeline from the regasification plant to the power plant will be included. In this thesis, margin will be left out to be set by an individual supplier, since the purpose of the thesis is to make a general guidline to all the possible sides willing to import LNG to a particular country.

In order to calculate the costs of LNG supply, when analysing a specific developing country appart from determening the location of FSRU Unit, it is also necessary to assume one gas supplying region, according to the previous analysis and supply arrangements of company Gas Natural Fenosa.

6. Developing Markets - LNG Projects

6.1. Ghana

6.1.1. Country Overview

Quick Facts	
Capital	Acra
Population	25.6 million
Surface	238.535 km 2
GDP (PPP)	$109 billion 8 % 5-year compound annual growth
CAGR	8.0%

Table 5: Ghana – Quick Facts (Heritage, 2014)

Picture 20: Location of Ghana, (Wikipedia, 2015)

Africa´s frontier emerging country, Ghana (officially: Republic of Ghana), is a unitary presidential constitutional democracy, a country which is situated in the West part of African continent, exposed to both Gulf of Guinea and Atlantic Ocean. Countries surrounding it are Ivory Coast, Burkina Faso and Togo. (Wikipedia, 2015)

It is a country with population of approximately 27 million, ethnically and religiously diversified. Ghana is one of the top ten fastest growing economies in the World and the highest growing in Africa. According to Heritage, it is among average countries in the World measuring the Economic Freedom Score (Chart 7).

MAIN INDICATORS (GLOBAL POSITION)

	RATING Moody's	GDP (PPP) USDB$	GDP GROWTH %	SURFACE Thous. of km²	POPULATION (Thousands)	Prod. elec. TWh	Cons. gas bcma
SPAIN	Baa2	1.534 (17)	1,3 (174)	505	47.738	277 (15)	30 (32)
MOROCCO	Ba1	254 (57)	3,5 (91)	446	32.987	24 (70)	1 (88)
IVORY COAST	B1	72 (92)	8,5 (8)	322	22.848	6 (114)	1,6 (82)
GHANA	B3	109 (80)	4,5 (61)	238	25.758	11 (95)	0,6 (99)
BENIN	B	20 (142)	5,5 (45)	113	10.161	0,1 (191)	0
SOUTH AFRICA	Baa2	683 (31)	1,4 (167)	1.219	48.376	258 (16)	4,6 (63)

Table 6: Ghana - Main Indicators (CIA, 2015)

Government: Constitutional Democracy
President: John Dramani Mahama (Jul-12); 4 years
Parliament: 275 members (Dec-12); 4 years
Administrative Regions: 10
Legal System: English Common Law

In the past years, it has significantly improved its economic and monetary freedom. Also, it is the 2nd country in Africa by the freedom of press. In the beginning of 2015, it signed an agreement for a loan of 940 million dollars with IMF for supporting the economic reform. This would lead to fiscal adjustment in the years 2015-2017. The main aim is to restore debt sustainability. (IMF, 2015)

Still, country needs to reach a higher level in microeconomic sense in order to have a sustainable growth. Apart from this, even though some measures had already been taken to tackle these issues, there are still problems with bribery and corruption as well as freedom of investments. When it comes to the investments, foreign investors are treated equally by the Law, but sometimes in the process of procurement, domestic companies can be favoured. Some of this might be disadvantageous for future energy projects. In order to reduce the fiscal deficit by the means of eliminating subsidies, a fuel-price adjustment mechanism was established. Ghana is well-known for its natural resources, including diamonds, gold, manganese ore, bauxite and oil. It has runner-up position in gold production in Africa. Its export drivers are gold, oil and cocoa. (Heritage, 2015)

Economy Overview	
GDP (Oficial):	**35 USb$**
[50% services, 29% industry, 21% agriculture]	
GDP (PPP):	**109 USb$**
GDP per capita: 4.200 US$	
GDP Growth:	**4,5%**
7,1% (2013) 8,8% (2012) 15% (2011)	
Inflation:	**15%**
Unemployment: (2000)	**11%**
Deficit / GDP:	**−9,6%**
Public Debt:	**72.7% of GDP**
Exports:	**13,5 USb$**
[12% FR, 9% IT, 8% CH, 8% NL]	
Imports:	**16,0 USb$**
[22% CH, 12% NG, 6% NL]	
Currency:	**GHS Ghana Cedi**
Exchange Rate: GHS/USD: 0,259	

Table 7: Ghana Economy Overview (CIA Factbook, 2015)

For the power sector analysis, GDP figure is very important. In the Quick Facts table it can be seen that 5-year GDP compound growth of Ghana was around 8%. For a developing country, this figure is satisfying but still, by analysing the trend more thoroughly, it can be noted that since 2011 this indicator decreased from 15% to 4,5% implying that there was a negative growth in the industry sector. Nevertheless, the long-term prospects for Ghana are positive, with a projection of achieving the 7,8% growth rate again by the year of 2017 as a result of IMF measures and oil export, which is expected to be the main driver of the economic growth in medium term.

To secure further economic growth, Ghana is seeking for new projects which will enable secure and diversified energy supply. It is planning to keep investing in hydroelectricity and oil resources, but also plans to make significant investments in power plants that will be using natural gas.

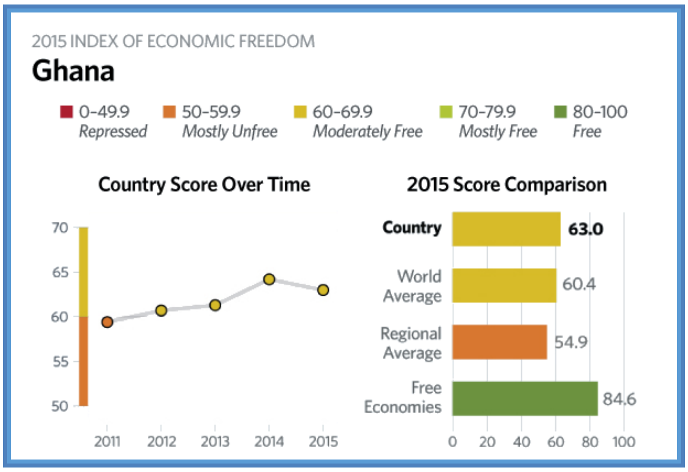


Chart 7: 2015 Index of Economic Freedom – Ghana (Heritage, 2015)

Advantages:

- Economy with the highest growth-rate in Africa.
- One of the most stable nations in the World.
- In 2014 contract was signed with International Monetary Fund for fixing fiscal imbalances securing long-term prosperity.

Opportunities:

- Economy growth, supported by the IMF.
- Gas to power projects supported by the government

Disadvantages:

- Energy crisis with electricity blackouts are slowing down the development of the country.
- Problems with the corruption, bribery and freedom of foreign investments.

- Threats:
- Global financial conditions that might have an influence on reducing the private capital entering Ghana
- Sustained recession in international prices of gold, cocoa and oil

6.1.2. Power Sector Analysis

Historically, the power sector of Ghana was dependent mostly on hydro resources, manifested with the river of Volta. After several years in which the country had problems with the draught, which caused load-shedding around the country, they decided to reduce their reliability on only one resource. The first solution was thermal power. The first thermal power plant was built in Takoradi in 1997 by the subsidy of Volta River Authority, which is the main generator and supplier of electricity in Ghana. By now, 7 more plants were built, with the capacities shown in the picture 10. Ghana is also working on increasing the energy generated from the solar sources with a goal of achieving 6% in the generation mix until 2016. Currently, generation mix is as it is shown in the chart 8. Hydro is still dominant, but now with significant share of thermal. In both cases Volta River Authority is in charge in most of the production activities. The rest is being produced by Independent Power Producers.

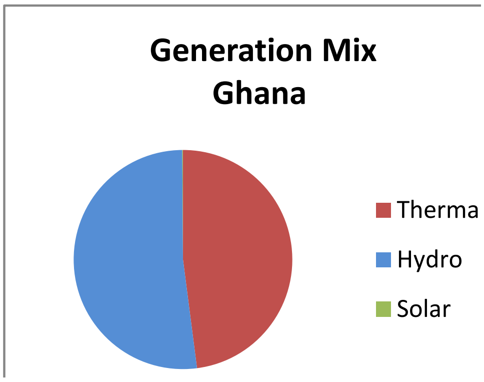


Chart 8: Generation Mix Ghana (VRA, 2015)

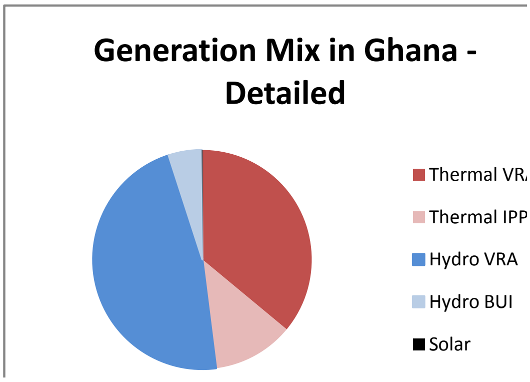


Chart 9: Generation Mix – Detailed (VRA, 2015)

In 2014, Ghana had dependable installed capacity 2589 MW (picture 10), though due to various issues that power sector of Ghana is experiencing, the expected utilization is very low. In case of thermal plants, it amounts for 53.6%. Around 27% of thermal generation in 2014 was produced from natural gas. In the graph, list of existing generation plants is given. It is important to emphasise that starting from 2016 all the open cycle power plants will be converted to combined cycle. (VRA, 2015)

In 2013, total grid electricity generated was 12,87 GWh, 6% more than in 2012. Unmet demand was between 1700-2480 MWh which can be expressed as 240-330 MW of thermal capacity. (Energy Commission, 2014)

		INSTALLED CAPACITY		2014 Expected Utilization	
GENERATION PLANT	FUEL TYPE	INSTALLED (MW)	DEPENDABLE - 2014 (MW)	% of Dependable	Net Capacity (MW)
Hydro Power Plants:					
Akosombo	Hydro	1,020	960	90%	864
Bui	Hydro	400	380	30%	114
Kpong	Hydro	160	140	90%	126
Sub-Total		**1,580**	**1,480**	**74.6%**	**1,104**
Thermal Power Plants:					
Takoradi Power Company (TAPCO)	LCO/NG/diesel	330	300	70.0%	210
Takoradi International Company (TICO)	LCO/NG/diesel	220	200	10.0%	20
Sunon–Asogli Power (SAPP)	NG	200	180	75.0%	135
Takoradi T3	NG	132	120	10.0%	12
Tema Thermal Plant1 (TT1P)	LCO/NG/diesel	126	110	70.0%	77
CENIT Energy Ltd (CEL)	LCO/NG	126	110	70.0%	77
Mines Reserve Plant	Diesel/NG	80	40	75.0%	30
Tema Thermal Plant2 (TT2P)	NG/diesel	50	45	70.0%	32
Sub – Total		**1,264**	**1,105**	**53.6%**	**593**
Other:					
Genser Power	LPG	5	2	70.0%	1
VRA Solar	Solar	3	2	30.0%	1
Sub – Total		**8**	**4**	**50.0%**	**2**
Total		**2,851**	**2,589**	**65.6%**	**1,699**

Chart 10: Installed Capacity Ghana (Energy Commission, 2014)

Some of the factors that are influencing low utilization are limited gas supply which will be analysed later in the paper, aging equipment and consequently major maintenance work, poor management, high fuel prices and low water levels of hydro stations, especially the biggest one – Akosombo.

All of this has an impact on the final price of electricity paid by the end consumers, since when the shortage of gas occurs and there is a draught, the only option is expensive oil as a fuel. Thus, a partial solution to the problems that Power Sector of Ghana is experiencing and which has an influence on high electricity prices lies in finding a suitable gas supply option to cover the shortfall and substitute more expensive fuels. When we compare average electricity end-user prices paid in Ghana with similar middle-income countries, it can be concluded that the difference is significant, unfavourable for the consumers in Ghana. Ghana also has the largest difference between industrial and residential tariffs.

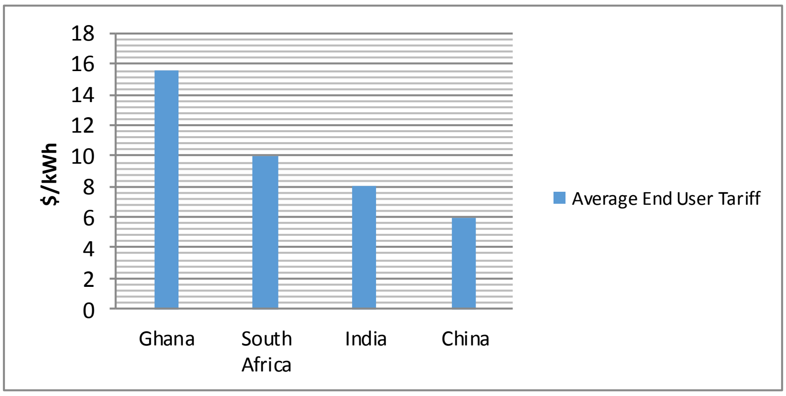


Chart 11: Average End User Tariff Comparison of Middle-Income Countries, (Energy Commission, 2013)

Load shedding is a measure that as a consequence of all the things previously mentioned is taken very often in Ghana. Direct impact of this measure on the industry sector can be seen in the chapter 5.1.1, in which GDP was analysed. Drop of 7.5% in Annual GDP Growth Rate since 2011 was provoked by the negative growth in the Manufacturing and Services sectors due to the inability of power sector to meet the existing demand. The percentage of the demand that was not met by the supply in 2013 was around 10-15%. (Energy Commission, 2013)

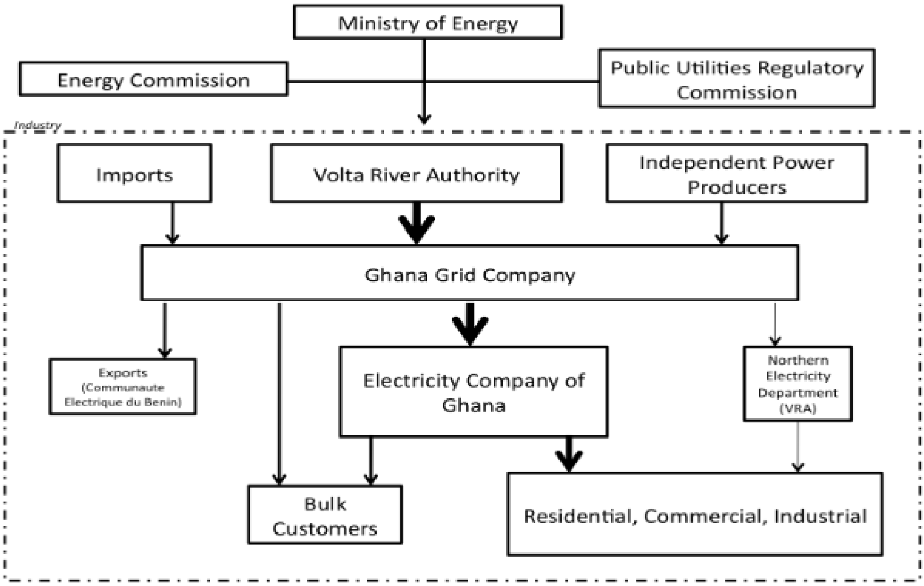
Electrification rate in Ghana was 75% in 2013. According to the National Electrification Scheme, the complete electrification of 100% should be in place by 2020.

The Structure of Power Sector

Activities in the power sector of Ghana are unbundled. Liberalisation is an on-going process. Prior to 2005, one company was in charge with generation and transmission activities, but for the reasons of attracting new investments in the generation sector, after this year it needed to hive off its transmission activities to another company. Under the current law, transmission is a regulated activity, which is together with system operation done by one company. Generation and distribution are open to competition. In the generation side there is one dominant company and larger number of Independent Power Producers (IPPs). As for the distribution, there are two companies in charge with this activity.

In the wholesale market there is a spot market and a bilateral one. Spot market is not sufficiently developed due to the small number of players.

Power generators in Ghana have an opportunity to enter into Power Purchase Agreements (PPA´s) with off-takers outside Ghana.



Picture 21: The structure the power sector in Ghana (Ministry of Energy & Petroleum, 2015)

Ministry of Energy is in charge of formulation of policies and programs for the whole sector. It is also in charge of implementation of the National Electrification Scheme. Volta River Authority (VRA) is a state-owned company in charge of power generation. Apart from VRA, there are also Independent Power Producers (IPPs) as well another state-owned company Bui Power Authority (BPA), in charge with Bui Hydro Electric Power Project. Transmission activities and system operation of The National Interconnected Transmission System (NITS) is assigned to state-owned Ghana Grid Company (GRIDCo). Power distribution activity is done by two companies. In Southern Ghana it is done by Electricity Company of Ghana, a state-owned company and in Northern Ghana by Northern Electricity Company (NEDCo), a subsidiary of Volta River Authority. Energy Commission of Ghana (EC) is in charge of licensing, advising to Ministry of Energy on energy planning and policy and formulation of standards. Public Utilities Regulatory Commission (PURC) is an independent regulatory agency in charge of tariff setting, monitoring of quality as well as all the consumer-related issues. Energy Commission of Ghana and Public Utilities Regulatory Commission regulate electricity supply activity. (Ministry of Energy & Petroleum, 2015)

6.1.3. Fuel Supply for Thermal Power Generation

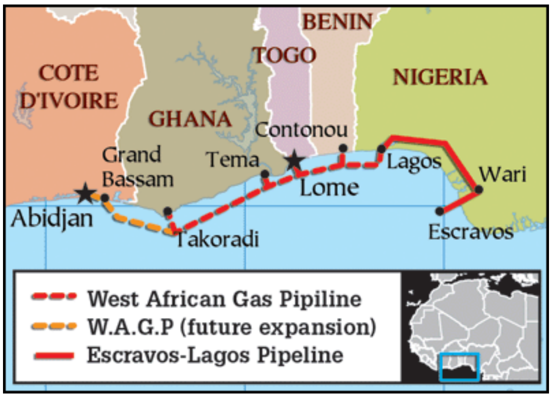
The National Petroleum Authority (NPA) is in charge of the regulating, overseeing and monitoring petroleum downstream industry in Ghana

As it is shown in the Graph X, thermal plants in Ghana run on following fuels:

- Natural Gas (NG)
- Crude Oil - Light Crude Oil (LCO)
- Distillate Fuel Oil

Ghana is a net importer of **natural gas**. It is supplied mainly from Nigeria and from Ivory Coast in mainly via West African Gas Pipeline. Domestic production is mainly organized around Jubilee Oilfield.

WAGP is a natural gas pipeline which is supplying gas from Nigeria to Benin, Togo and Ghana. Daily, millions of standard cubic feet is been supplied through WAGP pipeline. In 2013, total of 11.6 trillion standard cubic feet (Tscf) of gas was delivered by WAGP, around 25% less than in the previous year. In average, supply from WAGP in 2014 was 31 MMSCFD. Price of gas supplied from WAGP is indexed to Light Crude Oil (LCO) and reviewed every 6 months. In 2013, it the price was 8.27-8.38 $/MMBtu. The problem with gas supplied through this pipeline is that it is unreliable. Currently, all the thermal power plants, except for Mines Reserve Plant (MRP) run on natural gas supplied through WAGP. Sunon Asogli Power Plant that represents around 8% of the total generation is designed so that it can only run on natural gas, thus any problem that WAGP might experience could influence seriously on the security of supply. (Grid Company, 2014)



Picture 22: West African Gas Pipeline, (Ventures-Africa, 2012)

Table 23. WAGP Delivered Gas Price Components in 2013

Details	Customer Price	
	Foundation	Standard
	$/MMbtu	
Gas Purchase	2.4688	2.4688
ELPS Transport	1.2745	1.2745
WAGP Transport	4.2378	4.3465
WAGP Credit Support Charge	0.2000	0.2000
WAGPA Charge	0.0600	0.0600
Delivery or shipper fee	0.2000	0.2000
Pipeline Protection Zone charge	0.0300	0.0300
Fuel Gas – Commodity	2.4688	2.4688
Fuel Gas - ELPS Transport	1.2745	1.2745
Shipper Fee	0.0000	0.0000
Delivered Gas Price ($/MMbtu)[80]	**8.2711**	**8.38**

Source: Adapted from WAPCo, 2014

Table 8: WAGP Delivered Gas Price Components in 2013 (WAPCo, 2014)

Jubilee Field is the source of domestic gas production in Ghana. It was discovered in 2007 in deep waters offshore Ghana. It was one of the greatest discoveries in the past 20 years in West Africa. Average supply from Jubilee Field is 80-100 MMSCFD. It has estimated reserves up to 1.4 trillion cubic feet of gas. (Energy Commission, 2014)

One of the new fields that were developed in 2013/2014 are TEN (Tweneboa-Enyenra-Ntomme) fields which will be supplying between 63-70 MMSCFD by 2017. Production from this field together with some others is projected to be between 300-500 MMSCFD by 2020, which is still insufficient for the demand which is projected to be over 800 MMSCFD by 2017.

Current shortfall of gas that Ghana is experiencing is around 300 MMSCFD.

Light crude oil (LCO) is petroleum with low density, supplied to Ghana from Nigeria. It produces higher percentage of gasoline and diesel fuel (Wikipedia, 2009). In order to have some reference price for this type of Crude Oil, a comparison has been made with index largely used for pricing of gas – Brent. By analysing quarterly data provided on the website of Energy Commission of Ghana for the time period 2005-2013, the conclusion is that very strong correlation exists between prices of LCO and spot prices of Brent.

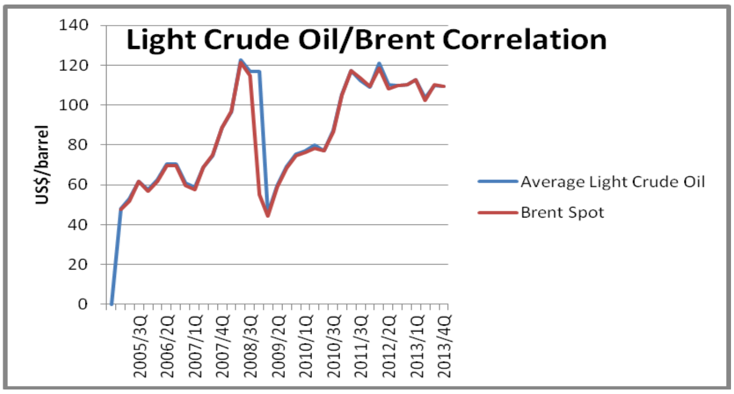


Chart 12: Clight Crude Oil/Brent Spot Prices Correlation (Data from: Energy Comission, Gas Natural Fenosa Database, 2014)

6.1.4. Potential Demand for LNG

Due to the long period of dry seasons which were disabling Ghana´s hydro power stations to remain being the main producers of energy, the focus was switched to thermal generation. West African gas pipeline was providing Ghana with natural gas, but due to its failures and unreliability, usage of crude oil has increased. Since then, prices of electricity have gone up. It became evident that alternative for the supply of gas for both of these reasons needs to be found, especially taking into consideration the demand increase.

As it is mentioned in paragraph 5.1.3., total gas demand projection for the year of 2017, according to Energy Commission is around 800 MMSCFD. The total shortfall if we summarize all the current and arranged gas supply contracts is around 300 MMSCFD, or expressed in the terms of a yearly gas supply 3,285 billion cubic metres (bcm).

In order to make a demand projection, it is necessary to determine one location for the FSRU unit and the possibilities that arise with having a regasification unit at this particular place. One FSRU unit will be considered and its peak regasification capacities will be assumed.

Picture 23: Takoradi, Ghana - Location of the FSRU Unit (Google Maps, 2015)

The location that is chosen for the FSRU Unit is Takoradi. Apart from the technical advantages of this location (ease of access to the LNG infrastructure), this location is also interesting for potential LNG suppliers since it is in the proximity of West Africa Gas Pipeline (WAGP) as well as Jubilee pipeline.

The peak regasification capacity of the project in case of Ghana for the above mentioned location is assumed to be 375 MMSCFD. Expressed in billion cubic metres (bcm), it is equal to a yearly gas supply of 3,375 bcm. Nominal capacity in which FSRU will typically operate is assumed to be equal to 65% of the peaking capacity which is around 250 MMSCFD (2.7 bcm).

If we analyze power plants that exist and that are yet to be built nearby Takoradi, we can see that currently there are 7 existing and 10 yet to be built power plants, which are potential source of the demand. They are located in Takoradi and Aboadze reigion, which is 24 km away.

Power Plant	**Installed Capacity (MW)**
Takoradi International Company (TICO)	220
Takoradi Power Company (TAPCO)	330
Takoradi T3	132
Tema Thermal Plant (TT1P)	126

Simple Cycle Plants´ Conversion to CCGT	**Installed Capacity (MW)**
Takoradi International Company (TICO)	110
Sunon-Asogli Power (SAPP)	360
Takoradi T3	132
Total	1410

Power Plants - Yet to be constructed	Installed Capacity (MW)
Rotan	660
Amandi	239
Jacobsen	330
One Energy	1000
ASG Ghana Limited	200
Chrispood Hydro Power Ltd	340
ERL Systems Ltd	370
Amanful Power Ltd	660
One Energy Ltd	1278
KATT Power Ltd	49
Total	5126 MW

Table 9: Power Plants in Takoradi and Aboadze Regions, (Energy Comission, 2014)

This list is not definite, but it represents the most realistic options for this LNG to Power project. It has been given as a proof of the existing need for gas very close to the place that is choosen as a location for the FSRU. They are all gas fired power plants, mostly combined cycle. If we consider that their efficiency is 50%-55%, the yearly energy they can produce is around 26 280 GWh, which requires gas supply of 2.26 bcm. This covers more than 80% of the planned supply in this project.

6.1.5. Regulatory Framework in relation to LNG

Ghana does not have a single source of law for its power sector.

When it comes to ownership of LNG facilities, they can be owned by Ghanian companies, companies or partnerships theat are registred in Ghana and also foreign companies subject to specific capital requirments. The operator of an LNG Facility has to be registred in the National Petroleum Agency. This agency is also in charge with ensuring fair competition downstream. Another permit that the operator of an LNG facility needs to obtain is a licence from the Environmental Protection Authority. (ICLG, 2015)

LNG sector is liberalised in terms of prices or service. Third-party access rights are determined by the law of the contract and market forces. (ICLG, 2015)

6.1.6. Building a Competitive LNG Price Reference

Electricity Prices

Electricity production in Ghana was in the past mostly based on hydro resources, which led to lower cost of production. The situation changed when this resource had become insufficient, leading to an increase in electricity production costs from 2 cents per kWh in the late 1990s to 6 cents per kWh in 2002 by including thermal generation.

End-user tarrfs in Ghana are build in that way that the key variables influencing the cost of electriciy are revised on quarterly basis and passed onto the consumers. Automatic adjustment formula includes all these varibles and is used for setting both electricity and water tariffs (PURC, 2015):

- Ghana Cedi US$ Exchange Rate
- Inflation
- Fuel Mix (Crude Oil, Natural Gas, Distilate Fuel)
- Power Purchase Cost
- Demand Forecast
- Chemical Cost (Water)
- Electricity Cost (In case of water production, this is the major cost component)

Most recent regulated prices were published in 2013. As a reference we will be using price for high-voltage price (energy component), which is available on the website of Public Utility Regulatory Commission (PURC). It amounts to : 9 cents/kWh or **26,47$/MMBtu**[1] .

This price in terms of fuel price for this electricity generation, considering the efficiency of 55% for CCGT that runs on natural gas is **14,55 $/mmbtu.**

Costs

In order to calculate the costs of LNG supply, when analysing a specific developing country appart from determening the location of FSRU Unit, it is also necessary to assume one gas supplying region, according to the previous analysis and supply arrangements of company Gas Natural Fenosa.

Supplying Region: Sabine Pass, Louisiana, USA
Gas Natural Fenosa has a 3.5 mtpa LNG contract with Sabine Pass Liqufaction, a subsidy of Cheniere for 20 years supply starting from 2015/2016. (Chenier, 2015)
FSRU Unit Location: Takoradi, Ghana

Picture 24: Shipping distance between supplying region and Ghana (Google Maps, 2015)

Shipping distance from Louisiana, USA to Takoradi, Ghana is around 10.000 km.

1. **LNG Free On Board (FOB) price** consideres costs of supplied gas with price of liquefaction included. It will be estimated according to a published supply contract with supplier Chenier, using an average price for the following five years of Henry Hub Index (HH), which is used in this supply point. Even though LNG supply contracts are made for more than 5 years, the estimation is made for this number of years in order to reduce the uncertanty that goes with fixing one price for a gas index. For the purpose of simplification, no changes in the value of CPI (Consumer Price Index) will be included for this perod of time.

[1] Conversion rate used: 1 kWh=0,0034 MMBTu

The price formula for Sabine Pass is (Cheniere, 2015):

P_{FOB} = 115% HH + (0,86-0,14*CPI/CPo)*Xo

Where:

HH - Henry Hub Index
Xo – Liquefaction Costs (14% influenced by the ratio of CPI Index change, assumed to be 1 in this case)

For the purpose of this thesis, value of Henry Hub Index will be fixed to **3.6 $/MMbtu** which is calculated as an average of 5-years historic values (March 2009 – March 2015) and forward prices for following 5 years (april 2015 – april 2020). (Gas Natural Fenosa Database, 2015)

As for the liquefaction costs the value of 3.5 $/MMbtu is used which represents the liquefaction costs with ommited change due to the effect of the inflation, since it has a very small effect on the final price.

The estimation of LNG FOB price is

P_{FOB} = 115% * 3.5 $/MMbtu + 3.5 $/MMbtu = **7.525 $/MMbtu**

2. **Shipping Costs**

According to the privious studies done by the company Gas Natural Fenosa, for the given distance between Louisiana and Takoradi in Ghana the price of shipping 1bcm of gas in a regular supply activity is around **1.35 $/MMbtu** in LNG tanks with 174 000 cubic metres of capacity. (Gas Natural Fenosa Business inteligence, 2015)

3. **Regasification Costs**

Taken as an average of global regasification costs the price that will be considered for this process is **0.6 $/MMbtu.** (Gas Natural Business Intelligence, 2015)

4. **Total costs**

Total costs of supplying LNG from Terminal Sabine Pass in Louisiana, United States of America, to Takoradi, Ghana is **9.475 $/MMbtu**. This includes costs of Free on Board gas supply (with costs of liquefaction included), costs of shipping in adequate LNG tanker and costs of regasification. In this particular case, since the location of power plants which will be main consumers of supplied gas, costs of transport via pipeline has been ommitted.

Comparing electricity prices expressed in terms of gas supply and total costs for introducing LNG from this source, it can be conclued that under these prices, the offer is not competitive.

6.2. Lebanon

6.2.1. Country Overview

Picture 25: Location of Lebanon (Wikipedia,

Quick Facts	
Capital	Beirut
Population	4.5 million
Official Language	Arabic*
GDP (PPP)	$80,51 billion 4.5% 5-years compound annual growth
Religions	Shia Muslims, Sunni Muslims, Christians and Druze

Table 10: Lebanon – Quick Facts (Heritage, 2013)

*Article 11 of the Constitution of Lebanon states: "Arabic is the official national language. A law determines the cases in which the French language is to be used.

Lebanon is a unitary parliamentarymulti-confessionalist republic located in Western part of Asia, sourounded by Syria on the North and Israel on the South. Due to its geographical position and rich history, it is culturally and ethically diversified. Since it is a county with very high literacy, it was historically a centre for trading activities in the Middle East, as well as a country referred to as ¨Switzerland of the Middle East¨ due to its strong banking sector. It is one of the countries which take part in European Union's European Neighbouring Policy (ENP), aimed at making the connections between European Union and its neighbours stronger.

Government: Unitary parliamentary multi-confessionalist republic
President: Tammam Salam
Legislature: Parliament
Legal System: Based on French legal system
(Wikipedia, 2015)

One of the consequences of this diversity is sectarianism which is present in political scene of Lebanon. Ever since it claimed its independence from France in 1943, it was building on a prosperous country profile, regarded as a financial and trading centre of the region. It is a country of seemingly free trade, free from governmental restrictions to foreign investors, but also this liberty is undermined by the possible corruption problems and high taxes, which had an influence on the score in this year's Index of Economic Freedom Report, published by Heritage.org. Its economic growth slowed down in past few years from 8% to 1-2%.

Chart 13: Lebanon Annual GDP Growth Rate (Trade Economics, 2015)

Lebanon is highly indebted country, ever since the civil war in 1975 after which it needed to borrow a lot of resources in order to rebuild its infrastructure. Tax revenues are mostly spent on debt repaying and on transfers given to electricity sector, not on investments for infrastructure improvements. State-owned electricity segment takes around one third of all the government revenues. In spite of this fact, Lebanon had managed to reduce its level of debt as a percentage of GDP for more than 50% in the time period 2007-2012. Below, the chart presenting this is given, as well as the projections from the International Monetary Fund about the future debt dynamics that will be achieved through fiscal measures.

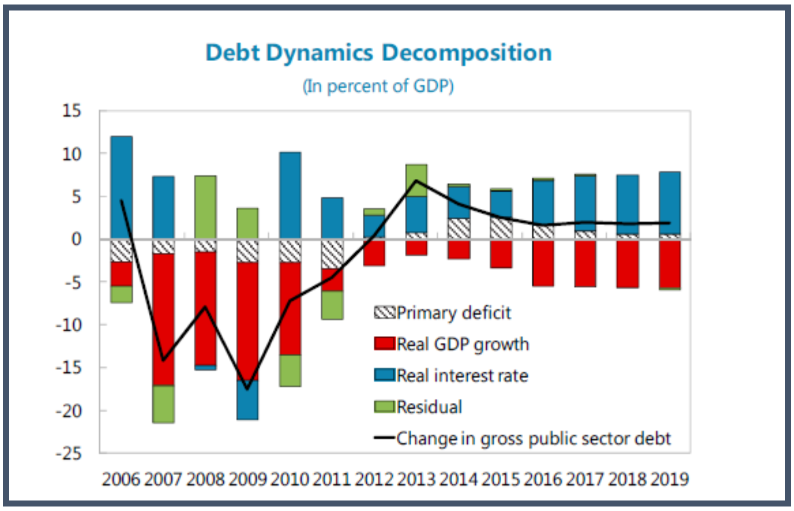


Chart 14: Lebanon – Debt Dynamics Decomposition (IMF, 2015)

Economy Overview

GDP (Oficial): **47,5 USb$**
[2014]

GDP (PPP): **80,51 USb$**
GDP per capita: 17.900 US$

GDP Growth: **1,5%**
1,5% [2013] 2,5% [2012]

Inflation: **1,5%**
5.6% [2013]

Deficit / GDP: **-9,8%**

Public Debt : **142,4% of GDP**

Exports: **4,092 USb$**
[UAE 10,8%, SA 9,6%, IQ 9,3%]

Imports: **20,08 USb$**
[CH 11,9%, IT 8,1%, FR 6,7%]

Currency: **Lebanon, Pound**
Exchange Rate: LBP/USD = 0.00066

Table 11: Lebanon – Country Overview (CIA Factbook, 2014)

As for its external relations, Lebanon has been influenced by neighbouring Syria for years. This influence is in particular visible in the way their policies are designed. Lebanon was occupied by Syria from 1976 until 2005. It is currently passively involved in the on-going Syrian War. The borders between these two countries as well as between Lebanon and Israel are still not determined. The number of refugees from Syria in Lebanon has reached one quarter of the total population in 2014. (CIA, 2015; Heritage, 2015)

Picture 26: Lebanon - Neighbouring Countries (BBC, 2015)

The economy of Lebanon is mostly service oriented. Tourism makes a significant share, as well. Both are currently influenced by the unrest in neighbourghing Syria. Even with this downward trend, that is expected to last for some time, the FDI index (Foreign Direct Investment) went up around 9% in 2013. (Boell, 2015)

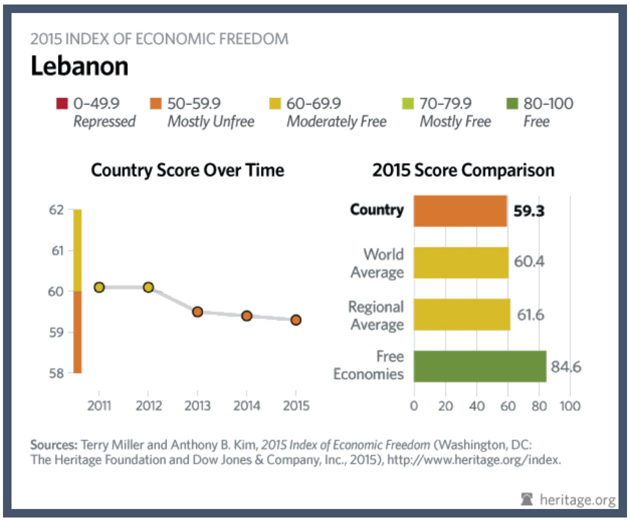


Chart 15: 2015 Index of Economic Freedom – Lebanon (Heritage, 2015)

Country at a glance (BBC, 2015):

- In 1990 civil war was ended but Lebanon was involved in the war with Israel in 2006 over Hezbollahs (Pro-Syrian Shia Islamist militant group and political party based in Lebanon). Syrian war passed through the borders into Lebanon.

- Government is fragile after these international instabilities.

Advantages:

- The security in the country is improved which had a postive influence on the tourism

Opportunities:

- Structural reform, especially of the electricity sector

Dissadvantages:

- Fiscal disbalancies and current economic downturn influencing and high level of poverty and unemployment as consequences
- International instability (neighbouring countries)

Threaths:

- Syrian crisis development
- Delays of structural reforms

6.2.2. Power Sector Analysis

This section is built according to the publicly available data. In most of the cases they are not very recent. For the purpose of this study, the data from 2010-2013 is mostly used since there have not been any significant investments in the power sector, thus these data are providing a trustworthy picture of the state of the power sector.

Energy resources of Lebanon are mostly dependent on imports. 90% of its oil demand was imported in 2010. There are potential oil and gas reserves, but no on-going exploration project, for many reasons. One of them is the fact that one part of the territory where this potential resources are located is in a conflicting area with neighbouring country Israel. These conflicts might have an influence on termination of exploration projects in this 300 square metres area. (EIA, 2015)

Lebanese Power Sector has theoretical legal framework for liberalization, but it is not applied. This framework exists alongside a decree 16878/1964 which gives one company (Electricité du Liban) exclusive authority in the activities of generation, transmission and distribution.

Power Sector of Lebanon generally is one of the main sources of GDP deficit. It has had a poor performance in the past years, accounting to 40% of country's public debt. It was in the state of crisis for long period of time, due to technical, as well as problems with poor management, corruption and political issues. According to World Bank, in 2013, average daily supply was 17 hours.

Installed Capacity

Total installed capacity in Lebanon is 2355 MW. Ministry of Energy has a plan of increasing production by between 455 megawatts and 565 megawatts by 2020. In 2013 installed capacity was covering only 18 hours per day on average, since the peak demand is 3195 MW. (World Bank, 2013)

Location	Utility	Installed Capacity (MW)	Generation Type	Fuel
Zouk	Electricite du Lebanon (EDL)	607	Combined Cycle Gas Turbine (CCGT) & Steam Turbine (ST)	Fuel Oil
Zahrani	Electricite du Lebanon (EDL) and Enel Produzione	470	Combined Cycle Gas Turbine (CCGT)	Diesel Oil and Natural Gas
Deir Ammar	Electricite du Lebanon (EDL) and Enel Produzione	435	Combined Cycle Gas Turbine (CCGT)	Diesel Oil and Natural Gas
Jieh	Electricite du Liban (EDL)	346	Steam Turbine (ST)	Residual Oil
Litani	Litani Water Authority	199	Hydraulic Power Plant (HPP)	Hydro
Al-Hreesha	Electricite du Liban (EDL)	75	Steam Turbine (ST)	Residual Oil
Tyre	Electricite du Liban (EDL)	70	Open Cycle Gas Turbine (GT)	Diesel Oil
Baalbek	Electricite du Liban (EDL) and Enel Produzione	70	Steam Turbine (ST)	Diesel Oil
Nahr Ibrahim	Societe Phoenicienne des Forces de Nahr Ibrahim des Eaux et Electrecite	32	Hydraulic Power Plant (HPP)	Hydro
Kadisha Valley	Electricite du Liban (EDL)	21	Hydraulic Power Plant (HPP)	Hydro
Al-Bared	Al Bared Concession	17.2	Hydraulic Power Plant (HPP)	Hydro
Richmaya, Safa	Electricite du Liban (EDL)	13.4	Hydraulic Power Plant (HPP)	Hydro
	Total Installed Capacity (GW)	2.3556		

Table 12: Total Installed Capacity in Lebanon (EDL, 2014)

<u>Electricity production</u>

In Lebanon, electricity is mainly produced from oil resources. They are taking 95,1% percent in the generation mix, according to the newest information available publicly. The rest are hydroelectric sources. Small amount of electricity is imported. Electricity production in 2011 amounted to 15.42 billion kWh.

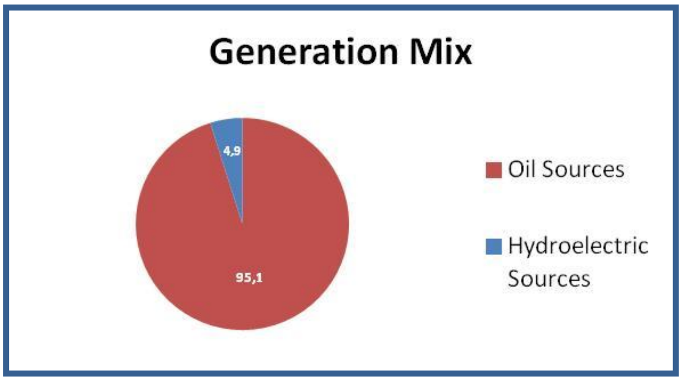


Chart 16: Generation Mix – Lebanon (Mecometer, 2013)

<u>Self-generation</u>

Self generation has an important share in the electricity consumption balance. According to the World Bank, it amounts for 33-38%. In the self-generation both industrialists, hospitals, schools are involved.

<u>Electricity Consumption</u>

According to the CIA World Factbook, the electricity consumption in Lebanon in 2011 was 14,4 GWh. This is the most recent publicly available information.

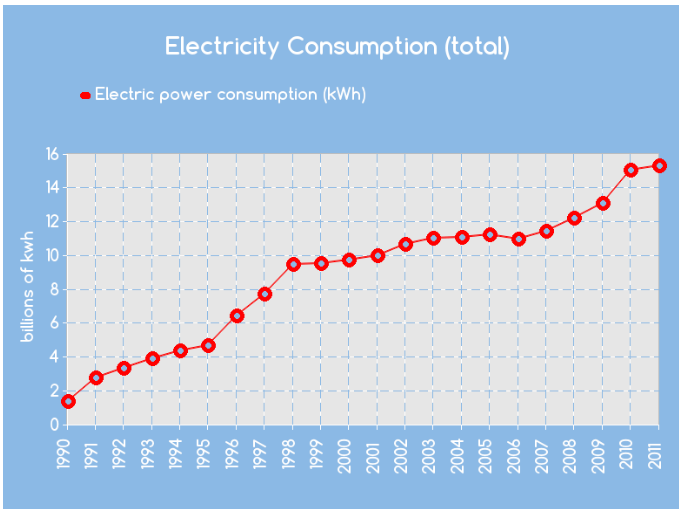


Chart 17: Electricity Consumption – Lebanon (Mecometer, 2015)

Currently, power sector of Lebanon is suffering from frequent, almost regular load shedding. This is both a consequence of increased demand and an unreliable grid. The main cause of the problems with electric grid is the Lebanese Civil War that lasted from 1975 to 1990, as well as some more recent wars, including the one in 2006. All of them had an influence on damaging the electric grid infrastructure. Also, there is 40% of losses problem, from which only 15% are technical. (Ministry of Energy and Water, 2012)

The other issue is the increasing demand. This is partially due to the immigrants coming from Syria and Palestine in the past years. Currently, only 60% of peak demand is covered at peak hours. (BERC, 2014)

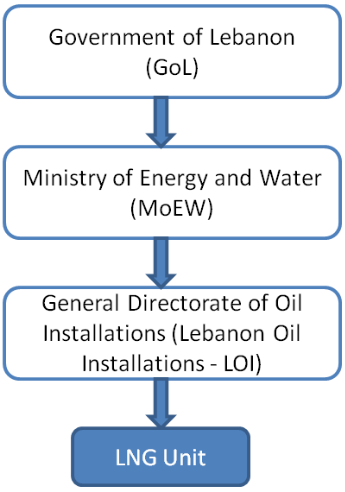
Lebanon is part of Eight Country Interconnection Project, a project which is connecting grids of all its members (Egypt, Iraq, Jordan, Libya, the Palestinian territories, Syria, and Turkey), but due to the instabilities, some of the countries are disconnected.

Structure of PS

Ministry of Energy and Water is the one and only responsible ministry for energy affairs.

In 2010, the Ministry of Energy and Water developed a policy paper that serves as a framework for national organisation of energy sector.

Lebanon Oil Installations (General Directorate of Installations) is a directorate within the Ministry of Energy and Water (MoEW), in charge with construction, management, operation and maintenance of petroleum facilities. It is in charge with importing gas oil, fuel oil and natural gas as well as determining the technical specifications and quality of the imported products. Lebanon Oil Installations own the storage facilities and terminals, as well as the part of GASYLE gas pipeline that is connecting Beddawi region with Syria. LNG Unit exists as a part of Lebanon Oil Installations.



Picture 27: Hierarchy of Authorities for Energy Sector in Lebanon

Electricité du Liban (EDL) is a vertically inntegrated state owned company in charge with electricity generation, transmission and distribution. It is controling over 90% of Lebanese Electricity Sector. The remaining 10% reffers to the hydro plants owned by Litani River Authority. (EDL, 2015)

Total thermal capacity is 2038 MW, but the actual capacity is different and it equals 1685 MW. All thermal plants belong to the company Electricité du Liban.

Thermal Plant	Total Installed Capacity (MW)	Fuel
ZOUK	607	Fuel Oil
JIEH	346	Residual Oil
TYRE	70	Diesel (Gas*)
BAALBEK	70	Diesel (Gas*)
ZAHRANI	470	Diesel (Gas*)
DEIR - AMMAR	435	Diesel (Gas*)
ALHREESHA	75	Residual Oil
TOTAL	2038	

Table 13: Total Thermal Capacity – Lebanon (EDL, 2013)

Two of these thermal plants are combined cycle – CCGT. They are located in Deir Ammar (Beddawi) and Zahrani and both of them are burning Gasoil (Diesel), due to non-existent natural gas supply. These, very important plants have a very high cost of production. Government of Lebanon has a primary goal of importing LNG in order to reduce currently very high cost of electricity production in these two significant power plants. Generally, power plants used for power generation in Lebanon are very old. Even though the nominal capacity of thermal plants is around 2000 MW, there are very frequent outages and the available capacity is insufficient.

Prices of electricity did not change since 1996, when the price of a barrel of oil was 23 dollars. The missing money problem due to the significant changes of prices of oil and other fuels was thus “solved” by the Government in the form of the subsidies to the state-owned Electricite du

Liban (EdL). At the time when Brent (crude oil index) was reaching 133 USD per barrel, electricity was sold to the Lebanese citizens as if the price was still 23 dollars per barrel. This was the first point in which the subsidies reached historical maximum, which can be seen in the chart below. Afterwards, the trend continued because of the lagged payments. Following this logics, the current trend in which the international prices of oil are dropping is actually improving the position of Lebanon in this sense.

Electricity Subsidies account for the significant amount of the transfers that the government is giving as subsidies. In 2013, it amounted for 4,5 percent of GDP. The drop of subsidies in 2009 was due to the introduction of gas into fuel plan. (IMF, 2015)

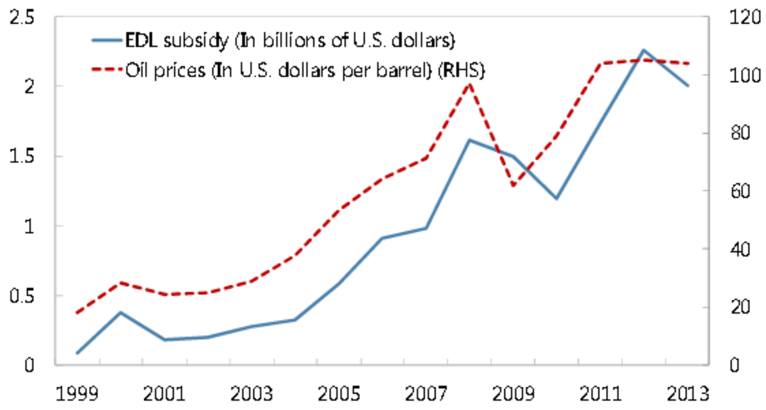


Chart 18: EDL Subsidies and Oil Prices (IMF, 2015)

Restructucturing of the Power Sector

World Bank was involved in restructuring the power sector of Lebanon. The main objectives of the project were institutional reform that would reduce the costs and improve the supply. One of the results that are important for this master thesis is the completion of the prefeasibility study to construct a LNG marine terminal that would significantly reduce the costs of the current fuels supply. There is an open tender for building the regasification plant.

6.2.3. Fuel Supply for Thermal Power Generation

Lebanon is currently importing all of its fuel sources and this is likely to be the case in the following years, taken that the offshore hydrocarbon deposit has not been explorated.

Oil is the main source that Lebanon uses for its power generation.

Coal is used only marginally.

Currently, there is no consumpiton of **natural gas** in Lebanon.

As previously mentioned, there are studies about the potential natural gas reserves in the offshore area of Lebanon of about 25 trillion cubit feet (Tcf). This was anounced by the government of Lebanon. Still, until exploration starts, this is just an estimation.

As for the imports, The Arab Gas Pipeline was supposed to deliver gas to Lebanon from Egypt, but this pipeline is passing through Jordan and Sirya (currently a major conflicting area) and is having interruptions due to the regional problems.

Picture 28: The Arab Gas Pipeline (Wikipedia, 2015)

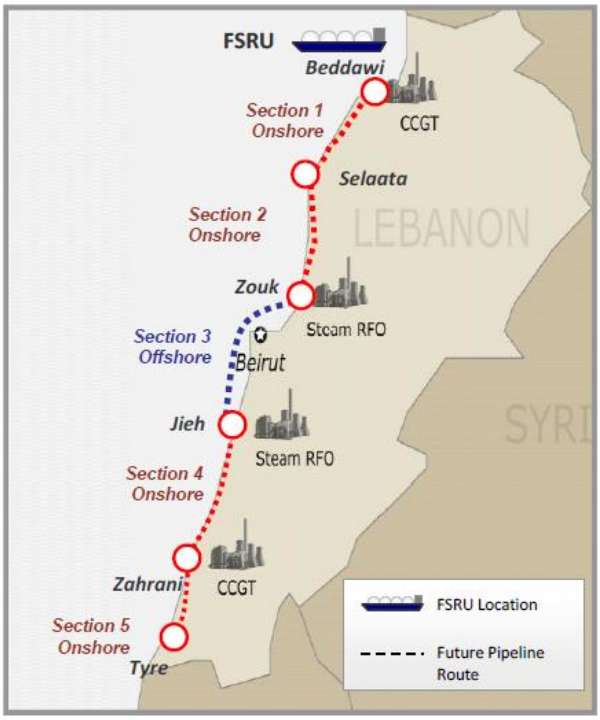
6.2.4. Potential Demand for LNG

The main demand for natural gas in Lebanon is power sector.

Primary destination for imported LNG are CCGT power stations located in Beddawi (North) and Zahrani (South). These plants both have 435MW of installed capacity and are currently burning expensive Gasoil, even though they are built to operate on Gas.

For the purpose of this thesis, only building one FSRU in Beddawi will be considered and the supply possibilities that are likely to arrise with this infrastructure.

Apart from current demand for the CCGT plant in Beddawi, imported LNG will be used for covering the future CCGT capacity expansion projects.



Picture 29: Lebanon Power Stations and Gas Infrastructure (GNF Knowledge Base, 2014)

According to the confidential materials of Gas Natural Fenosa, an expansion of beddawi CCGT plant of 500 MW to current capacity of 435 MW is planned in 2016. An additional plant that could be supplied from the FSRU in Beddawi is Zouk (194 MW), which is also conditioned to the completion of the pipeline project presented on the picture below. In total, it is around 1129 MW.

Accordingly, the demand for LNG that is necessary amounts to : **1.8 bcm.**

6.2.5. LNG Regulatory Framework

Ministry of Energy and water published in June 2010 a regulatory framework for energy sector - ¨Policy Paper for Electricity Sector¨, a policy for the medium and long term. There is no specific regulation related to LNG.

6.2.6. Building a Competitive LNG Price Reference

Since there is no wholesale electricity market developed in Lebanon, it is not possible to know the average price they pay to EdL for the production of electricity. As the reference price thus is necessary to take a look at the tarrifs that the end users are charged and extract information from there.

Electricity Tariffs

It is previously mentioned that one of the problems with the economy of Lebanon is the fact that inefficient electricity sector is been given subsidies by the government. We can suppose that these subsidies are mostly given to ¨home and commercial use¨. The tariff that is most close to the actual revenue provided to the EdL, which should represent the cost of electricity is the High Tension Active Energy Tariff. In this case it amounts for 115 Lebanese Pounds or **7,6 US cents per kWh,** or in the units more suitable for LNG analysis **- 22,35$/MMBtu** (1kWh=0,0034mmbtu).

Low Tension			
Lighting, home and commercial use		Street lighting, public establishments, free medical care centers, hospitals, mosques, churches, cinemas, charity groups, hotels	Industry, craftsmen, agriculture, water treatment and pumping stations
Slab in kWh	Tariff in LBP/kWh	Tariff in LBP/kWh	Tariff in LBP/kWh
1 - 100	35	140	115
101 - 200	55	140	115
201 - 300	55	140	115
301 - 400	80	140	115
401 - 500	120	140	115
over 500	200	140	115

Medium Tension				High Tension
Industry, craftsmen, agriculture		Other subscribers		All subscribers
Tariff in LBP/kWh (Active Energy)	Tariff in LBP/kVARh (Reverse Energy)	Tariff in LBP/kWh (Active Energy)	Tariff in LBP/kVARh (Reverse Energy)	Tariff in LBP/kWh (Active Energy)
130	50	140	50	115

Industrial			
Summer Season (April 1 - September 30)		Winter Season (October 1 - March 31)	
	Tariff in LBP/kWh		Tariff in LBP/kWh
Night Rate (from 00:00 to 07:00)	80	Night Rate (from 00:00 to 07:00)	80
Day Rate (from 07:00 to 18:30)	112	Day Rate (from 07:00 to 16:30)	112
Peak Rate (from 18:30 to 21:30)	320	Peak Rate (from 16:30 to 20:30)	320
Day Rate (from 21:30 to 23:00)	112	Day Rate (from 20:30 to 23:00)	112
Night Rate (from 23:00 to 24:00)	80	Night Rate (from 23:00 to 24:00)	80

Table 14: Electricity Tariffs – Lebanon (EdL, 2014)

This price in terms of fuel price for this electricity generation, considering the efficiency of 55% for CCGT plant is **12,292 $/mmbtu,**

Costs

Supplying Region: Sabine Pass, Louisiana, USA
Gas Natural Fenosa has a 3.5 mtpa LNG contract with Sabine Pass Liqufaction, a subsidy of Cheniere for 20 years supply starting from 2015/2016. (Chenier, 2015)

FSRU Unit Location: Beddawi, Lebanon

Picture 30: Shipping distance between supplying region and Lebanon (Google Maps, 2015)

Shipping distance between supplying region and Lebanon is aroun 12.000 km.

1. LNG Free on Board Price consisted of cost of gas with the cost of liquefaction.

In this case, the price formula for Sabine Pass in Lousiana which would be the supplying region in this case is (Cheniere, 2015):

P_{FOB} = 115% HH + (0,86-0,14*CPI/CPo)*Xo

Where:

HH - Henry Hub Index
Xo – Liquefaction Costs (14% influenced by the CPI Index change)

For the purpose of this thesis, value of Henry Hub Index will be fixed to 3.6 $/MMbtu which is calculated as an average of 5-years historic values (March 2009 – March 2015) and forward prices for following 5 years (april 2015 – april 2020). (Gas Natural Fenosa Database, 2015)

As for the liquefaction costs the value of 3.5 $/MMbtu is used which represents the liquefaction costs with ommited change due to the effect of the inflation, since it has a very small effect on the final price.

The estimation of LNG FOB price is

P_{FOB} = 115% * 3.5 $/MMbtu + 3.5 $/MMbtu = **7.525 $/MMbtu**

2. Shipping Costs

Acoording to studies of Shipping Department of Gas Natural Fenosa, the cost of shipping LNG from Louisiana USA to Beddawi, Lebanon (distance of around 12.000 km) is approximately **1.687 $/MMbtu.** (Gas Natural Fenosa Business Intelligence, 2015)

3. Regasification Costs

As mentioned in the section dedicated to the analysis of Ghana, regasification costs calculated as the average of global regasification costs is **0,6 $/MMbtu $.**

4. Total Costs

Total costs that are necessary for the supply of LNG from terminal Sabine Pass in Lousiana, United States to Beddawi, Lebanon is **9,812 $/MMbtu**.
In this amont the Free on Board gas supply is included, as well as shipping costs and costs of regasification.

Comparing electricity prices expressed in terms of gas supply and total costs for introducing LNG from this source, it can be conclued that under these prices, the offer is not competitive. Solution can be an introduction of a hybrid formula.

6.3. Hawaii

6.3.1. Country Overview

Picture 31: Location of Hawaii (Wikipedia, 2015)

Quick Facts	
Capital	Honolulu
Population	1,419,561 (Asian 37.7%, Caucasian 22.7%, Mixed 19.4%, Native Hawaiian 9.4%, Hispanic 8.9%, African American 1.5%, Other 0.4% (2010 census)
Surface	28,311 km^2
GDP (PPP)	$78,110 millions
CAGR (2003-2013)	2%
Official Language	English, Hawaiian
Official Religions	Christianity and the Church of Jesus Christ of Latter Day Saints (Mormon) are the largest religions
Time Zone	Hawaii-Aleutian Standard Time (UTC-10). Hawaii does not observe Daylight Savings.

Table 15: Hawaii – Quick Facts (Wikipedia, 2014)

Hawaii is one of the states that are forming the United States of America (USA). Hawaii was the last one from the 50 states that joined the USA. It is consisted of thousands of islands and it is located in the Oceania. From all the islands, there are 8 which are the biggest and the only inhabited ones: Kahoolawe, Maui, Lanai, Molokai, Oahu, Kauai, Niihau and Hawaii Island, which is the largest one. The capital is Honolulu, located in the Oahu Island. (Wikipedia, 2015)

Hawaii is the state which is one of the largest in the USA and has the least population, but it is on the other hand, one of the most densely populated states with a high diversity. Its culture has a significant influence of North America and Asian cultures. It is the only country in the USA that has Asian constituting the demographic plurality. Most of the people are living in Oahu.

Hawaii has astonishing nature, diverse climate, which is mostly tropical. The area covering the islands is not very urbanized, and it is well known for its wild landscapes and beaches. (Wikipedia, 2015)

Main products of Hawaii are: cane sugar, pineapple, and flowers and nursery products. Nevertheless, the main source of income is certainly tourism, and everything related with it. In 2013, the industry that had the biggest share in GDP was finance, leasing, real estate and rental. It accounted for 22% of the GDP with a 2,2 percent growth. It was followed by the government (22,4%). Significant amount of the GDP (around one tenth) is spent on energy, which can be noticed in the chart below. Compared to the average spendings in the USA, this figure is much higher. (IEA, 2014)

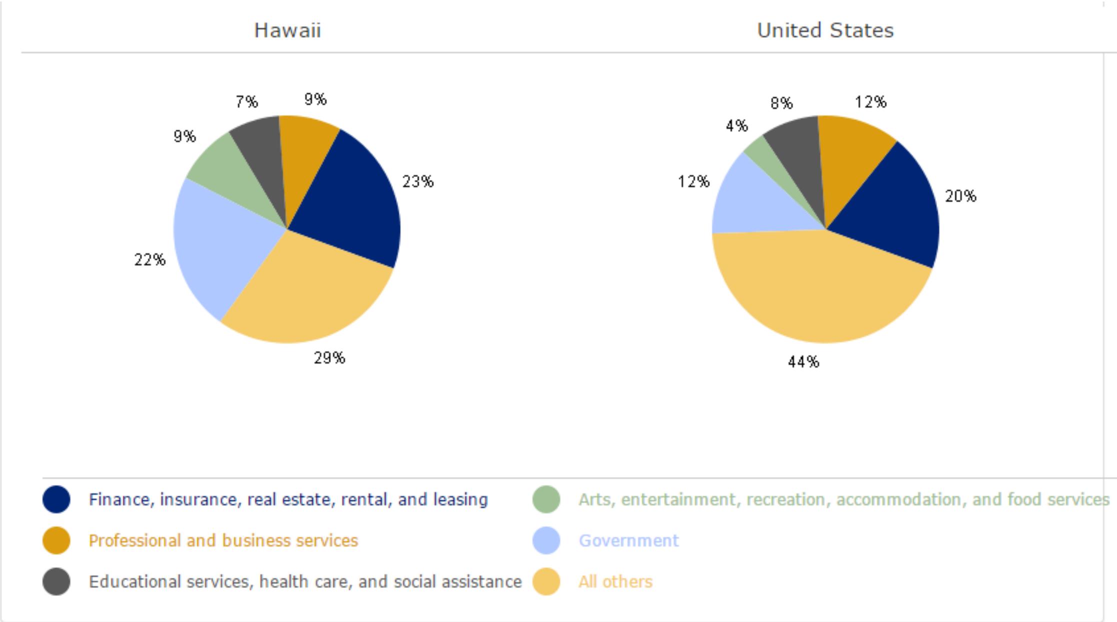


Chart 19: GDP by Industries – Hawaii and USA (BEA, 2015)

Economy Overview	
GDP : [2013]	**75.235 USb$**
GDP (Real): [2013]	**70.110 USb$**
GDP Growth:	**3,75% [2013]**
Inflation: [2013]	**1,5%**
Unemployment Rate:	**4,4 %**
Currency:	**U.S. Dollars (USD)**

Table 16: Economy Overview (CIA Factbook, 2014)

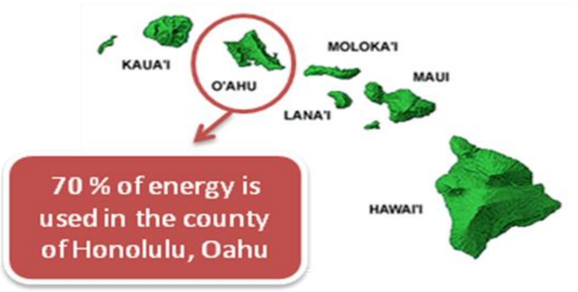
Governor: David Ige, D (to December, 2018)
Lieut. Governor: Shan Tsutsui (December, 2018)

6.3.2. Power Sector Analysis

(EIA, 2015)

It was previously stated that significant resources are given for energy in Hawaii, even though it is not a state with energy intensive industry, since tourism is the main driver. The real reason for this is the position and isolation of Hawaii that makes it the most petroleum-dependent state in the United States of America, and at the same time, the state with the highest electricity prices. There is neither interconnection with the rest of the USA nor between the islands. It has completely different infrastructure from the rest of the states and unlike the rest of it, where less than 1% of energy is created using oil resources, this share in the state of Hawaii is significantly higher.

As previously mentioned, the region where most of the residents of Hawaii live and where greatest share of energy is consumed is the island of Oahu, particularly the capital Honolulu.



Picture 32: Hawaii Islands (Hawaiicity, 2015)

Recently, a Hawaii Clean Energy Initiative (HCEI) was published with goals of achieving 70% of clean energy in Hawaii by 2030. The plan is that 30% of it will be done by applying certain efficiency measures and the rest by locally generated renewable sources. This is an initiative that started as a response to the current energy mix that is used for electricity generation.

Installed Capacity

Hawaii is one of the eight countries in the USA which has installed geothermal capacity, accounting for 35% of the whole renewable portion in the generation mix. It also has an electricity generator fuelled exclusively with bio fuels. (IEA, 2015)

Electricity Production

Great share of generation mix belongs to oil and oil products. The share of oil in the electricity production mix in 2013 was 70 percent, which is significantly higher comparing to the rest of the country, in which oil is used only in 1% of electricity production.

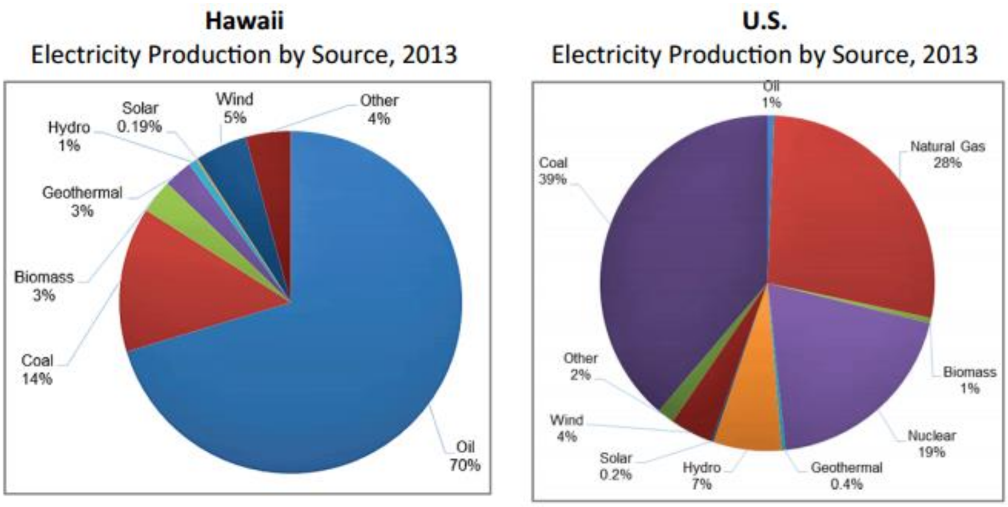


Chart 20: Electricity Production Hawaii (Hawaii State Energy Office, 2015)

Apart from oil, second source is coal (14%), followed by biomass and geothermal, which is present only in Hawaii. Natural gas, which has a significant share in the U.S. mix for electricity production, is not used in Hawaii due to inexistence of pipeline interconnections with the coast.

Total electricity generated in the state of Hawaii amounted for 9,88 billions of KWh, of which 5,84 billions of KWh were not generated by the utility companies. (Hawaii Economic Data, 2015)

Electricity Consumption

Due to its mild climate and service-oriented industry, consumption is very low, one of the lowest in the USA. In 2012, 93% of its energy was imported. In 2014 total electricity consumed was 9,4 billion kWh. (Hawaii Economic Data, 2015)

Electricity Prices

Due to previously mentioned reasons, the prices of electricity in Hawaii are three times higher than the average price in the US.

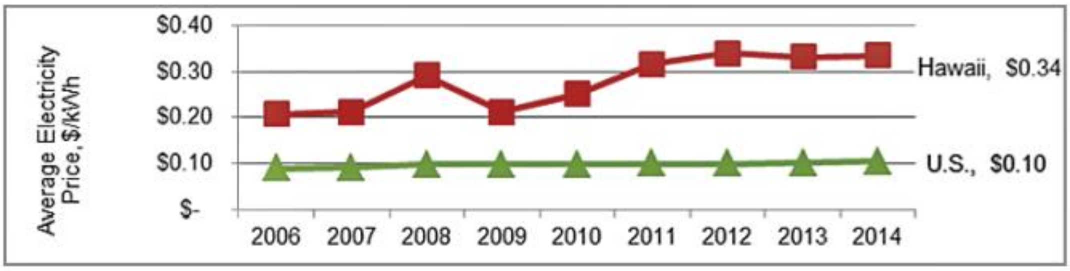


Chart 21: Comparison of electricity prices in Hawaii and in the rest of the US (Hawaii Energy Facts and Figures, 2015)

Below the key information about different islands and Hawaii island as a whole is given, regarding electricity generation and fuel prices.

Monthly Energy Trend (September 2014)	**Hawaii**	**Oahu**	**Maui**
Electricity Generated by Diesel	40,439,754 kWh	4,171,88 kWh	72,312,696 kWh
Electricity Generated by Main Power Plant	573,127,335 kWh	407,989,488 kWh	81,650,296 kWh
Electricity purchased form IPP	333,558,006 kW	254,0213,392 kWh	20,116,006 kWh
Fuel Oil Avg. Cost/Bbl of Oil consumed	131.12 $	137,74 $	96,85 $

Maui has more than **50%** of electricity generated by DIESEL

Most of the generation is in **Oahu**

Brent Historical Spot Price (09/14): **97,297 $/Bbl**

Table 19: Electricity and fuel generation and prices in Hawaii – Highlights (Compiled based on data from Hawaii Economic Data, 2015)

The most important are following information:

- Oahu has most of the generation - *Oahu will be chosen for the location of the FSRU*
- The prices of fuel oil are following trend that index Brent has, but are much higher

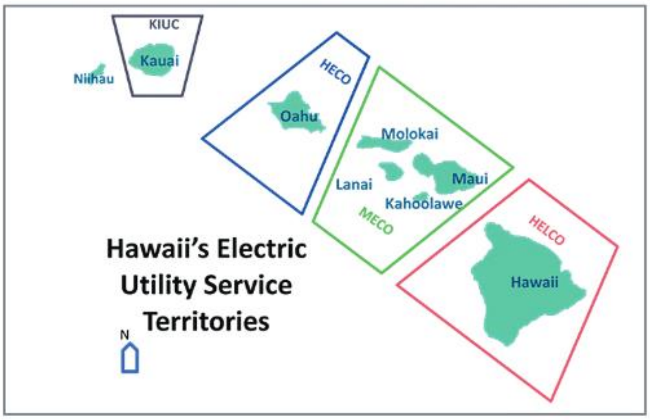
The Structure of Power Sector

The power sector of Hawaii is split into 6 small power sectors, which are not interconnected among themselves and have separated electrical grids. There are four different utilities serving the island in the business of electricity generation, purchase, transmission, distribution and sales. The market exists only in power generation segment, but in a form of Independent Power Producers (IPPs), which are allowed to compete for the lacking power that the utilities are unable to produce.

Hawaii Public Utilities Commission (PUC) is the appointed organ that is in charge of regulating the utilities that are operating in Hawaii. On top of it, there is the **Federal Energy Regulatory Commission (FERC)**, which is an independent agency that regulates the transmission of electricity, natural gas and oil inside the United States of America. They are also in charge of reviewing liquefied natural gas (LNG) proposals and infrastructure projects. It is important to mention that FERC is not in charge with regulating local distribution natural gas pipelines.

The most important and greatest supplier of gas in Hawaii is **Hawaiian Electric Industries Inc.** They are in charge of supplying power to 95% of population that is living in the state of Hawaii's .

Hawaiian Electric Industries Inc. are operating via its electric utilities: Hawaiian Electric Company (HECO), which operates in the island of Oahu, Hawaii Electric Light Company (HELCO), which serves the Hawaii Island and Maui Electric Company (MECO), operating in the islands of Maui, Molokai, Lanai and Kahoolawe. Kauai is supplied by the company Kauai Island Utility Cooperative (¨KIUC¨). MECO and HELCO are wholly owned subsidies of Hawaiian Electric Company (HECO). (Wikipedia, 2015)



Picture 33: Hawaii´s Electric Utility Service Territories (Hawaii State Energy Office, 2015)

Electricity in Hawaii is either generated by these utilities or by the power generated by the Independent Power Producers (IPPs). For these purposes, a framework exists and it is called "Competitive Bidding Framework". The procedure for IPPs is regulated by the Hawaii Public Utilities Commission (PUC). Independent Power Producers that are allowed to bid have to have capacities greater than:

1. 5MW – Oahu
2. 2.72 MW – MECO, HELCO

Below there is the breakdown of the different fuels that are used in the different islands and the different companies - subsidies of Hawaiian Electric Industries Inc. that are in the state of Hawaii. This is representative for the whole island, because Hawaiian Electric Companies cover 95% of Hawaiian population.

Fuel Sources	Hawaiian Electric (Island of Oahu)	Hawaii Electric Light (Island of Hawaii)	Maui Electric (Islands of Maui, Molokai and Lanai)	Hawaiian Electric Companies
Oil	73.40%	59.46%	75.35%	71.95%
Coal	18.92%	0	1.12%	14.38%
Biofuel	0.40%	0	0.11%	0.31%
Biomass	0	0	3.42%	0.43%
Geothermal	0	24.28%	0	2.95%
Hydro	0	3.05%	0.40%	0.42%
Solar	0.38%	0.13%	0.42%	0.36%
Solid Waste	5.21%	0	0	3.92%
Wind	1.69%	13.08%	19.18%	5.28%
TOTAL:	100%	100%	100%	100%
Total from Renewable Resources	7.68%	40.54%	23.53%	13.67%

*Based on the amount of electricity generated by the Hawaiian Electric Companies and purchased from independent power producers in 2013

Table 17: Fuel Mix – Hawaiian Electric Utilities and purchased from the IPPs (Hawaiian Electric, 2013)

Hawaiian Electric is analysing the possibilities to convert some of its plants to run on LNG.

6.3.3. Fuel Supply for Thermal Power Generation

Hawaii is the most fossil fuel dependent state in the USA. The main reasons for this are following:

1. Scarcity of fuel oils
2. Vulnerability to fluctuations in oil prices and availability.

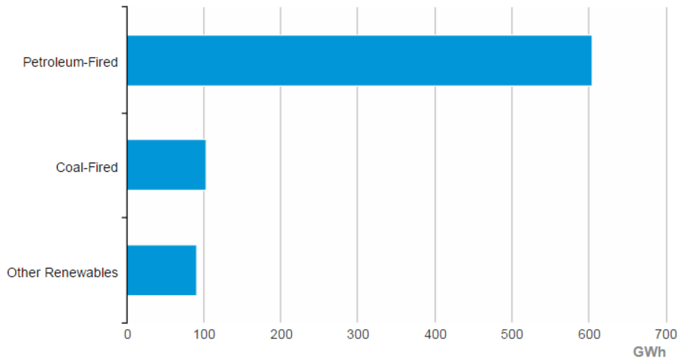
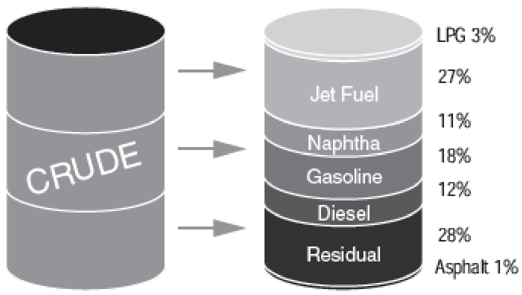


Chart 22: Hawaii Net Electricity Generation by Source, (IEA, 2015)

Petroleum

There is neither production of petroleum nor the reserves in the state of Hawaii, thus it is a petroleum-importing country. The sources where the imported crude comes from are Pacific Rim countries, Africa, Russia, South America as well as the Middle-East. As for the processing, two refineries exist and are situated in Honolulu. Electric sector is the second by the usage of petroleum. The largest consumer is transportation sector.



Picture 34: Crude Oil Products in Hawaii (Gas Natural Fenosa Knowledge Base, 2015)

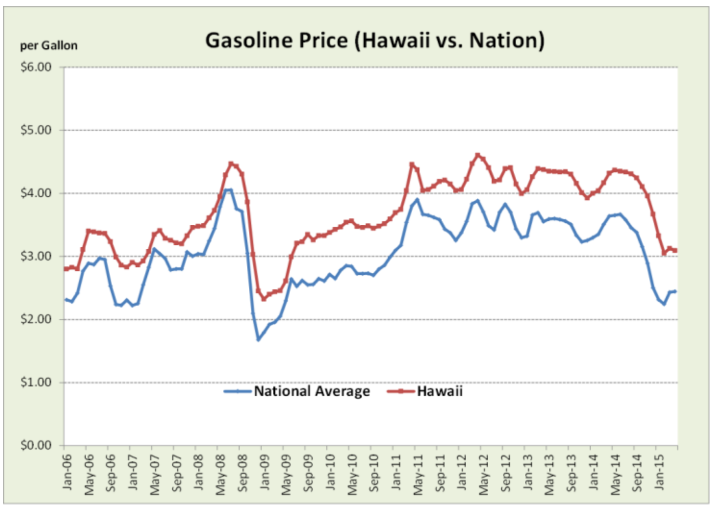


Chart 23: Gasoline Prices: Hawaii Vs. Nation (Hawaii Economic Data, 2015)

Natural Gas

Similar to petroleum, there is neither production of natural gas nor any reserves in the state of Hawaii. What is produced instead is called syngas, in a plant located in Oahu. Hawaii has the lowest consumption of gas among the states in the US.

¨Syngas, or synthesis gas, is a fuel gas mixture consisting primarily of hydrogen, carbon monoxide, and very often some carbon dioxide. The name comes from its use as intermediates in creating synthetic natural gas (SNG) and for producing ammonia or methanol. Syngas is usually a product of gasification and the main application is electricity generation.¨ (Wikipedia, 2015)

Coal

The use of coal in Hawaii started in the end of the eighteens. It was a measure that was aimed at reducing the dependence on petroleum, particularly in the power sector. There are no reserves of coal in state of Hawaii.

6.2.4. Potential Demand for LNG

For the almost entirely petroleum-based power sector as it is the case with Hawaii, and the rest of the systems that are islands, the only way of reducing the prices of electricity is by diversifying the fuel mix. Developments in the sector of gas are now creating possibilities of reaching these isolated places and provided them with gas in the form of LNG. Historically in this type of systems, petroleum products were the easiest ones to transport of all the other fossil fuels. Nowadays, technological innovations are allowing gas to become competitive, as well. In this aspect, the most important are developments of regasification plants as well the innovations in the shipping part of the LNG value chain. For power system of Hawaii shipping method innovations are of the greatest importance. Recently standardized cryogenic (refrigerated) shipping containers allow small quantities of LNG to be transported to a certain location, without the need for a specialised LNG vessel. This could in case of Hawaii be used also for bypassing the Jones Act, which will be explained in the following paragraph.

Globally, world is facing relatively low natural gas prices, and combining this with the developments of floating storage and regasification units, which require lower investments and less time for building as well as standardized cryonic shipping containers, there are possibilities for LNG to become competitive.

	Plant Name	Operator	Generation Technology	Capacity [MW]	Maximum Generation [MWh]	Actual Generation [MWh]	Utilization Rate [%]	Average Heat Rate [Btu/kWh]
HAWAII								
	Hamakua Energy Plant	Hamakua Energy Partners LP	CCGT	66.0	578,160	215,791	37.3%	8,610
	Kanoelehua	HELCO	IC	9.5	83,220	299	0.4%	12,013
	Kanoelehua	HELCO	GT	11.5	100,740	20	0.0%	28,200
	Keahole	HELCO	IC	7.5	65,700	3,107	4.7%	11,003
	Keahole	HELCO	GT	63.6	557,136	197,173	35.4%	12,185
	Puna	HELCO	ST	15.5	135,780	68,039	50.1%	14,733
	Puna	HELCO	GT	23.6	206,736	12,979	6.3%	12,058
	Shipman	HELCO	ST	15.0	131,400	4,719	3.6%	17,343
	W H Hill	HELCO	ST	37.1	324,996	195,390	60.1%	13,062
	Waimea	HELCO	IC	7.5	65,700	1,836	2.8%	11,355
HONOLULU								
	Honolulu	HECO	ST	113.0	989,880	95,534	10%	13,876
	Kahe	HECO	ST	559.0	4,896,840	2,996,653	61%	10,218
	Waiau	HECO	GT	102.0	893,520	8,810	1%	18,081
	Waiau	HECO	ST	397.0	3,477,720	1,014,460	29%	10,696
	Kalaeola Cogen Plant	Kalaeloa Partners LP	CCGT	214.0	1,874,640	1,445,668	77%	8,410
KAUAI								
	Kapaia Power Station	KIUC	GT	39.1	342,516	211,971	62%	8,669
	Port Allen	KIUC	CCGT	41.4	362,664	32,338	9%	15,539
	Port Allen	KIUC	IC	91.4	800,664	168,360	21%	9,284
MAUI								
	Hana Substation	MECO	IC	2.0	17,520	97	1%	10,990
	Kahului	MECO	ST	34.0	297,840	176,582	59%	14,321
	Maalaea	MECO	CCGT	133.2	1,166,832	636,642	55%	8,858
	Maalaea	MECO	IC	96.6	846,216	189,227	22%	10,116
	Miki Basin	MECO	IC	10.4	91,104	19,595	22%	10,249
	Palaau Power	MECO	GT	2.5	21,900	239	1%	18,435
	Palaau Power	MECO	IC	12.6	110,376	33,395	30%	9,942
Total Oil						7,728,924		
HONOLULU	AES Hawaii	AES Hawaii Inc	ST	203.0	1,778,280	1,382,098	78%	10,730
Total Coal						1,382,098		
Grand Total						9,111,022		10,169

Table 18: Fossil Fuel based Power Generation Plants in Hawaii (EIA, 2011)

Power sector is the main driver for LNG imports. Below, a breakdown of the 2011 LNG - equivalent by county and fuel is given. 64% takes place in Oahu. According to the studies of Gas Natural Fenosa, total amount of fuel that is possible to be replaced amounts to nearly 1,9 mtpa of LNG.

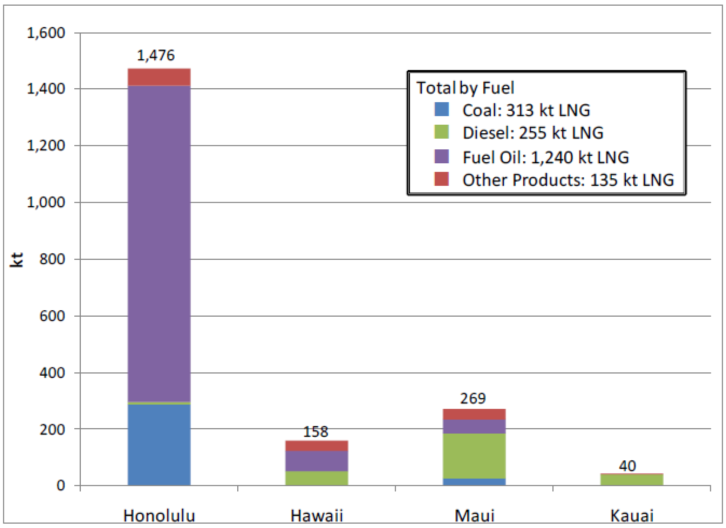


Chart 24: Hawaii – LNG Demand Projection Material (GNF Knowledge Base, 2015)

6.2.5. LNG Regulatory Framework

The most important regulatory issue that could be a problem for possible imports of LNG to Hawaii are related to The Jones Act and its requirements for the shipping aspect of any trade in the United States.

The Jones Act requires any trade between two US ports to be carried on US-built, US-flagged vessels, in which the crew must be three-quarters comprised of US merchant seamen. There was a try to make an amendment to this Act in January 2015, but it was unsuccessful. The size of US-Built LNG Carriers is too big for Hawaii´s import needs. It is not certain whether FSU/FSRU are considered to be a ´´ship´´ under the Jones Act. There are no Jones Act-qualified LNG tankers available to carry US natural gas to Hawaii (according to Congressional Research Service Report from July, 2014).

6.2.6. Criteria for the Suppliers of LNG

In November 2014, a public Invitation to bid for the suppliers of LNG has been published by Hawaii Gas Utility. Below the requirements and evaluation criteria for possible suppliers is given.

Invitation to Bid - Hawai'i Gas Bulk LNG Supply Project | **November 14, 2014**

4.3.6. **Short List Selection**

Hawai'i Gas shall have the right, in its absolute discretion, to select bidders for short-listing on the basis of its analysis of the non-binding bids. It anticipates completing its review and short-listing process by **April 2, 2015**.

4.4 **Selection Criteria**

Interested parties may be a company or a consortium of companies. Bidders' proposals will be evaluated on the following criteria; note, however, that these lists are not to be understood as being exclusive, and that Hawai'i Gas reserves the right to apply other criteria in evaluating bids:

LNG SUPPLY BID EVALUATION CRITERIA	
Criteria	**Remarks**
Key Criteria:	
Ability to supply	The bidder should demonstrate its ability to procure and supply sufficient LNG to meet the gas supply needs of Hawai'i's market as described in this ITB throughout the term of the LNG SPA and FSRU Services Agreement, as they may be extended. For instance, the bidder could describe to Hawai'i Gas (i) the contracted quantities it has secured from upstream LNG suppliers, and (ii) the duration of the relevant gas supply contracts. Such upstream supplies could be procured from third party LNG suppliers or from the bidder's own planned/committed LNG supply assets, potentially substantiated in the form of an upstream Sales and Purchase Agreement or equivalent document.
Supply risk (country, portfolio diversity)	The bidder should demonstrate its ability to procure LNG from reliable and secure supply sources, in a manner which supports Hawai'i Gas' objective of supply diversification at both country and portfolio levels. The bidder should characterize the risk associated with its proposed supply portfolio taking into account (i) *country risk* (*e.g.*, concentration of supply sources from a single country); and (ii) *concentration risk* (*e.g.*, how negatively would LNG supply to Hawai'i be affected if the proposed supply project were to be compromised).
Price competitiveness and flexibility	The bidder should demonstrate its ability to offer competitively-priced gas to Hawai'i's gas buyers throughout the term of the LNG SPA and FSRU Services Agreement, as they may be extended. The bidder should provide and describe (i) its proposed price formula; (ii) mechanisms that will help to manage price volatility (*e.g.*, price reviews); and (iii) the measures the bidder would take to ensure that its LNG price would remain competitive throughout the term of the LNG SPA and FSRU Services Agreement, as they may be extended.
Creditworthiness	The bidder should demonstrate sufficient credit standing to meet its obligations to (i) its upstream supplier, if any (*e.g.*, ability to make payments for the supply of LNG cargoes and fulfil any Take-or-Pay ("TOP") obligations as they become due); (ii) any involved LNG terminal operator (*e.g.*, ability to pay LNG terminal tolling charges); and (iii) Hawai'i Gas and/or other LNG buyers (*e.g.*, the ability to compensate

Picture 35: Invitation to Bid – Hawaii Gas Bulk LNG Supply Project, page 1 (Hawaii Gas Utility, 2015)

LNG SUPPLY BID EVALUATION CRITERIA	
Criteria	**Remarks**
	buyers in the event that it fails to supply).
<u>Secondary Criteria:</u>	
Upstream project risk	The bidder should characterize completion and performance risks associated with any proposed upstream project on which the bidder proposes to rely for the supply of LNG it will use to support deliveries to Hawai'i (*e.g.*, whether Final Investment Decision on the project has been taken; status of project development; anticipated date of project completion; risk mitigants such as access to alternative LNG supply sources available to the bidder).
Price indexation diversity	Bidders who offer gas price mechanisms that do not rely exclusively on oil indexation will be considered favorably, as such mechanisms should mitigate Hawai'i's exposure to oil price levels and to oil price volatility.
LNG market experience	Bidders who have substantial expertise and experience in managing upstream gas/LNG projects and in serving downstream gas markets will be considered favorably.
Flexibility of terms	Bids which offer more flexibility in contract terms (*e.g.*, substantial intra-month and annual offtake flexibility) will be considered favorably relative to bids which offer less flexibility.
Credit support requirements	Bidders who request less demanding or more flexible credit support requirements on buyers will be considered favorably.
<u>Other Considerations:</u>	
Supply chain control	Bidders who have more control over the LNG supply chain (*e.g.*, bidders holding equity stake in upstream LNG projects, or who own LNG carriers or who have LNG carriers under long-term charter) will be considered favorably as this can be expected to provide greater supply resilience.
Contract start date & duration	Bidders who can supply LNG as and when the FSRU is on-station and are prepared to commence commissioning and commercial operations, and who can offer flexibility as to first LNG deliveries, will be considered favorably.
Dispute Resolution	Preference will be given to bids which propose dispute resolution procedures that should result in the speedy resolution of disputes at minimum cost.
Deviation from Term Sheet Provisions	Preference will be given to bids which propose the fewest substantive departures from the terms and conditions suggested in the FSRU Services Agreement Term Sheet.
Business Practices	Preference will be given to bids which incorporate detailed and robust provisions addressing compliance with applicable anti-bribery, anti-terrorism and similar laws.

Picture 36: Invitation to Bid – Hawaii Gas Bulk LNG Supply Project (Hawaii Gas Utility, 2015)

This invitation is published for the case of Hawaii, but the requirements and criteria that are presented in it can be used as a starting point for suppliers to other countries as well.

6.2.7. Building a Competitive LNG Price Reference

Electricity Prices

In the chart below it can be noticed that both electricity prices as well as the prices of gasoline in Hawaii State follow the worldwide index of crude oil – Brent.

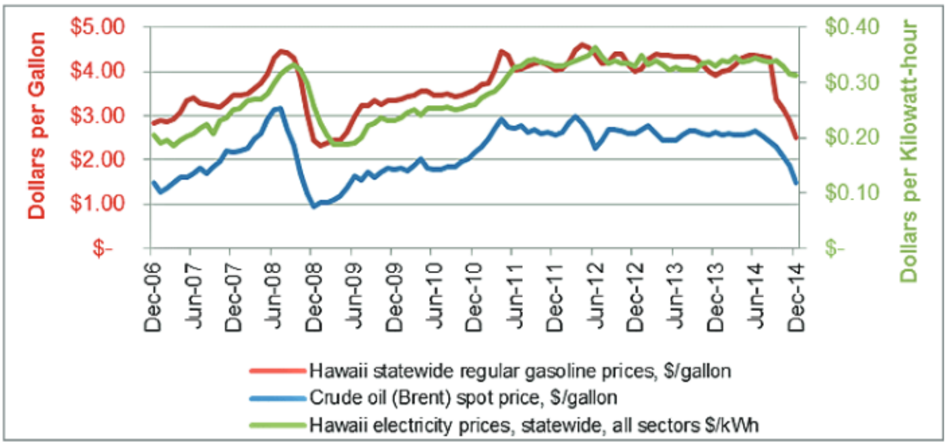


Chart 25: Brent crude oil comparison to Hawaii State Energy Office, 2015)

Electricity Prices: 0,3$/kWh or **88,23 $/MMBtu**.

This price in terms of fuel price for this electricity generation, considering the efficiency of 55% for CCGT using natural gas is **48,526 $/mmbtu**,

Costs

	Potential Savings			
	2015	2020	2025	2030
Alaska	na	na	8%	8%
Australia	-8%	3%	3%	4%
Canada	na	14%	15%	16%
US Gulf Coast	33%	35%	32%	31%
US West Coast	na	47%	44%	43%

Indexed to **international oil prices** Savings are **not substantial.**

Indexed to **US natural gas prices** **31-47%** of savings if LNG is imported from the US Coast

** Because of new EPA policies, LS diesel is expected to be the main utility fuel in Hawaii before 2020. At present, on Oahu LS diesel and LS fuel oil are almost identical in cost per mmBtu.*

Picture 37: Supplying options for Hawaii

Even though West Coast is closer, in the mid-term East Coast is more realistic option because in the West Coast there are no projects that could supply in the following years.

Supplying Region: Sabine Pass, Louisiana, USA
Gas Natural Fenosa has a 3.5 mtpa LNG contract with Sabine Pass Liqufaction, a subsidy of Cheniere for 20 years supply starting from 2015/2016. (Chenier, 2015)

FSRU Unit Location: Oahu, Hawaii

1. LNG Free on Board Price consisted of cost of gas with the cost of liquefaction.

In this case, the price formula for Sabine Pass in Lousiana which would be the supplying region in this case is (Cheniere, 2015):

P_{FOB} = 115% HH + (0,86-0,14*CPI/CPo)*Xo

Where:

HH - Henry Hub Index
Xo – Liquefaction Costs (14% influenced by the CPI Index change)

For the purpose of this thesis, value of Henry Hub Index will be fixed to 3.6 $/MMbtu which is calculated as an average of 5-years historic values (March 2009 – March 2015) and forward prices for following 5 years (april 2015 – april 2020). (Gas Natural Fenosa Database, 2015)

As for the liquefaction costs the value of 3.5 $/MMbtu is used which represents the liquefaction costs with ommited change due to the effect of the inflation, since it has a very small effect on the final price.

The estimation of LNG FOB price is

P_{FOB} = 115% * 3.5 $/MMbtu + 3.5 $/MMbtu = **7.525 $/MMbtu**

2. Shipping Costs

Acoording to studies of Shipping Department of Gas Natural Fenosa, the cost of shipping LNG from Louisiana USA to Oaho, Hawaii (distance of around 10.000 km) is approximately **1.35 $/MMbtu.** (Gas Natural Fenosa Business Intelligence, 2015)

3. Regasification Costs

As mentioned in the section dedicated to the analysis of Ghana, regasification costs calculated as the average of global regasification costs is **0,6 $/MMbtu $.**

4. Total Costs

Total costs that are necessary for the supply of LNG from terminal Sabine Pass in Lousiana, United States to Oaho, Hawaii is **9,475 $/MMbtu**.
In this amont the Free on Board gas supply is included, as well as shipping costs and costs of regasification.

Comparing electricity prices expressed in terms of gas supply and total costs for introducing LNG from this source, it can be conclued that under these conditions and prices, offering LNG to Hawaii is competitive and can bring substantial savings to this state.

7. Conclusions and Remarks

Natural gas represents the only fossil fuel with projected future growth. This is due to several reasons. Firstly, is a transition fuel from carbon intensive fossil fuels. For power generation industry this means a cleaner way of producing electricity for numerous economic, operational and environmental reasons. It is a hydrocarbon with greatest amount of reserves. It is cheaper than the rest of the liquefied petroleum gasses. With the development of liquefied natural gas industry, this resource is made available for numerous countries worldwide. This paper focused on LNG as a fuel for power generation projects in developing countries. These countries mainly have inabilities or difficulties in constructing huge infrastructures in the form of gas pipelines or some geopolitical problems, but have a power sector with increasing demand. In some of the cases, for this reason, these countries are using more expensive fuels. This paper suggests introduction of LNG together with flexible and inexpensive floating storage and regasification units (FSRUs) that would serve as a solution for their increasing demand issues and offer competitive price. In the previous works, this solution was proven to be efficient. This paper complements previous work with a framework-methodology for analyzing these countries any other possible developing market worldwide.

In the first section of the paper where the global LNG market overview and projections are given, there are some guidelines for future LNG-to-Power projects. In future research connected with this topic focus should be given to region of Asia-Pacific which will have the highest growth.

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