Impact of Renewable Energy Sources in the European Gas Network.

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Abstract: At the present, there are a large number of studies about the effects and requirements for the integration of renewable generators with the electric grid, in comparison with those focusing on the interactions with the natural gas grid. Nevertheless, studies centred on natural gas could be important.

A model was developed to study the actual capacity of gas infrastructure and his response to a high renewables shared in the energy mix, hence the special interest in analyse the actual behaviour of the elements which bring flexibility to the systems.

Considering a Centralized RES scenarios, in general, the current European gas infrastructure, within the interconnection capacities, storages facilities and LNG imports, might be suitable for response the additional daily demand. However some plans must be made to account for the potential variability related to the gas-fired power generation used to balancing the variable renewable generation.

Keywords: Gas Value Chain, Modelling, Renewable Energy Integration, Energy Storage, Natural Gas.

1 INTRODUCTION

To achieve the EU's energy and climate objectives established by the European commission, the penetration of variable renewable energy sources in the electricity sector is expected to increase significantly over the next two decades. The fluctuating production of renewable sources creates particular challenges for the daily balancing process, i.e. for balancing any difference between the planned or forecast production and demand. Most studies assume a strongly increased contribution from wind and/or solar power developments until the year 2030.

The purpose of building the European Gas Market Model is to provide a better understanding the implications in the current of European natural gas network, the integration of significant amounts of variable renewable generation on the electric grid. A model was developed based on several previous studies, as well using the most recent capacity and transmission data from The European Network of Transmission System Operators for Gas (ENTSOG) [1]

This paper provides a synthesis of the implications of the integration of renewable energy sources, in the electricity and gas sector; the modelling approach; and the implementation of the model in a particular case: Centralized renewable energy sources (RES) scenario.

2 BACKGROUND

A total of around 840 GW of electricity generating capacity is installed within the EU28 [2] of this, 55% is conventional thermal generation capacity (*i.e.* heat-driven generation technologies, such as coal- and gas-fired power plants); these units deliver around 58% of the total amount of electricity generated. Natural gas fired generation has a significant market share in the European energy mix and therefore has enough installed capacity to play a significant role supporting RES.

3 Electricity and Gas Balancing

The participation of RES in the European energy mix, imply that the electricity sector will require significant additional flexibility to be available for daily balancing. Although various studies have shown that these effects may be mitigated by transmission expansion, demand response or an increased use of electricity storage, the same studies have also shown that it would not be economical to fully compensate the corresponding impacts.

Natural gas, coal and nuclear generation technologies, all have the technical capabilities to vary their output in response to changes in power demand. Of these, natural gas-fired technologies are best suited to respond to fast demand changes, due to their high ramping capabilities as well as short start-up times and lower start-up costs. Based that, the gas-fired power plant will be supply-side technology, the main challenges that gas and electricity sectors have to face to balancing an important growth of RES generation are:

- *The ability to cover an increasing spread between peak and trough load on a daily basis.*
- *The need for supplying increased ramp rates.*
- *The ability to deal with increased forecast errors and hence a decreasing predictability of the residual load to be supplied during the day*.

Depending on the future increase of energy efficiency measures, related with a decrease in gas demand, i.e. space heating. These developments could reduce the need for diurnal flexibility in the gas sector. However, these developments are difficult to predict, such that the (positive) impact on the demand for flexibility in the gas sector remains highly uncertain

4 METHODOLOGY:

4.1 Modelling Approach

It has applied the current European gas capacity in an optimization model[1]. The model optimizes the operation mode of each element of the Annex B: Gas value chain (Annex B), in the daily bases, on the cost minimization on linear programming for supply-demand.

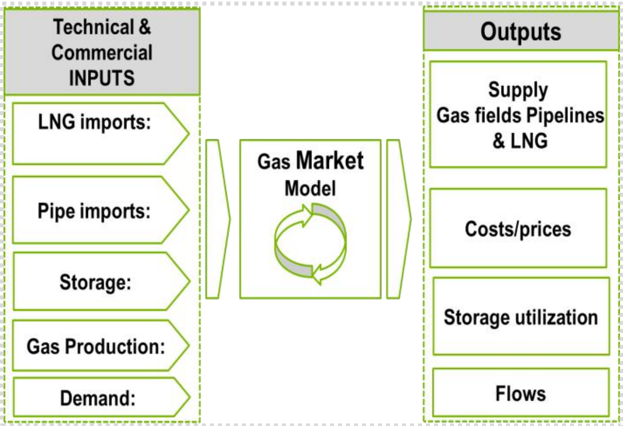

Figure 1: Modelling approach

The Figure 1, indicates the modelling approach used, It takes into account the actual technical and commercial figures, mostly from ENTSOG [1] capacity and transmission reports. The gas demand profile was created for a daily base, related with the average temperature for each European country.

4.2 Model Topology

The European gas infrastructure in the model it is represented by an aggregated structure, presented in ANNEX A: Model Topology. However, this structure does align with the way the EU gas market is commercially set up: all market areas, i.e. the so-called entry-exit systems, were included in the model. In each market area the storages, gas production, LNG regasification and interconnection capacities respectively were aggregated. This topology is flexible; it can easily be updated with additional infrastructure for further research.

4.3 Demand profile

The shared of natural gas in Europe is meanly for householder 36% in 2012, this consumption is directly related with heating space. The total demand profile was built taking account to patterns, which represent aggregate shared by sectors: Householders and commercial; and industrial and power generation.

[1] PLEXOS: is power market modelling and simulation software that uses mathematical programming and stochastic optimization.

The gas demand profile has a predicted pattern en function of the outside temperature (OT); it can be described by two behaviours around a set temperature (ST), if the OT minor to this ST, the demand has a notable curve shape; and for the OT major or equal ST has a smooth almost constant shape. In the profile built the temperature set was 16℃

$$G(T,t) = aT^2 + b + C$$
$$T < 16℃ \therefore a = 0; b = -0.3, ; c = 5.3332296$$
$$T > 16℃ \therefore a = 0.004329; b = -0.2212; c = 3$$

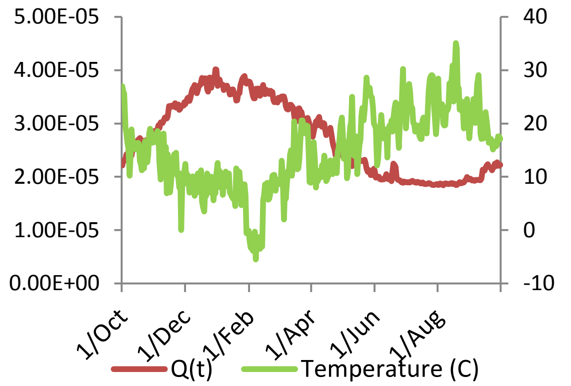

Figure 2: Variable load Profile

4.4 Gas Supply

The access to the current supply data is limited; for some strategic reason the TSOs restricted this information. Nevertheless, it was considered that, in the European electricity system, the natural gas is the marginal fuel and will supply a large part of the required flexible electricity supply. Both nuclear- and coal-fired generation capacities will run as much base-load as possible. This assumption amplifies the role of natural gas in supporting RES, as other instruments such as coal, hydro storage and interconnection would be also play a role. But it clearly shows the challenges the natural gas market might face.

4.5 Model Validation

To validate the model, the current capacities and volumes with the built demand profiles were applied, and compared with the actual figures of the European gas network. Overall the outcomes of the model are consistent and according with that would be expected when comparing to actual insights and considering the model approach.

The model will be used to study the actual capacity of gas infrastructure and his response to a high renewables shared, hence the special interest in analyse the actual behaviour of the elements which bring flexibility to the systems: storages and LNG terminals

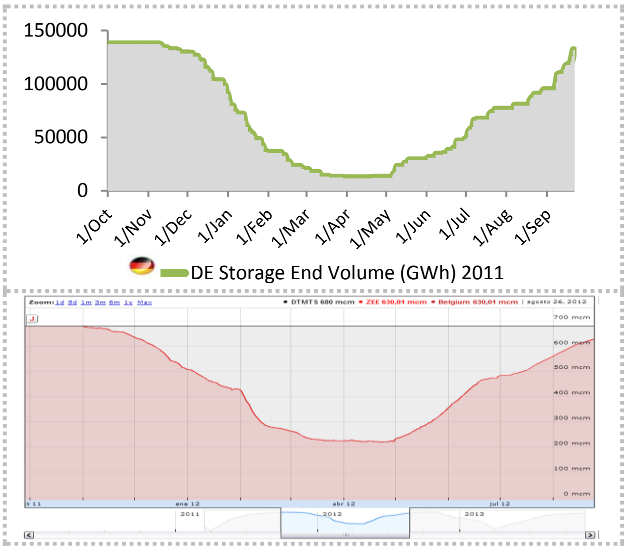

Figure 3: Storages End Volume (Upper PLEXOS Germany NCG market zone, Bottom GSE) **[3]**

In the actual infrastructure, the storages facilities has only one cycle, and this dynamic behaviour has evidenced in the model; Figure 3, for the established horizon the storages facilities start with almost full capacity and virtually depleted in spring season.

Looking in detail the patterns in Figure 4, it is possible to identify the cycle and the characteristic behaviour of LNG terminal. The patterns different is due to the aggregation of the all LNG terminals for each country.

The modelled LNG storages have a similar dynamic to the reals terminals, Figure 4, characterize by multi cycles, switching from injecting to sending out several times per month. It also presented a high volume demand for the peak period (winter time) and a relative relaxation for others periods.

The Supply-demand schema differs from the actual, due to the minimal cost approach, some of the keys factors that influences in market price were negligee, such as the relationships between buyers and sellers, the non-homogenous production, externalities, etc.

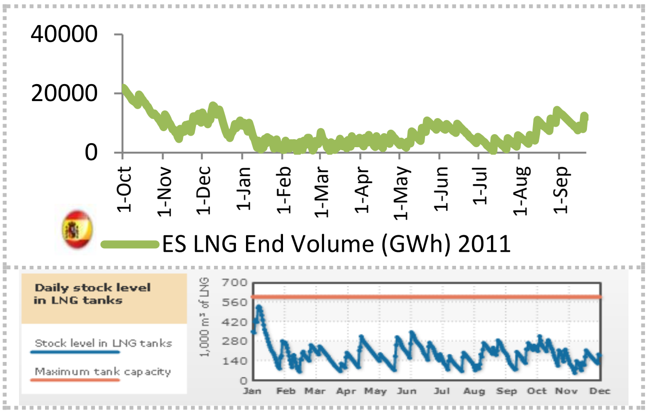

*Figure 4: LNG Storage pattern (Upper Plexos Model 2011-2012, Bottom Enagas 2012 **[4]**s)*

5 Study Case

The case study implement a centralized RES scenario, under the assumptions of the Roadmap 2050 [5], this scenario consider a limited demand growth and a diminution in the total contribution by nuclear power. The scenario is characterized by:

- High share of centralized off-shore wind, particularly in the North Sea (both fixed and floating installations).
- Regional concentration of solar power, including CSP, in Southern Europe.
- Smaller amounts of decentralized on-shore wind and PV.

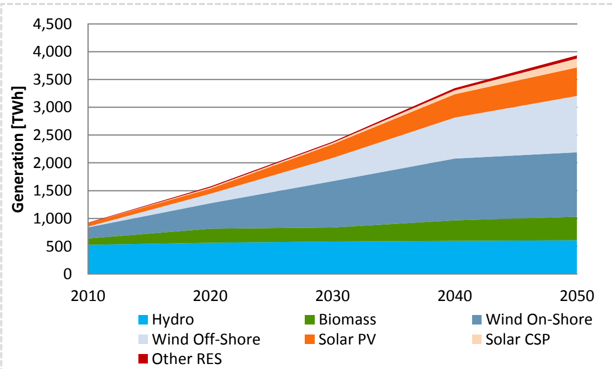

Figure 5: RES Generation in the Centralized scenario

5.1.1 Gas demand

In the case study, the gas demand profiles were built with 3 patterns components: householders and commercial; Industrial and power generation shared.

$$Load(t) = (a * F(t) + b * G(T,t) + c\, H(t) * Av * Load$$

Where *a* is the industrial share (constant shape); *b* householders share (variable in the time and with the temperature, explained section 4.3) and *c* share of power generation.(Database from DNV-GL a HANZE research partner).

The flickers in the patterns show in Figure 6, it represents the variability of daily demand of the supply-side generator for compensated the fluctuations of the renewable energy generators. It is noted that for countries with small shared in power generation, the change in the demand profile is negligible. As the figure below shows Poland with high Gas power generation has more daily variation then Switzerland, which has low gas-power generation.

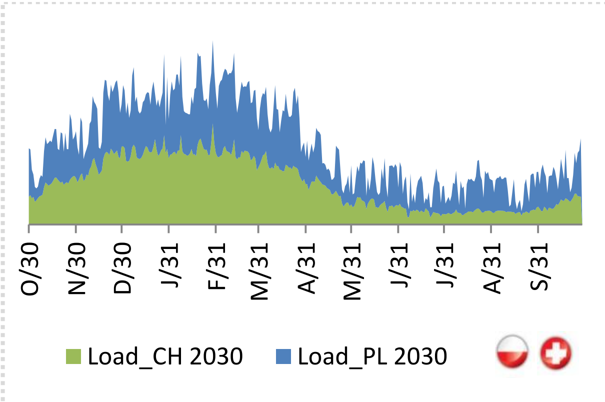

Figure 6: Gas demand profile 2030

Considering the Centralized RES scenarios presented, it was calculated the changes in the gas demand, and the new demand pattern was applied in the model, with the current technical and commercial capacities of the European gas network

In general, the current European gas infrastructure, within the interconnection capacities, storages facilities and LNG imports, might be suitable for response the additional daily flexibility requirements, as a result of high RES shared in the European energy mix, under the scenario study.

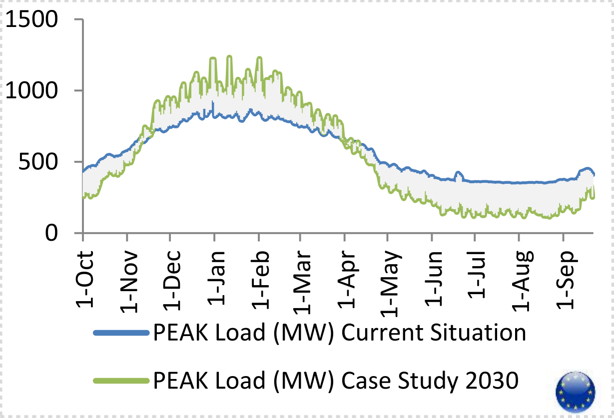

Figure 7: EU Peak Demand 2011 vrs 2030

Although, the increase of seasonal demands fluctuations, it also increases the required send-out capacity due to the increasing spread in fuel demand.

The solution shows it was not possible to supply the demand in periods of peak demand. A scrutiny around the model showed, that the unmatched supply-demand was in, essentially the Italian region. The infeasibilities were eliminated adding to the region additional storages capacity.

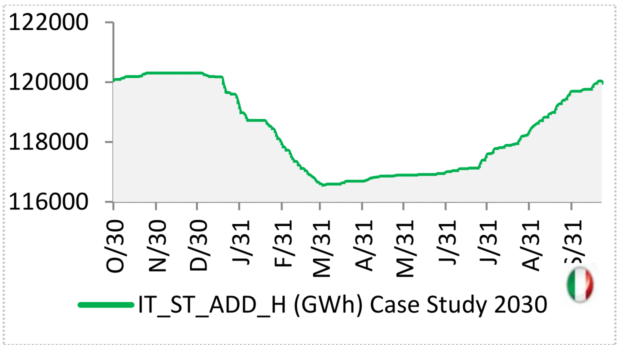

Figure 8: Additional Storage Italy

For countries with a small demand and connected with countries with major and developed gas market, can be helpful, that is the case of Denmark, which under the marginal cost assumption, the actual flexibility demand is cover by the interconnections. However for the case study, the amount of increased demand variability carries a spare supply, it also increases the required send-out capacity as a consequence of the increasing spread in fuel demand Figure 9This new requirements could be provide by the current local storage capacity

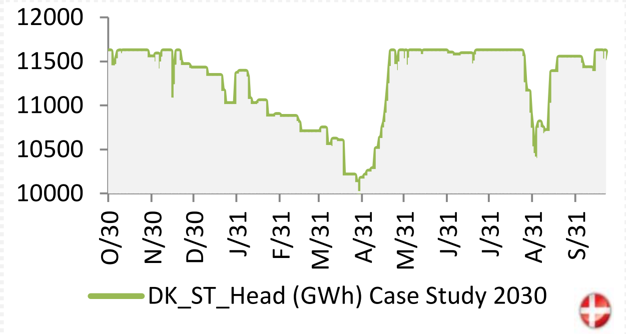

Figure 9: Storage Case study DK

Furthermore, for some countries, which are currently developing their gas markets, the interconnection capacities and storage should increase. It is the particular case for countries such as Croatia and Greece

5.2 Considerations:

The main observations mentioned some infeasibilities were found, a possible solutions for relief the needs of additional flexibility in Italy, will be expanding the storage capacity i.e. building additional storage facilities, and this is one of several options that could be implemented. In general, there is always a trade-off between the several alternatives that Italy might consider, among which stand out: Increasing the interconnectivity, by investing into new interconnections or negotiate more flexible terms in its supply contracts with surrounding. Or increasing LNG import capacity, Italy already has five LNG terminals, and its perfect location, make the additional LNG terminal a suitable options

It is not the purpose of this study to bring the cost-benefit solution for this issue, principally is to measure the overall European gas market capabilities, responding the flexibility requirements for allocated a large renewable energy shared in Europe energy mix.

Therefore, it has not been considered all the possibilities. The presented approach does show that the introduction of additional gas storage could resolve the problems. Whether this is the most cost effective option should be analysed in further research. Moreover, the horizon time must be considered, those decisions may postpone until decrease the uncertainty of the assumed scenario takes place.

6 CONCLUSION AND FURTHER RESEARCH

The natural gas demand in Europe has relatively predictable[2] pattern. A higher RES share changes this pattern; The RES does indeed affect gas-fired power demand, even though in a limited degree. The variability of gas fired demand increases when variations in RES become larger than the existing shared in energy mix. Exactly at which market this happens, differs by country and depends on both national RES output, electricity sector and the shared in gas demand.

A growing RES in the energy mix also changes the way in which existing flexibility instruments are used; the increase of RES may increase the requirement of multi-cycle natural gas storage facilities, sending out and injecting several times per year. It also increases the required send-out capacity due to the increasing the difference between low and high fuel demand.

A higher spread demand and the decreasing demand predictability will not be an issue in the European gas network, as was revealed in the results; in the other hand, for local problems, the natural gas systems have several mechanisms available that could be applicable to improve the local system, which can supply both short and long term flexibility. For example, increasing natural gas storage capacity can deliver additional fuel flexibility; increasing the flexibility in import contracts or increasing the access to more flexible supply sources such as LNG.

6.1 FURTHER RESEARCH

In the present study, not all the renewable energy sources were studied. The emphasis was on the well-known intermittent renewables, such as wind and solar power. However, the model can also help to understand the effect of other renewable energy sources e.g., a large scale biomass gasification gains foothold the impact of these new sources could be analysis. Also, other renewable technologies, those that are currently still in the research stage and may change “the rules of the game” in the future. i.e., Power to Gas (P2G) where the power generated by renewable source, is transformed into (hydrogen) gas to be transported, stored and used.

[2] It is predictable in function of exterior temperature. However can be affected by externalities, for example the total volumes have decreased in the past due to the economic crisis which was difficult to predict.

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ANNEXES

ANNEX A: Model Topology

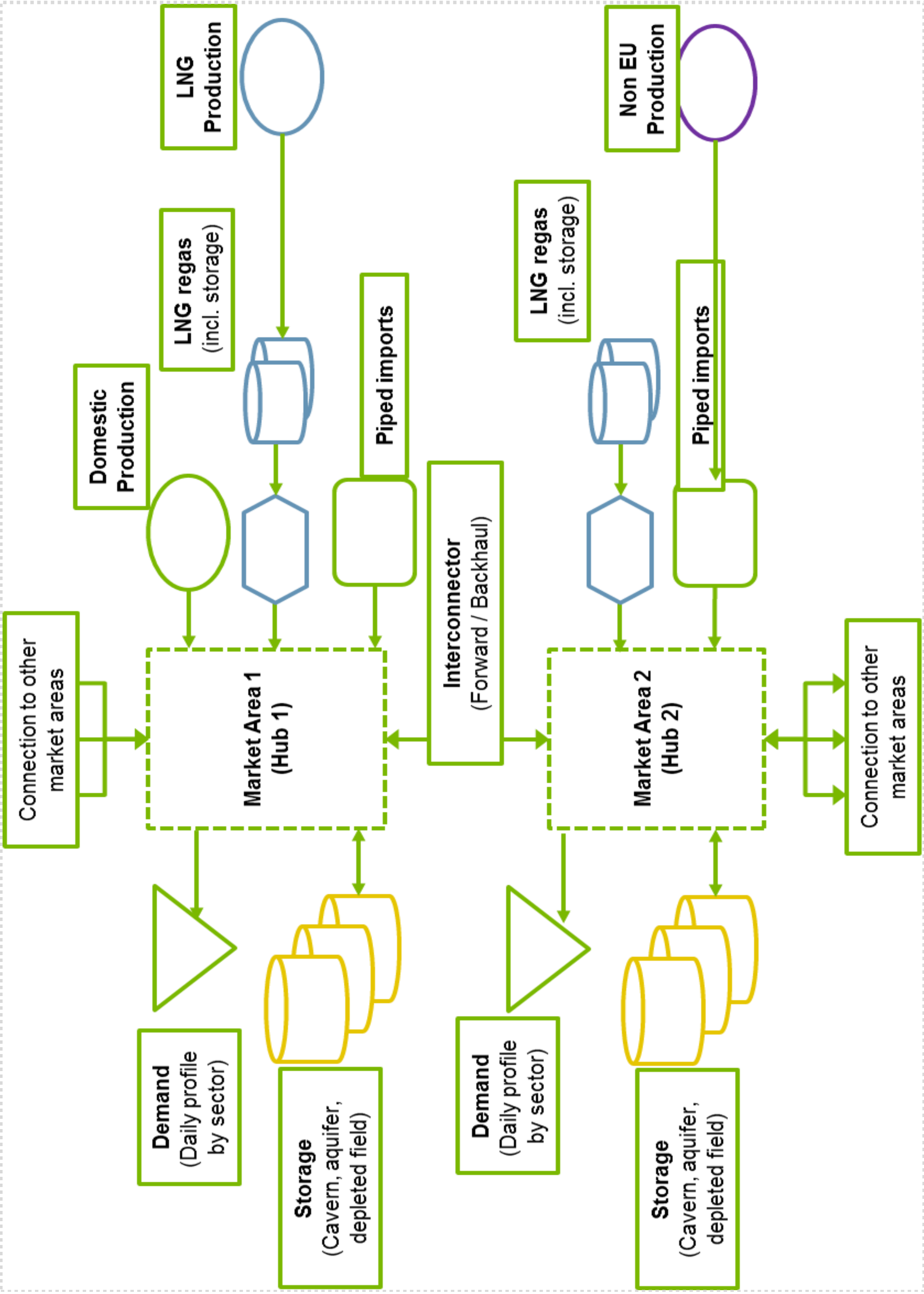

Figure 10: Model Topology

Annex B: Gas value chain

The natural gas value chain can be described by three main processes: Upstream, Midstream and Downstream. The processes can be subdivided into seven activities: exploration, production, processing, transmission, storages, distribution and consumption.

- The Upstream consists of the characterization of the natural gas reservoirs or gas fields (E*xploration*), development and management of production infrastructure and transport form reservoir to surface (*Production*), and finally removing impurities and mixing to reach the required calorific value (*Processing*).
- The Midstream is the next step in the chain, It is the transportation from the production location to consumers: storages facility, large consumers or to small consumers (D*istribution and supply*).
- The Downstream, here the natural gas is transported through a distribution network to the final consumer, in the distribution stage, the gas in transported at lower pressure.

Figure 11: Gas Value Chain, (Source: DNV Kema)

LNG Facilities
LNG (liquefied natural gas) occupies a special position in the value chain. Natural gas can be turned into LNG through liquefaction[3] and regasified through the regasification process. In the liquid state the LNG is transported by special LNG ships and reserved it in storage facilities. As such it is part of Midstream, however for some purposes it can also be considered in the Upstream. Europe is supply by two main geographic LNG markets: the Atlantic and the Mediterranean basins.

Gas Storage Facilities:
Gas storage facilities are essentially used to meet load variations. The gas is injected into storage during periods of low demand and withdrawn from storage during periods of peak demand. But it is also important for strategic purposes, including: balancing the flow in pipeline systems.

- Maintaining contractual balance.
- Levelling production over periods of fluctuating demand
- Market speculation.
- Insuring against any unforeseen accidents.
- Meeting regulatory obligations.
- Reducing price volatility

[3] The natural gas is then condensed into a liquid at close to atmospheric pressure (maximum transport pressure set at around 25 kPa by cooling it to approximately −162 °C

There are three principal storage types: Depleted gas reservoirs, aquifer reservoirs and salt cavern reservoirs. Each of these types has distinct physical and economic characteristics which govern the suitability of a particular type of storage for a given application.

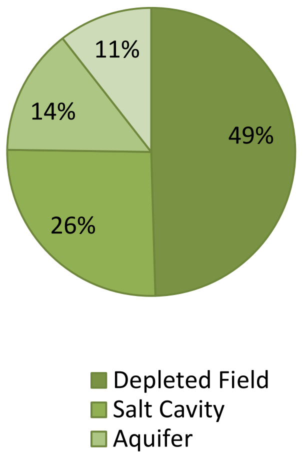

Figure 12: Type of Storages in EU 2013

Type	Depleted GR	Aquifer R	Salt cavern R
Base gas	50%	50-80%	20-30%
Injection	200-500days	200-500days	20-40days
Withdrawal	100-150 days	100-150 days	10-20 days
Working capacity	86%	10%	4%

Table 1: Gas Storage Facilities

The development of gas storage capacities has been increasing since 1990. The largest development took place in the Northern EU region in the form of salt caverns, while in the South-West region it focused on depleted fields. In 2008, the EU storage capacity amounted to approximately 78 bcm in terms of working volume. It is expected for the next decade a growth of 42.6% in the Northern region, 19.6% in the South-West region and 37.8% in the South-East region.

ANNEX C: Model Set up

Table 2: Gas market Model Detail

Type	Simulation/ optimization	Simulation of gas supply from Gas fields to Region Demand/ Anticipation of demand		
Time-Space	Continuous	From 01-10-2011 to 31-12-12 Future other cases		
Function	Linear	ST Schedule and the Mon/ power flow equations are entirely linear		
Detail	Macro	39 Regions, 28 EU countries other gas producers countries, and only France and Germany has sub Market areas		
Software	PLEXOS	Mathematical programming and stochastic optimization, friendly user interface.		
Analysis Type	Economical / Dynamic	Price/MWh per region,		
INPUTS	Demand Escalators	MAX Capacities MW	MAX Volumes GWh	Production Constrains
OUTPUTS	Peak Load	Supply Energy MW	End Volumes Gwh	Prices $/Mwh