Mixed integer linear programming in the natural gas industry

Karima Sabaou

E.ON Rhurgas AG
Huttrpstr. 60
45138 Essen – Germany
`karima.sabaou@eon-ruhrgas.com`

Abstract. Natural gas utilities supply about a quarter of the enrgy nedds in Europe, from wellhead to consumer, opertations are governed by an astounding diversity of purchase, transport and storage contract agreements which prepare a distribution system to meet future demands. In this report we formulate a natural gas problem, and we evaluate it using the rolling intrinsic valuation.

1 Introduction

Gas storage is principally used to meet seasonal load variations.
Gas is injected into storage during periods of low demand and withdrawn from storage during periods of peak demand.

The natural gas industry has undergone market reforms in many countries across the world. As part of this process, the role of storage in the gas market has changed. Traditionally, storages were owned by utilities for balancing the variability in demand of their customers. As a result of the deregulation in the US and Europe, the natural gas storage service is unbundled from the sales and transportation services, meaning that storage is offered as a distinct, separately charged service. In combination with the development of active spot and futures markets, it has become possible to adjust storage trading decisions to price conditions.

Storage is ultimately needed to ensure security of supply. The seasonal demand for gas is traditionally linked to gas heating of houses, resulting in higher gas demand in winter than in summer. Besides the usage of gas storages, one option is to regulate the output from gas fields to match the current demand. This can only be done as long as the fields are reasonably full and close to the gas grid. Finally, on a short-term basis line packing can be used. This means that the volume in the pipeline system is temporarily increased.

While gas demand in the US, Europe and Asia is growing year on year, the indigenous production flexibility is steadily falling. This explains the growing interest to invest in new gas storage facilities. The International Energy Agency (2004) estimates the global underground storage capacity to double in the next 30 years (2000-2030), requiring an estimated annual investment in storages between 10 and 20 billion dollars. Additional flexibility in supply will come from the fast growing sector of Liquefied Natural Gas (LNG). The LNG-chain consists of liquefaction plants, LNG-ships, LNG-storage tanks and regasification plants. The combined investment in this flexible LNG supply chain is expected to absorb an annual investment of 25-40 billion dollars. These market developments call for accurate investment analysis methodologies, incorporating the various operating characteristics of storages and the random nature of natural gas prices.

2 E.ON AG

E.ON is one of the major public utility companies in Europe and the world's largest investor-owned energy service provider. As result of mergers, E.ON inherited the subsidiaries of VEBA, VIAG and Ruhrgas in Central and Eastern Europe. It is also present in Russia, where it has a stake in the natural gas company Gazprom and control of the generation company OGK-4. E.ON is present in most of Scandinavia.

2.1 Market units

Currently, E.ON is organized in ten market units:

- Central Europe Market Unit led by Munich-based E.ON Energie AG
- Pan-European Gas Market Unit led by Essen-based E.ON Ruhrgas
- Spain Market Unit led by Madrid-based E.ON España
- Nordic Market Unit led by Malmö-based E.ON Sverige, which supplies power in Scandinavia
- U.K. Market Unit led by Coventry-based E.ON UK
- Italy Market Unit led by Milan-based E.ON Italia
- Russia Market Unit led by Moscow-based E.ON Russia Power
- U.S. Midwest Market Unit led by Louisville-based E.ON US
- Climate and Renewables Market Unit led by Düsseldorf-based E.ON Climate and Renewables
- Energy Trading Market Unit by Düsseldorf-based E.ON Energy Trading.

2.2 E.ON Rhurgas

E.ON Ruhrgas is the lead company of the Pan-European Gas market unit of the E.ON Group and is responsible for the European gas business from exploration to the supply of major customers.

With a purchasing and sales volume of approximately 700 billion kWh,of gas

and a turnover of over 20 billion a year, E.ON Ruhrgas is one of the leading gas companies in Europe.
Alongside the long-term purchase agreements with producers, E.ON Ruhrgas is increasingly active in the upstream business, gas exploration and production. Through subsidiaries, the company has stakes in gas fields and exploration licences.

In order to tap the potential of new purchasing sources, E.ON Ruhrgas is involved in the LNG business. When cooled, gas liquefies and compresses to one six-hundredth of its original volume. In this state, LNG can be transported in special tanker vessels, which makes it possible to obtain gas from regions which cannot be developed cost effectively using pipelines. Once it has reached the port of destination, the liquefied gas is then returned to its gaseous form so it can be moved through pipelines on the rest of its journey to the customers. E.ON Ruhrgas is involved both in LNG production and regasification. In total, E.ON Ruhrgas has contracted regasification capacities of 8 billion mş at European terminals. Parallel to this, it is stepping up its involvement in gas liquefaction projects in the producer countries, particularly in north-west Africa and the Middle East. In the medium term, LNG is to contribute more than 100 billion kWh of gas to the E.ON Ruhrgas purchasing portfolio.

2.3 OR in E.ON Rhurgas

OR departement of E.ON Rhurgas consist of three teams:

OR-Development:

- Development of mathematical models and optimization technologies for solving complex planning problems
- Design and advancement of IT instruments for optimization, in particular the gas purchase optimization
- Identification of new fields of application for OR methods at E.ON Ruhrgas AG

OR-Consulting:

- Consulting on topics of OR for operating departments and customers of E.ON Ruhrgas AG as well as other companies of the E.ON group with the objective of cost minimization and profit maximization
- Rapid prototyping, individual solutions
- Selection of standard OR software

OR-Research:

- Observation of the state-of-the-art of science and technology in the field of Operations Research
- Cooperation with research institutes und universities
- Collaboration within the German Operations Research Society (GOR)

2.4 EPOS

EPOS is an optimization software developped by E.ON.

- Optimization of the utilization of the supply contracts and storages within the E.ON Ruhrgas portfolio
- Short-term (exact to the day up to 12 months), medium-term (exact to the month up to 5 years), long-term
- Taking advantage of the contract flexibilities (e.g. carry-forward rights, shortfall quantities)
- Determination of marginal prices, time and location swaps
- Sensitivity analysis for the identification of risks
- Stochastic programming, scenario analysis
- Objective:

Cost minimization / profit maximization

2.5 Results of optimization:

Optimal utilization of all supply contracts, storage contracts and transportation capacities within the E.ON Ruhrgas portfolio

- supply quantities per period, used carry-forward, shortfall quantities, remaining scope of action
- withdrawn and injected quantities per period, resellable storage capacities
- gas quantities available at each entry, exit or cross-border point, cross-market transfers, resellable transportation capacities
- sales quantities per period and market area
- purchase, storage and transportation costs, interest charges, sales revenues per period, overall profit

Results can be presented in tables, network graphs and charts and can be exported to Excel. They can be viewed on individual or aggregate level. For analysis purposes currently two scenarios can be compared.

3 Valuation in the natural gas industry

Natural gas storage valuation is a complicated topic in the field of asset and derivative valuation. One can think of natural gas storage as a dynamic basket of calendar spreads, including not only the spreads among forwards, but also the spreads between spot and forwards. On the one hand, the operation of natural gas storage is subject to many constraints, which make the valuation of the storage more complicated than a pure financial instrument. On the other hand, itŠs difficult to simulate the spot and forward curves of natural gas, especially when one wants to take both spot and forwards into account at the same time.

3.1 Gas supply objectives

The objective of gas supply plannig is to minimize gas supply costs while maintaining sufficient supply to meet potential peak requirements and provide for future growth in demand.

Over the short term, this means dispatching the available gas supply to meet varidable demand. On the long term, the objective of supply plannig is to construct an optimal portfolio of gas sources including gas purchases from pipelines, storage, and transportation of gas purchased directly from the producer.

3.2 Problem Constructs

- Time periods The dispatch periods can be daily, weekly, monthly,or any aggregation of these. The plannig horizon can range from one year to over a decade.

- Storage:
  Existing gas storage facilities or potential storage service contracts have a maximum monthly injection volume, a maximum monthly withdrawal volume, and a maximum storage capacity.

- Gas transportation:
  The dispatch of gas from sources to dispositiones can be characterized by defining a network of nodes and arcs. Each arc can be given maximum monthly flow value.
- objective function
  We want to maximize the cash flow, it means that the present value of all costs is minimized. this includes variable costs on all gas ressources, storages, and transportation arcs.

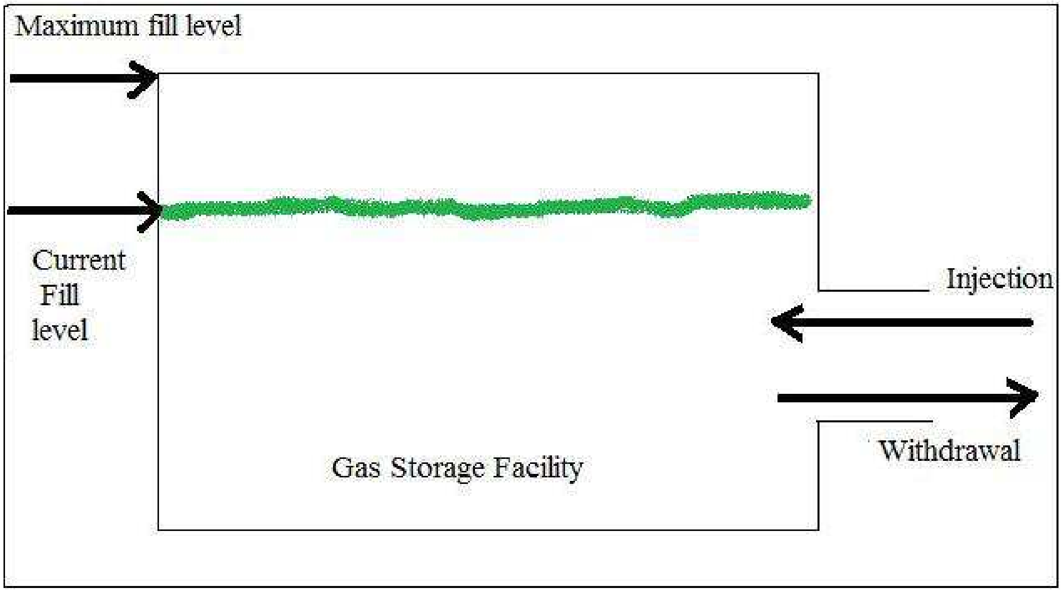


Fig. 1. Gas storage facility

4 Intrinsic valuation

Intrinsic valuation is the optimization of the storage given a single forward curve. In the intrinsic valuation, the objective is to find assets that are priced bellow what they should be, given their cash flow, growth and risk charateristics.
In this part, we will formule the model, and experiment it on OPL studio.

4.1 Define the model:

V : maximum injection .
W : maximum withdrawal.
v_i : injectionfor each month i.
w_i : withdrawal for each month i
fl_i : fill level

4.2 Constraints

In storages, we must not exceed the storage capacity, that why we define the maximum amount of injection and withdrawal in each month, it means :

$$v_i \leq V \qquad \forall i \in \{1, ..., n\} \tag{1}$$

$$w_i \leq W \qquad \forall i \in \{1, ..., n\} \tag{2}$$

We will see later that the injection and withdrawal depend on the fill level. the fill level is defined as the fill level of the month before,plus the amount injected minus the amount withdraw, without exceeding the maximum value.

$$0 \leq fl_i \leq maxlevel; \qquad \forall i \in \{1, ..., n\} \tag{3}$$

$$fl_b = v0 + \sum_{(i \in 1..(b-1))} v_i - \sum_{(i \in 1..(b-1))} w_i \qquad \forall i \in \{1, ..., n\} \tag{4}$$

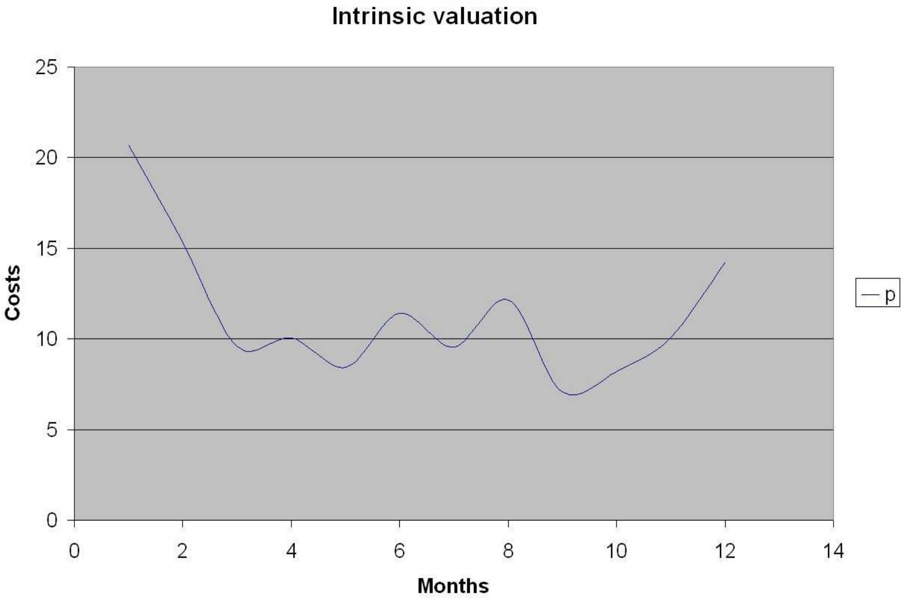


Fig. 2. Intrinsic valutation

4.3 Experimentation

we experimented the intrinsic valuation, using OPL Studio, with the data bellow :

Number of months n	12
V	500
W	300
t	0.1
p	[20.677423, 15.36418192, 9.589754844, 10.0454631, 8.458243217, 11.41387457, 9.54732029, 12.12946067, 7.07770257, 8.18243037, 10.08700768, 14.25066198]
$v0$	24.482
$maxlevel$	1200

Fig. 3. data of the intrinsic valuation

We obtain :

Months n	12
v	[500, 500, 0, 0, 0, 500 0, 500, 0, 0, 0, 24, 482]
w	[0, 0,300,300,300,0 300,0300,300,224, 48,0]
fl	[24.482 ,524.48,1024.5,724.48,424.48,124.48 624.48,324.48,824.48,524.48,224.48,0]
the objective function	11601.8324112726

Fig. 4. Results of the intrinsic valuation

5 Rolling intrinsic valuation

we have seen that the intrinsic valuation give us one curve, for one scenario, but in the real case, the curve can change , so for each period t we will have another scenario, that why we use the rolling intrinsic valuation with diferrent scenarios. A rolling intrinsic valuation acknowledges that over time the forward curve will change, and the previous optimal position might not be optimal any more.At that moment, we can unwind our existing position and assume the new optimal one. In that way we slowly add value above the initial intrinsic valuation. Before defining this method, we need to show how we get these scenarios.

5.1 Monte carlo methods

monte carlo methods are used in finance and mathematical finance to value and analyze instruments, portfolios and investments by simulating the various sources of uncertainly effecting value, and then determining their average value over the range of resultant outcomes.

The advantage of monte carlo methods over thechniques increases as the dimentions of the problem increase.

Features of E.ON price simulation model

To get price simulations ,we need to define the market parameters as follows:

- **Forward curves** : Actual Commodity Forward curves

- **Volatilitie**: Term-Structure-of-Volatility
  Volatility is a statistical standard deviation of the logarithmic percentage price changes whitch measures the non-smooth price fluctuations
- **Correlation**: it measures the linear relationship between two prices.
- **Cointegration**: Relationship between all different commodities
- **Mean Reversion**: is the expected time taken for the price to revert half way back to its normal level/equilibrium whitch measures the attraction of the normal price level (particularly after extreme price jumps)

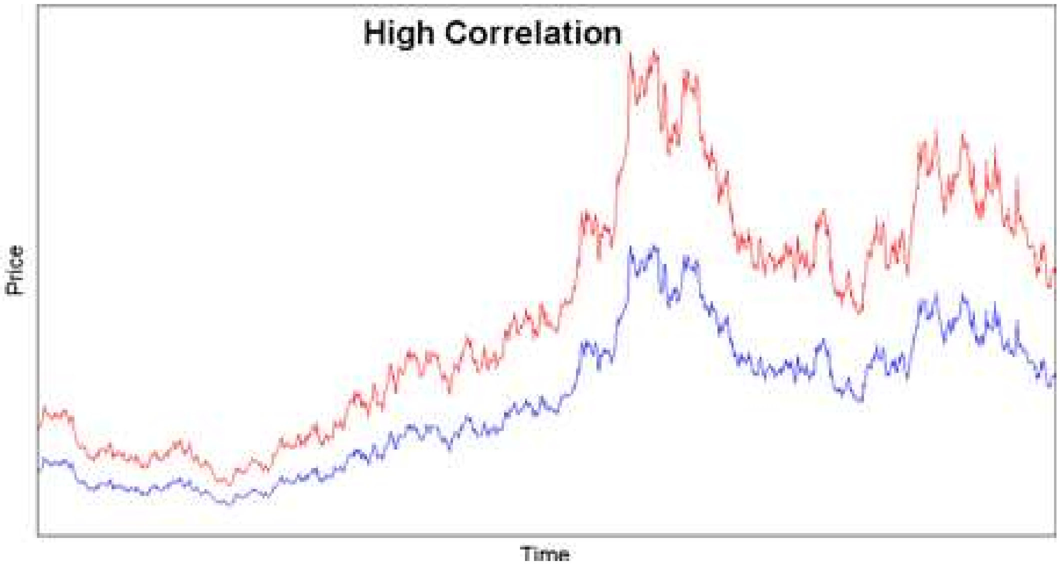


Fig. 5. High Correlation

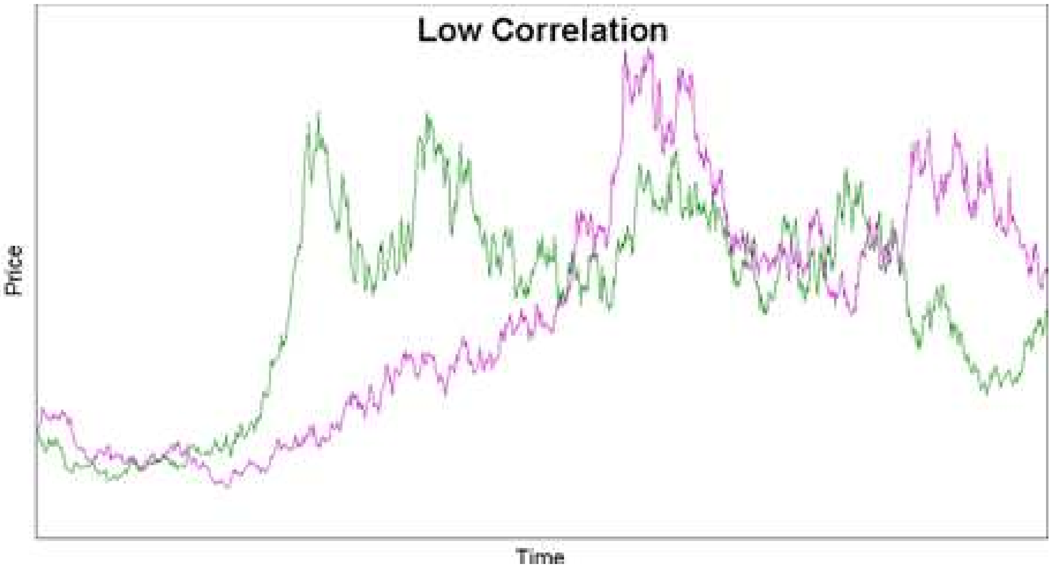


Fig. 6. Low Correlation

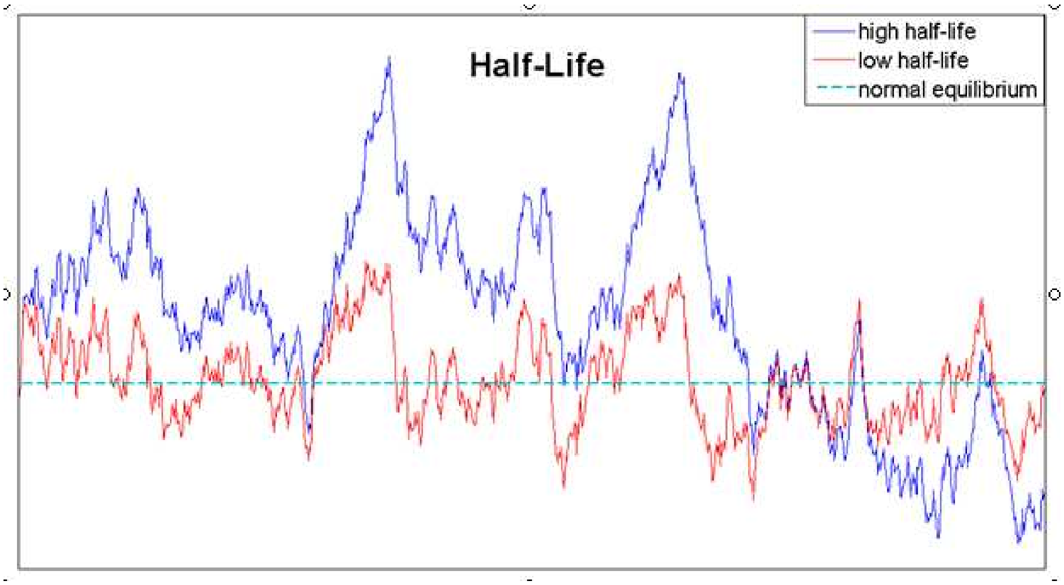


Fig. 7. Mean reversion

6 Define the model:

- V : maximum injection level
- v_{ij} : injection for each month i.in the scenario j
- W : Maximum withdrawal.in the scenario j
- w_{ij} : withdrawal for each month i, in the scenario j
- fl_{ij}: fill level for each month i in the scenario j
- p_{ij}: Gas cost for month $i$in the scenario j
- t_{ij} transaction cost for month $i$in the scenario j
- $fl0$ fill level at starting period
- $v0$ injection at starting period
- $w0$ withdraw at starting period
- $cf0$ cash flow at starting period
- $maxlevel$ maximun fill level

$bullet\ deltaw_{ij}$: difference between the volume injected in the month i,in the scenario j and the volum injected in month i, in the scenario j

$bullet\ deltav_{ij}$:difference between the volume withdrawed in the month i,in the scenario j and the volum injected in month i, in the scenario j

6.1 Constraints

- Storage constraints:

$$v_{ij} \leq V \tag{5}$$

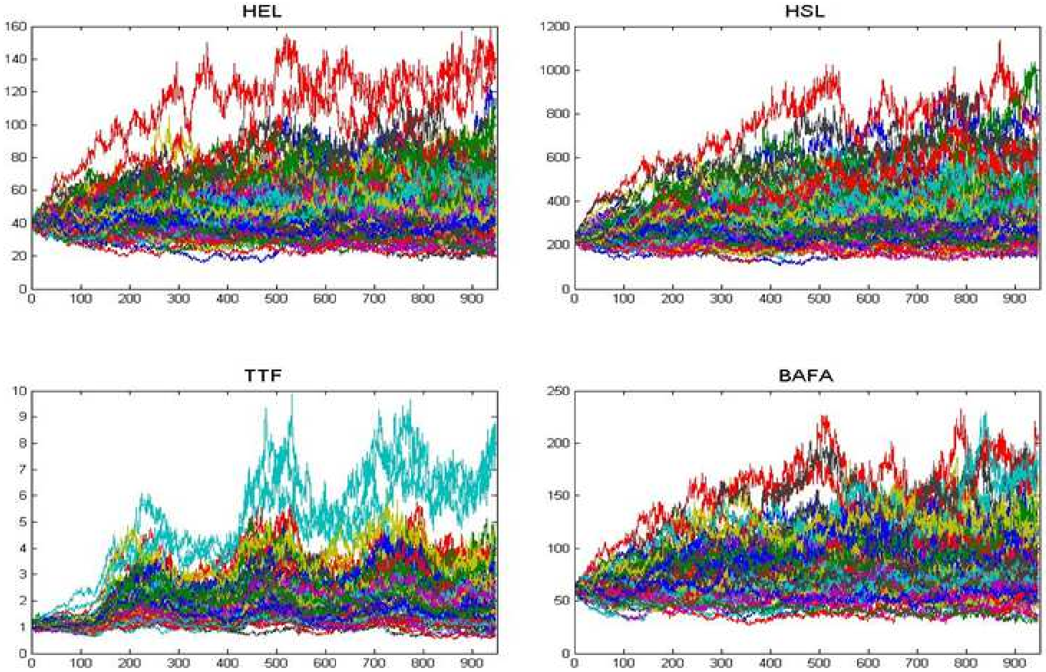


Fig. 8. Price simulation for 4 Markets

$\forall i \in \{1,...,n\}$

$$w_{ij} \leq W \qquad \forall i \in \{1,...,n\} \tag{6}$$

$$0 \leq fl_{ij} \leq maxlevel \tag{7}$$

$\forall i \in \{1,...,n\}$

$$fl_{bj} = v0 + \sum_{(i \in 1..(b-1))} v_i - \sum_{(i \in 1..(b-1))} w_i \tag{8}$$

$\forall i \in \{1,...,n\}$

$$v_{ij} = v_{i(j-1)} + deltav_{ij} \tag{9}$$

$$w_{ij} = w_{i(j-1)} + deltaw_{ij} \tag{10}$$

$$deltav_{i(j-1)} = 0; \qquad deltaw_{i(j-1)} = 0; \tag{11}$$

$\forall j \in Scenarios$

6.2 Experimention

1. In the first example, we have 12 scenarios for 12 months.
   using this data:
   give us the results bellow:

NbMonths	12
V	500
W	300
t	[0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1]
p	[9.54732029, 12.12946067, 7.07770257, 8.18243037, 10.08700768, 14.2506619816.02040065, 12.98122902, 11.02476992, 9.156611144, 9.129846038, 7.516150383]
$fl0$	24.482
$maxlevel$	1200
$v0$	[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]
$w0$	[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]
$cf0$	0

Fig. 9. Data of the rolling intrinsic valuation

scenario 1	Objective value: 7267.957158663176
scenario 2	Objective value: 7267.957158663176
scenario 3	Objective value: 8070.95090393344
scenario 4	Objective value: 8120.107300847179
scenario 5	Objective value: 8649.688366847178
scenario 6	Objective value: 8715.09096756984
scenario 7	Objective value: 8880.791115352282
scenario 8	Objective value: 8880.791115352282
scenario 9	Objective value: 11497.0110381054
scenario 10	Objective value: 11703.6937807422
scenario 11	Objective value: 11703.6937807422
scenario 12	Objective value: 11703.6937807422

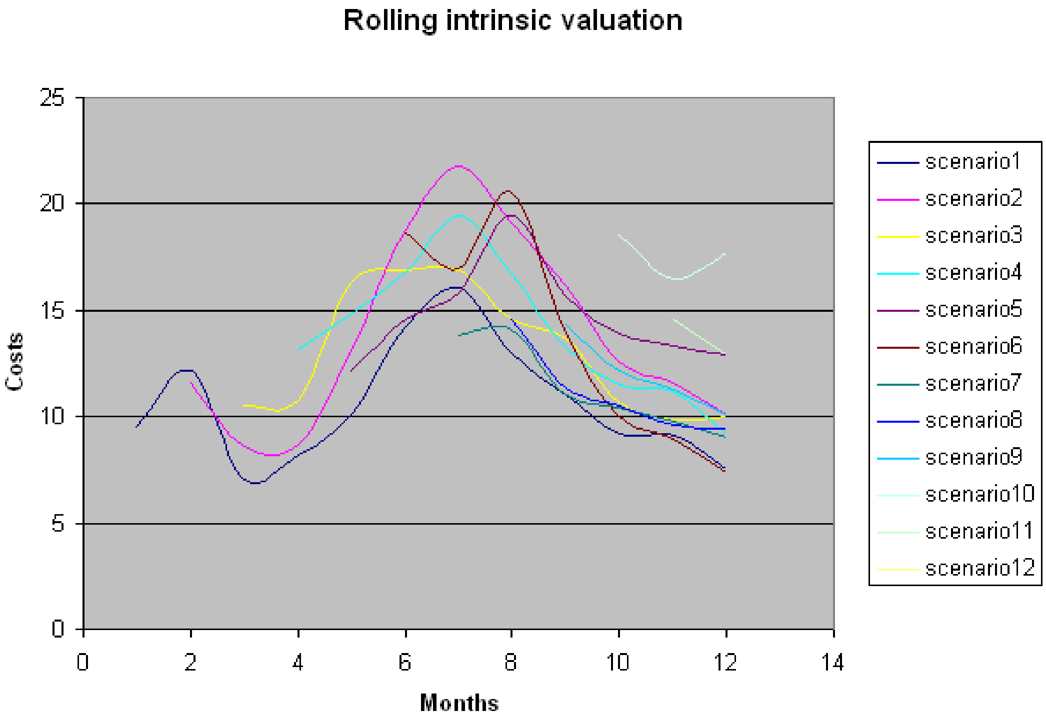
Fig. 10. Results of the rolling intrinsic valuation with one block

We note that the objective function value increases from scenario to another, and the optimal value of the objective function is the one of the scenario 16.

2. in the second example,we have 25 blocks, and each block consists of 12 Months and 16 scenarios. a block of months and scenarios is defined such that their results are dependent. We use the same data as before, the results are:

Block 1	Objective value: 5297.765954612345
Block 2	Objective value: 2646.573235893629
Block 3	Objective value: 4078.161997278785
Block 4	Objective value: 3155.237758243943
Block 5	Objective value: 5699.255651269528
Block 6	Objective value: 4278.797192644119
Block 7	Objective value: 3629.733772650141
Block 8	Objective value: 2929.830749169918
Block 9	Objective value: 2000.371327686692
Block 10	Objective value: 1747.530341636656
Block 11	Objective value: 3365.419708543585
Block 12	Objective value: 541.5914382119179
Block 13	Objective value: 3091.70121204948
Block 14	Objective value: 1759.463603720663
Block 15	Objective value: 3931.97260685539
Block 16	Objective value: 3155.769230737685
Block 17	Objective value: 3724.628738500594
Block 18	Objective value: 1738.796790547845
Block 19	Objective value: 3225.961468803787
Block 20	Objective value: 1233.420755908011
Block 21	Objective value: 4488.829081924042
Block 22	Objective value: 1064.306123917578
Block 23	Objective value: 8310.212229557803
Block 24	Objective value: 910.7355073100115
Block 25	Objective value: 3944.176638844106

Fig. 11. Results of the rolling intrinsic valuation with 25 blocks


Rolling intrinsic valuation
Costs
Months
0
5
10
15
20
25
0
2
4
6
8
10
12
14
scenario1
scenario2
scenario3
scenario4
scenario5
scenario6
scenario7
scenario8
scenario9
scenario10
scenario11
scenario12

7 Portfolio model

We have seen in the last part that the objective function is increasing, and therefore the best solution is the one of the scenario. The difference bettween the last objective value and the intrinsic value is called : extrinsic or time value of the asset.In this part, we apply the rolling intrinsic method on our portfolio,and we will see if it will be the same. First we will define the network and the model and finally give the results using OPL Studio.

7.1 Network builds

Our Model of gas transmition and ditribution is simple to visulize. Superficially, we summerize the problem as follows:
Base-demand natural gas is purchased at supply points, held in storage facilities, and tansported through the network to meet the demand of different market regions

7.2 Define the model

Some constants and variables are defined in the section before,.

- Storage constants and variables
  As an approximation, we will assume that the volume injection and volume withdrawal depend linearly on the fill level of the last month:
  let be :

  $alphav_s$
  $betav_s$
  $alphaw_s$
  $betaw_s$
  the coefficients of this two linear function.
  $minv_s(m):$ minimum injection in the sorage s, in the month m
  $maxv_s(m):$ maximum injection in the sorage s, in the month m
  $minw_{is}(m):$ minimum withdrawal in the sorage s, in the month m
  $maxw_{is}(m):$ maximum withdrawal in the sorage s, in the month m

- **Supply constants and variables**:

  $NbSuppliers:$ Number of suppliers
  $cy_{iy}(m):$ suppliers gas cost, in the month m
  $miny_{iy}(m):$ minimum supplier volume, in the month m
  $maxy_{iy}(m):$ maximum supplier volume, in the month m
  $Limits_y(m):$ special limits for the supplier volume (seasonal or yearly bounds), in the month m

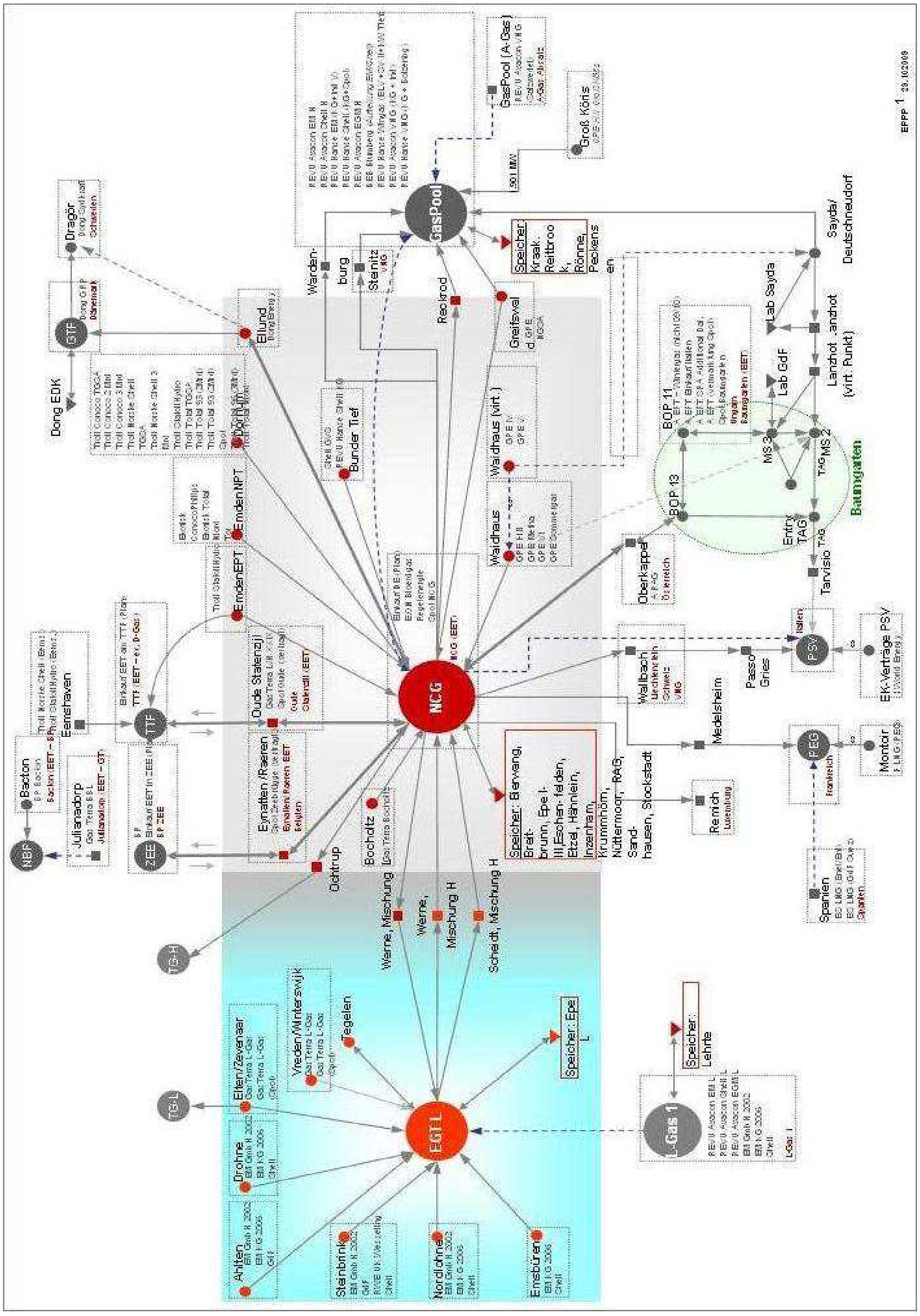


Fig. 12. E.ON Portfolio

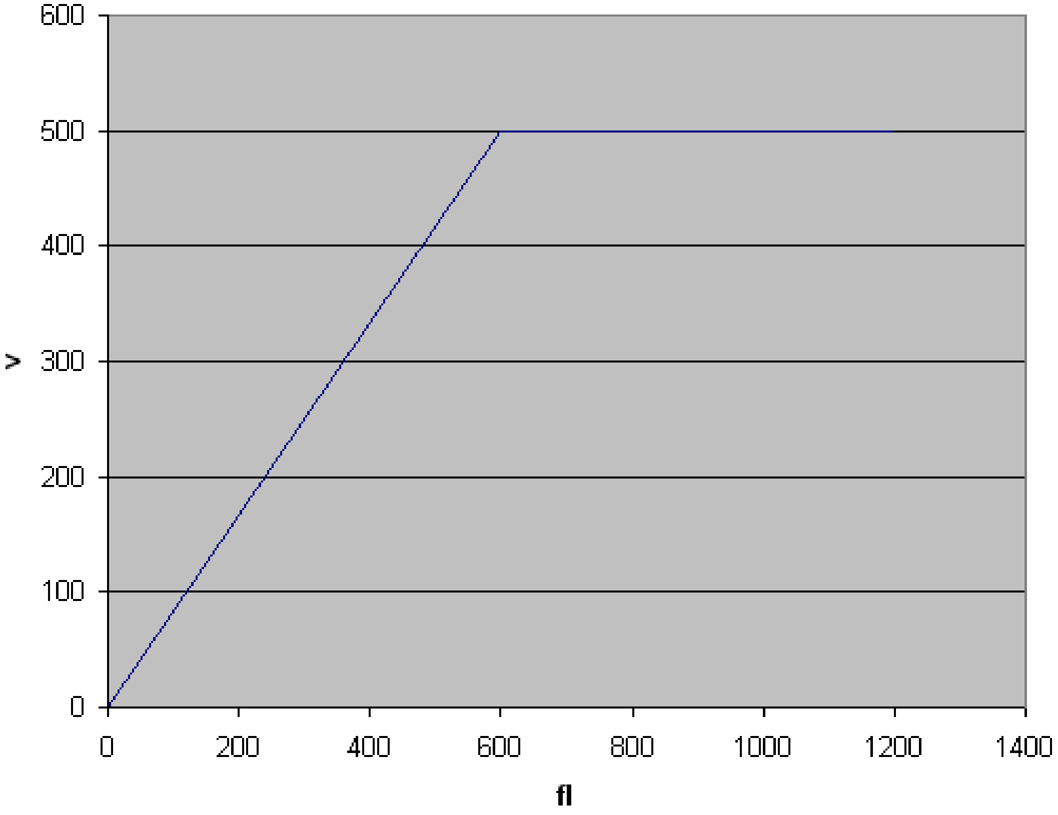


Fig. 13. Relationship between fill level and injection rate

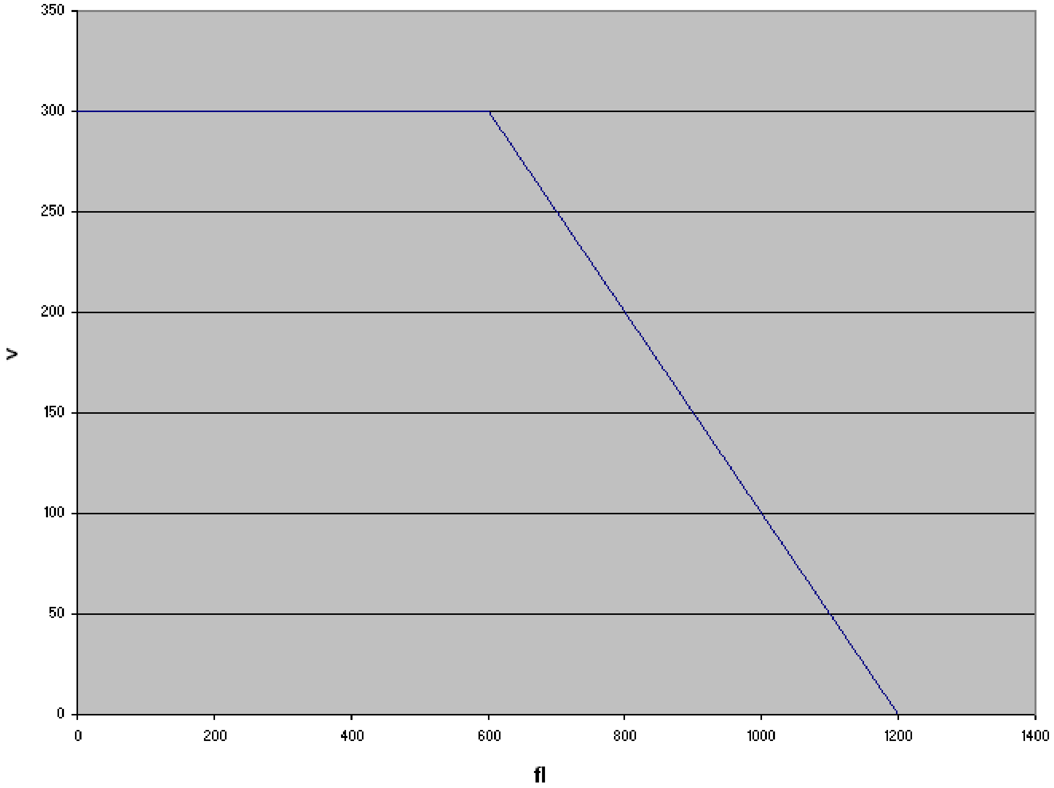


Fig. 14. Relationship between fill level and withdrawal rate

- **Hubs variables**:

  $NbHubs$ Number of hubs
  $p_h(m)$:hub gas cost;
  $t_h(m)$:transaction cost
  $PriceFactor_h(m)$:
  $MaxStep$: number of step of the piecewise constat price-demand function
  $ActualTrading_h(m)$ aggregated traded volume of all steps before
  $d_h(m)$: the demand of the market region associated with hubs$h$ in the month m

- **Network Varibles**:

  $ce_n(m)$: transportation cost of the edge n in month m
  $cap_n(m)$ capacity of the edge n in month m

- **Decision variables**:

  $v_s(m)$ amount injected inthe storage s,in the month m
  $w_s(m)$ amount withdrawn from the storage s,in the month m
  $fl_s(m)$ fill level of the storage s,in the month m
  $e_n(m)$ the flow of the edge n in month m
  $y_y(m)$ amount in supllier node y, in month m
  $x_h(m)$ amount bought at the hub h, in month m
  $xh_{hst}(m)$ amount bought from the hub h,with cost associated with step st of the price-demand function in month m
  $z_h(m)$ amount selt from the hub h, in month m
  $zh_{hst}(m)$ amount sold at the hub h,with cost cost associated with step st of the price-demand function in month m
  $d_h(m)$ Demand of hub h in month m
  CF cash flow.

7.3 Constraints

- **Storage constraints**:

  We have seen before that injection and withdrawal depend on the fill level, as shown in the example below, For the injection, if we assume assume an empty storage, we can inject the maximum value, then after it depends on the fill level. For the withrawals it's the inverse, in the beginning we withdraw the minimum, then it depends on the fill level. We note the maximum injection $V_s(m)$(resp maximum withdtawal $w_s(m)$), for any month and m,

$$v_s(m) \leq V_s \tag{12}$$

$$v_s(m) \leq alphav_s \times fl_s(m-1) + betav_s \tag{13}$$

$$w_s(m) \leq W_s \tag{14}$$

$$w_s(m) \leq alphaw_s \times fl_s(m-1) + betaw_s \tag{15}$$

- **Balancing constraint**:

  For each node of our network, the amount of gas entering the node is equal to that coming out of node.

  $$\sum_{s \in Storages} w_{sn}(m) + \sum_{h \in Hubs} x_{hn}(m) + \sum_{l \in Suppliers} y_{ln}(m) + \sum_{k \in Network} e_{kn}(m)$$

  $$=$$

  $$\sum_{b \in Demand} d_{bn}(m) + \sum_{s \in Storages} v_{sn}(m) + \sum_{hinHubs} z_{hn}(m) + \sum_{k \in Network} e_{kn}(m)$$

  $\forall\ n \in Nodes,\ m \in Months$

  $$0 \leq fl_i(m) \leq maxlevel(m) \tag{16}$$

  $\forall i \in \{1, ..., n\}$

  $$\sum_{m \in Months, s \in Storages} v_s(m) = \sum_{m \in Months, s \in Storages} w_s(m) \tag{17}$$

  $$fl_s(b) = fl0_s + \sum_{r \in 1..b} v_s(r) - \sum_{s \in 1..b} w_s(r) \tag{18}$$

  $\forall b \in 0..NbMonths, s \in Storages$

- **Suppliers constraints:**

  $$miny_y(m) \leq y_y(m) \leq maxy_y(m) \tag{19}$$

  $\forall y \in Suppliers, m \in Months$

$$lim.lb \leq \sum_{m \in Months: lim.StartPeriod \leq m \leq lim.EndPeriod} y_y(m) \leq lim.ub \tag{20}$$

  $\forall y \in Suppliers,\ \forall lim \in Limits_y$

- **Hubs constraints :**

$$\sum_{s \in 1..MaxStep} xh_h(m)(s) = x_h(m) \tag{21}$$

$$\sum_{s \in 1..MaxStep} z_h(m)(s) = z_h(m) \tag{22}$$

$\forall h \in Hubs, m \in Months$

$$xh_{hst}(m) \leq LiquidityStep_h(m) \tag{23}$$

$$zh_{hst}(m)(s) \leq LiquidityStep_h(m) \tag{24}$$

$\forall h \in Hubs, m \in Months, s \in 1..MaxStep$

- **Objective function**

$$CF = cf0 - \sum_{h \in Hubs, m \in Months, s \in 1..MaxStep} xh_h(m)(s) \times (p_h(m) \times (1 + PriceFactor_h(m)/100)^s + t_h(m))$$

$$+ \sum_{h \in Hubs, m \in Months, s \in 1..MaxStep} zh_h(m)(s) \times (p_h(m) \times (1 + PriceFactor_h(m)/100)^s + t_h(m))$$

$$- \sum_{m \in Months, i \in Storages} cw_i(m) \times w_i(m) - \sum_{l \in Suppliers, m \in Months} y_l(m) \times cy_l(m)$$

$$- \sum_{k \in Network, m \in Months} e_k(m) \times ce_k(m) + \sum_{b \in Demand, m \in Months} d_b(m) \times cd_b(m)$$

$$- \sum_{s \in Storages, m \in Months} v_s(m) \times cv_s(m)$$

7.4 Experimentation

Using the data in the table bellow:

We obtain :

Months n	12
cv	$[0.15, 0.25]$
cw	$[0.15, 0.25]$
$maxlevel$	$[14000, 5000]$
$fl0$	$[6000, 2000]$
V	$[3000, 2000]$
W	$[6000, 3000]$
$alphav$	$[0.285, 0.75]$
$alphaw$	$[-0.8, -1]$
$betav$	$[1000, 500]$
$betaw$	$[13200, 6000]$
$minv$	$[0, 0]$
$maxv$	$[3000, 2000]$
$minw$	$[0, 0]$
$maxw$	$[6000, 3000]$
$miny$	$[4000, 3000, 500]$
$Limits$	$< 20000, 32000, 1, 4 >, < 54000, 70000, 5, 16 >$ $< 35000, 42000, 1, 7 >, < 45000, 54000, 8, 16 >$ $< 35000, 42000, 1, 7 >, < 45000, 54000, 8, 16 >$
t	$[1, 0.5]$
$LiquidityStep$	$[1000, 500]$
$PriceFactor$	$[0.1, 0.05]$
$ActualTrading$	$[0, 0]$

Fig. 15. Data of the portfolio model

and the results are:

Scenario 1	$Objectivefunction$:443736.8282347734 CF:894554.6114669901
Scenario 2	$Objectivefunction$: 438447.0837316765 CF: 1206033.372046366
Scenario 3	$Objectivefunction$:254227.2166502991 CF: 1350947.99733401
Scenario 4	$Objectivefunction$:353544.446318626 CF: 1481620.290452667
Scenario 5	$Objectivefunction$:763459.591397444 CF: 1649054.608545753
Scenario 6	$Objectivefunction$:824022.7626345153 CF: 1773818.530086388
sScenario 7	$Objectivefunction$:858393.6415290105 CF: 1892717.633991169
Scenario 8	$Objectivefunction$:1084092.045114963 CF: 1999118.98632365
Scenario 9	$Objectivefunction$:1217931.68054853 CF: 2032988.448508124
Scenario 10	$Objectivefunction$:1353091.326135908 CF: 2042577.245630537
Scenario 11	$Objectivefunction$:362319.54040712 CF: 2043965.388223587
Scenario 12	$Objectivefunction$:1368319.077433004 CF: 2043151.481111899
Scenario 13	$Objectivefunction$:1492119.938331604 CF: 2043151
Scenario 14	$Objectivefunction$:1434056.660133362 CF: 2043151
Scenario 15	$Objectivefunction$:1327418.261962891 CF: 2043151

Fig. 16. Results of the portfolio model

7.5 Valuation on the portfolio model

We try to see the contribution of each to the resulting object value,the rolling intrinsic portfolio value of an asset is given bay the oppurtunitycosts resulting when the asset is deleted from the portfolio. we can see in the table below, that the values of two storages are note additional because the two hubs are linked one to another, so we can use the market which is connected to the storage removed. We do the same thing with the suppliers, we can see in the table bellow that if

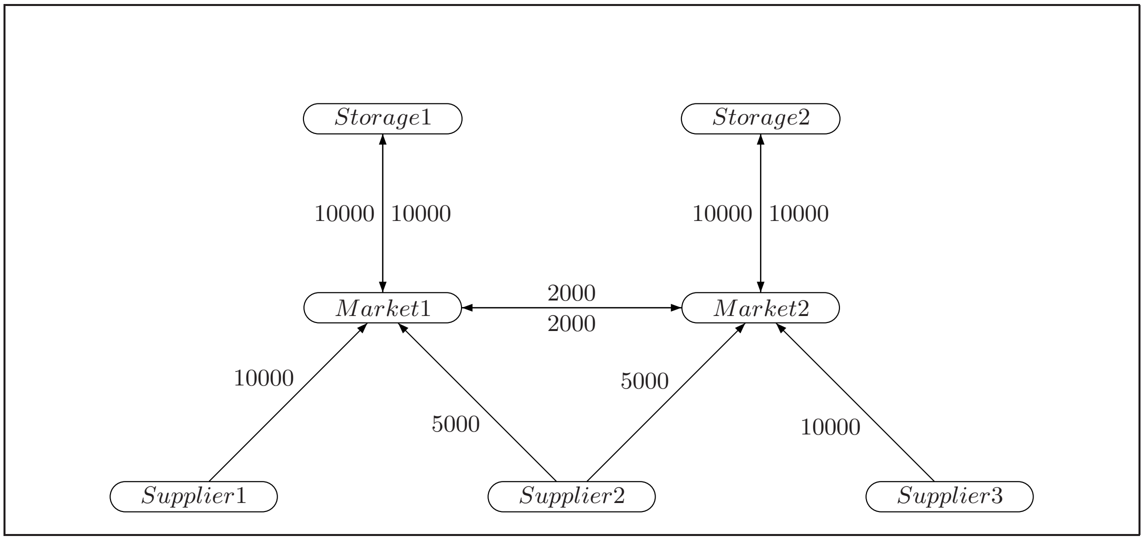


Fig. 17. Network of the portfolio model

we delete one supllier, the value of the objective function get higher, because, in our example, the supply cost are very expensive.

Results with storage 1	*Objectivevalue*: 1253094.015310288
Results with storage 2	*Objectivevalue*: 1228160.650088211
Results with two storages	*Objectivefunction*:1327418.261962891
Results with two suppliers	*Objectivefunction*:1829180.400267641

Fig. 18. Storage and supllier valuation

7.6 Compare rolling intrinsic results and portfolio results

If we look at the results of the rolling intrinsic method (stand alone the market evaluation), we notice that in the same block, the function is increasing,it means that each scenario gives us a better result as the previous one, and therefore the last value is indeed the best. But when we apply the rolling intrinsic method in the portfolio model, we see that this is not the case, and that because the portfolio model contains more constraints, especially in our example, supllier costs are very expensive.

8 Conclusion

In this report,we have formulalted a natural gas industry problem,with suppliers, hubs and storage constraints. We have defined and experimentee methods of valuation on OPL Studio, and we have applied these methods to our portfolio model. Thereafter, we will valuate each asset, to see the contribution of each one, we will try to remove, or add, assets,it depends on the cost of each one, and we will attempt to integrate these methods in the E.ON optmization software EPOS,and we'll see if it can make thousands of runs with this valuations.

References

William avery, Gerald G.Brown, John A. Rosenkranz, R. Kevin wood Optimization of purchase, Storage ans transmission contracys for natural gas utilities Matt Thompson, Matt Davidson, Hennig Rasmussen: Natural gas storage valuation and optimization