SCENARIO ANALYSES PERFORMED WITH THE DECISION SUPPORT MODEL: Methodology Description and Characterization.

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Glossary, abbreviations and acronyms

modeFRONTIER	Optimization platform software by ESTECO
VOLTA	Web-based collaboration platform software by ESTECO

1 INTRODUCTION

1.1 Overview

This document outlines the methodology employed to develop and finalize the Scenario Decision Support Model (Model) for the gas delivering to the identified markets as part of the Gasvessel project. In particular this methodology applies to the activities included in Work Plan 2 (WP2) and WP3.

The Scenario Decision Support Model is developed by Esteco using the optimization software modeFRONTIER and VOLTA web-based collaboration platform, both produced by ESTECO. The necessary data (inputs) were mainly provided by CNGV together with Navalprogetti.

1.2 Objectives

The main objective is to develop a tool (Scenario Decision Support Model) to optimize the delivery of gas from the identified source locations to the identified markets using the Gasvessel concept in different scenarios.

The outcome of the model is an estimation of the CNG transportation costs for the identified scenarios, providing essential information like the optimal ship size, the ship speed and the fleet size in order to reach the lowest gas transport costs per unit volume.

Three geographic areas have been chosen as they establish early take-up potential for the Gasvessel concept.

- Barents Sea Offshore Oil Field
- East Mediterranean Gas Fields
- Black Sea Region

In any case the model developed by Esteco can in the future be applied to other scenarios not yet defined at this stage, including exploitation and supply to Europe of stranded, associated and flared gas resources from outside of the European geographical area.

2 METHODOLOGY DESCRIPTION

2.1 The concept behind the model

The Scenario Decision Support Model (Model) is developed using the optimization software modeFRONTIER.

modeFRONTIER is an integration platform for multi-objective and multi-disciplinary optimization, it offers a seamless coupling with third party engineering tools or any in house/generic code enables the design process automation and facilitates analytic decision making.

For the Work Package 2 an in house script code is developed to calculate, within the modeFRONTIER platform, the proper output variables starting from selected input variables. For each scenario the input and output variables are identified by the partners (CHC, SINTEF, VTG, Navalprogetti and CNGV) and provided to Esteco.

The Model collects information from different parts of the Gasvessel transportation system and the optimization algorithms available in modeFRONTIER drives the process into an iterative loop (Figure 1) to reach the lowest costs per unit volume of the proposed technology.

The Model is also able to analyze the relationship between inputs and outputs and in particular to assess the effect of each input variable on the relevant outputs (sensitive analysis).

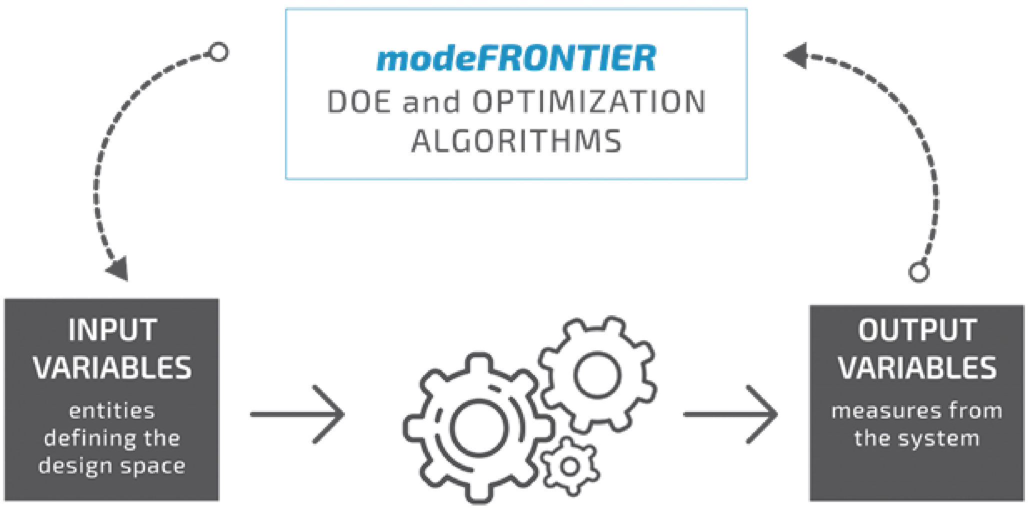

Figure 1 Optimization loop scheme

To allow an easy and efficient usage of the platform for any user, the optimization workflow has been fully integrated in the web-based collaboration platform of VOLTA, which allow the users to define the scenario parameters through a web interface, and retrieve the results by tables and charts.

2.2 Model Description

As mentioned before the Model is designed to be flexible, generic and easily suitable for any further scenario in new areas. The flow chart below (Figure 2) shows the logic:

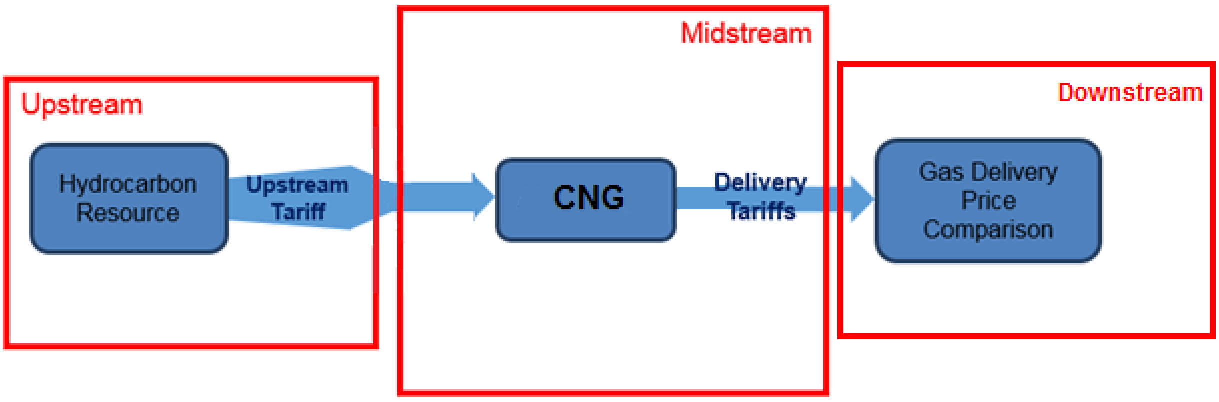

Figure 2 Gas transportation flow chart

The Model will optimize only the Midstream CNG transportation cost; gas Upstream tariff calculation and gas Downstream cost estimation are to be provided by the partners for each scenario. The model provides the transportation tariff but it can report separately the following contributes.

- CNG transportation tariff
- Gas source and delivery facilities cost
- Gas downstream tariff (Upstream tariff + CNG transportation tariff + facilities cost, including unloading cost)

Other alternative tariff options can be provided by the partners for comparison but are not calculated by the Model.

For each identified scenario, the Model will find the optimal ship size, ship speed and fleet size in order to fulfill the estimated gas demand in the area at the lowest costs per unit volume (Gasvessel transportation tariff), given the geographical characteristic and the facilities at departure and destination.

This kind of information is an important input for the entire Gasvessel project, in particular the results of the scenarios analysis will be used in the design processes of WP3 (pressure vessel), WP4 (pre-industrial prototyping of pressure vessels) and WP5 (ship design). WP7 will afterward perform an analysis of the markets to identify where the CNG concept is competitive compared to other monetization options.

2.3 Input variables

The input variables included in the Model are listed in the following tables.

The first table considers parameters related to scenario requirements and vessels typology.

Parameter name	Description	Notes / Assumptions
Total gas demand [Nm^3/day]	Gas demand in the identified market or total gas produced in a specific gas field. Note that the total demand can be provided to different destination ports in the same geographical area; in such a case the gas rate demand to each destination port must be given.	This quantity is considered in general as a constant datum, not as an optimization parameter (but the impact of the different total demand on the final cost can be estimated). The gas volume loaded in each ship must consider also the gas engine consumption for the transport
Ports distances matrix [Nautical Miles]	It represents the distance between the departure and the destination port(s). The distance is computed along the typical route from departure to destination	It is a fixed parameter (no optimization). For each scenario the data are reported in a matrix with all the distance between source ports and delivery ports
Ship capacity [Nm^3]	Gas capability using cylinder (Pressure Vessel). It is the gas amount the ships can transport in each trip, it is a parameter to be optimized (the allowed ship sizes number can however be discrete within a certain range)	Optimization parameter. The transport by containers option can be made also available if requested
Ship velocity [knots]	The ship speed is an important parameter for the gas delivery tariff. It is the average ship velocity during the trips over one year in that geographical area	Optimization parameter. Metocean (The weather conditions of the sea) conditions can influence the ship velocity and fuel condition

The second table considers parameters related to activity terms and financial parameters for each scenario:

Parameter name	Description	Notes / Assumptions
Working days per year [day]	It is the number of days that a ship is available over one year (considering all the stops for ordinary and extraordinary maintenance)	Metocean conditions of a certain route may affect this input. It is a fixed parameter (no optimization)
Activity years [year]	Life cycle of a ship for the scenario. This parameter is also influenced by the lifetime of the cylinders	it is a fixed parameter (no optimization)

Mortgage period [year]	It is the period that it shall be returned on payment of the debt (investment);	it is a fixed parameter (no optimization)
Interest rate [%/year]	it is the amount of interest due per period (one year) as a proportion of the amount lent	it is a fixed parameter (no optimization)

The third table considers parameters related to operational times, and in particular:

Parameter name	Description	Notes / Assumptions
Gas loading time [hours]	Gas loading time from the gas source to the Gasvessel	An accurate enough formula to estimate gas loading time as function of gas volume and pressure is given
Gas unloading time [hours]	Gas unloading time from Gasvessel to the delivery port	An accurate enough formula to estimate gas unloading time as function of gas volume and pressure is given
Operational time [hours]	The operational times necessary for the ship at each arrival port (mooring)	It may be different for each port

Finally, the fourth table reports cost parameters, and in particular:

Parameter name	Description	Notes / Assumptions
Ship unitary cost [M€]	Cost of one ship in Millions of Euro	It is a function of the ship typology (Cylinder costs/ capacity).
Storage cost [M€]	CAPEX cost express in Millions of Euro related to one storage unit.	Storage units are provided in destination ports to guarantee a continuous delivery
Storage unit capacity [M m3]	The capacity of one storage unit in Millions of m3	It is generally equal to 120.000 m3, but can be modified in the case.
Facilities cost [M€]	CAPEX cost express in Millions of Euro related to loading/unloading facilities	Facilities are provided in each port to allow loading/unloading operations
Ship OPEX [€/Year]	Ship OPEX cost per year express in Euro	Rough estimation 654000 €/Year a ship. Precise estimation will be provided at a later stage.
Other cost [M€]	Indirect cost, Tax, Port fee etc.	Analyze if other not mentioned cost it may worth to consider for the tariff estimation

Moreover, in order to estimate also the gas upstream and downstream tariff, it is necessary to include this additional information:

Parameter name	Description	Notes / Assumptions
Gas Upstream cost [M€]	Cost of upstream infrastructure	Since this data is not available at this stage only the midstream tariff can be calculated

Gas Downstream cost [M€]	Cost of downstream infrastructure	Since this data is not available at this stage only the midstream tariff can be calculated

The Model can take into account even other parameters and data necessary for the correct tariff estimation. These data are parameterized into the Model and can be assumed as constant based on either on-field experience or somehow calculated by estimation.

2.4 Output variables

The results which are provided by the platform are defined in the following table.

Parameter name	Description	Notes / Assumptions
Ships number [-]	Number of ships to be used in each scenario to fulfill the demand	The parameter can be eventually forced by the user (set the flag “force_ship_number” to 1 in the platform and then set the ships number manually)
Costal storage autonomy [day]	The minimum quantity of gas necessary at each port to guarantee the autonomy of the market express in days. It is basically the maximum time interval without receiving gas that the destination port can bear. In some cases however there is no need to set this quantity explicitly.	In some scenario the storage is not required, for example if the delivery point is a pipeline or a network grid that guarantees continuously the demand
Number of storage units [-]	It is related to the costal storage autonomy and daily gas demand of each location, besides the capacity of a single unit.	The parameter can be eventually forced by the user (set the flag “force_storage_unity” to 1 in the platform and then set the storage number manually)
Gas Midstream tariff (€/m3)	The final cost of gas for m3 taking into account the mortgage of Midstream costs	It includes Ship costs, CAPEX for storage and facilities, and ship OPEX
Gas Final tariff (€/m3)	The final cost of gas for m3 to the customer	It includes Midstream, Upstream and Downstream costs

2.5 Assumptions

The Model considers the following as assumptions.

- Gas composition (Pure gas)
- Gas pressure (Upstream gas pressure 240 bar)

- One ship can transport gas to more than one destination port (the model automatically check if this is possible and convenient) however each ship always goes back to the same departure port for the loading (this in case there were more than one departure port).
- In case there is a certain maximum autonomy period that has to be fulfilled, (i.e. the coastal storage autonomy quantity is greater than zero) the ship capability is enough to guarantee that autonomy period, for example if the ship capacity was 900.000 m^3 and the autonomy period was 7 days then the maximum gas demand over that 7 days period cannot be greater than 900.000 m^3. If this condition is not fulfilled an error is generated, in such a case it will be necessary either to increase the ship capacity or decrease the maximum allowed autonomy period.
- All the ships in a certain geographical area are identical (i.e. it is not possible to have ship of different size or characteristic in the same area.

All the assumptions can anyway be adjusted anytime in the Model at the best convenience.

3 SCENARIO DATA AND DESCRIPTION

Three different scenario cases were identified and characterized, representing both existing and new upcoming gas exploitations.

- **Barents Sea Offshore Oil Field** (unused gas due to limited pipeline availability and flared associated gas from the oil platform)
- **East Mediterranean Gas Fields** (new discovered gas field to be exploited)
- **Black Sea Region** (unreachable since there are no near existing gas pipelines)

In these cases, the Gasvessel technology may be a valid alternative opportunity.

3.1 East Mediterranean gas field

3.1.1 Scenario 1: Cyprus Aphrodite gas field to Crete

Gas demand: 1.4 Million Nm3/day

Distance matrix [NM]:

Ports	Aphrodite gas field
Crete	400

3.1.2 Scenario 2: Cyprus Aphrodite gas field to Lebanon

Gas demand: 3.70 Million Nm3/day

Distance matrix [NM]:

Ports	Aphrodite gas field
Lebanon	120

3.1.3 Scenario 3: Cyprus Aphrodite gas field to Egypt

Gas demand: 16.95 Million Nm3/day

Distance matrix [NM]:

Ports	Aphrodite gas field
Egypt	285

3.2 Barents Sea offshore oil field

3.2.1 Scenario 1: Alke gas field to Nyhamna

Gas demand: 1.18 Million Nm^3/day

Distance matrix [NM]:

Ports	Alke
Nyhamna	646

3.2.2 Scenario 2: Alke gas field to Polarled

Gas demand: 1.18 Million Nm^3/day

Distance matrix [NM]:

Ports	Alke
Polarled	377

3.2.3 Scenario 3: J. Castberg oil & gas field to Nyhamna

Gas demand: 1.29 Million Nm^3/day

Distance matrix [NM]:

Ports	J.Castberg
Nyhamna	686

3.2.4 Scenario 4: J. Castberg oil & gas field to Polarled

Gas demand: 1.29 Million Nm^3/day

Distance matrix [NM]:

Ports	J.Castberg
Nyhamna	422

3.3 Black Sea region

3.3.1 Scenario 1: Shah-Deniz gas field to POTI-Georgia, delivery to YUZNE-Ukraine

Gas demand: 6.3 Million Nm^3/day

Distance matrix [NM]:

Ports	POTI-Georgia
YUZNE-Ukraine	578

4 SHIP NUMBER AND SIZE ASSESSMENT BY THE DECISION PLATFORM

4.1 Optimization workflow in modeFRONTIER – engine behind platform

The model developed in modeFRONTIER contains the input variables described in the paragraph above; any of the previously mentioned input can be exposed, and all the necessary computations are implemented by a proper generic script. The output variables are then extracted and made available; see the workflow scheme below (Figure 3):

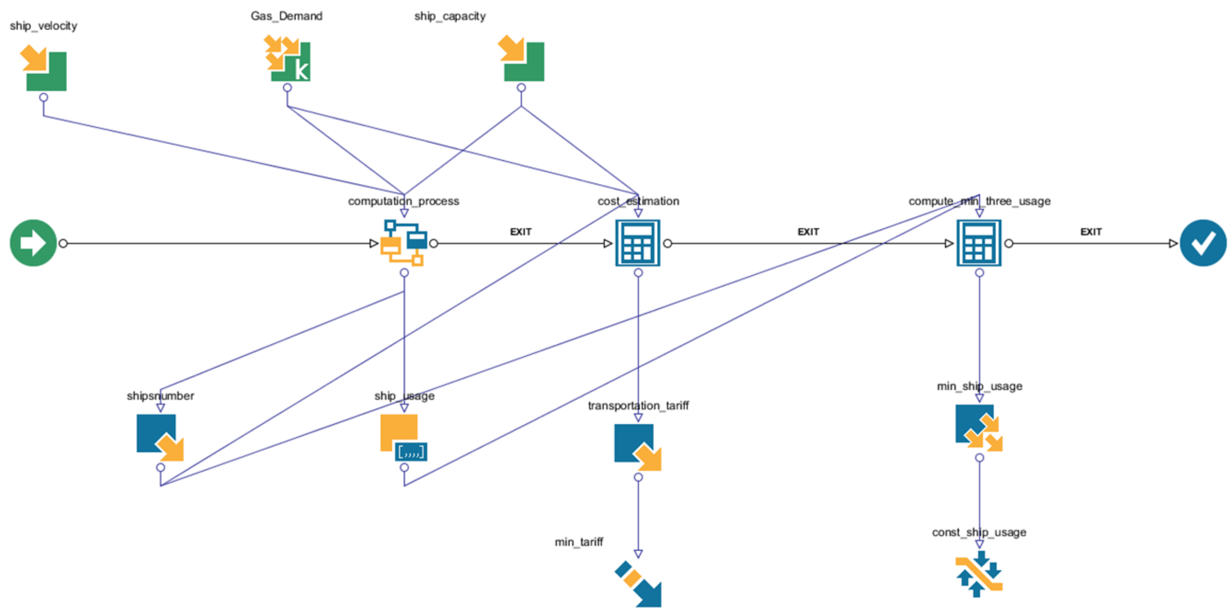

Figure 3 Model Workflow Scheme

Similar workflows are created for each scenario or variant, these workflows are intended as an independent sub-process below the main platform. In this way the final Model is flexible and easily adaptable for any new case.

A specific procedure has been implemented to find the optimal number of ships and size to satisfy the gas demand of the considered geographical areas.

The optimal solution considers the size and the number of ships necessary to fulfil the given gas demand trying at the same time to maximize the usage of the ships (the percentage of time the ship is on mission) reducing finally the cost/tariff. The procedure is developed by modeFrontier, the multi-objective optimization platform developed by Esteco that offers a wide range of optimization algorithms suitable for specific problem.

Possible scenario solution schemes:

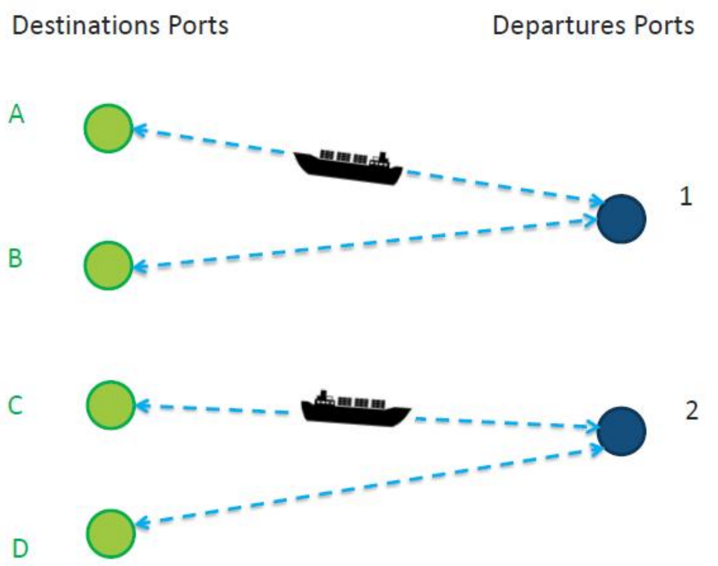

Figure 4 Source 1 is convenient for ports A and B, and Source 2 is convenient for ports C and D

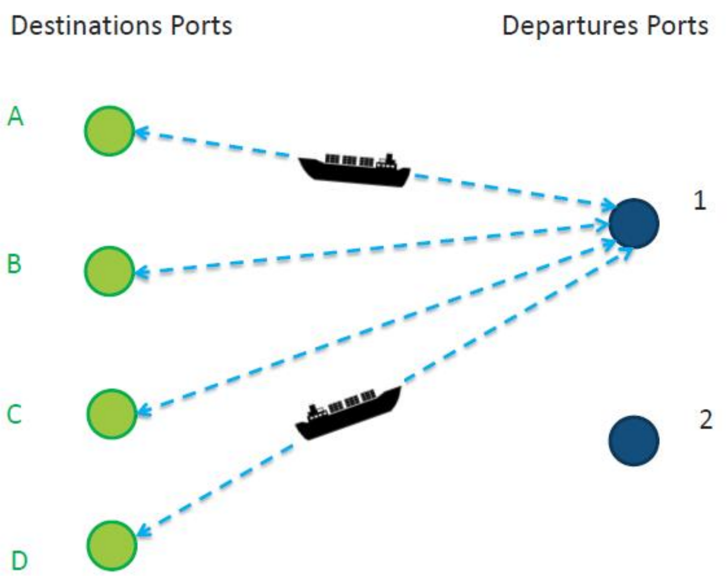

Figure 5 Source 2 is not convenient for ports A, B, C and D

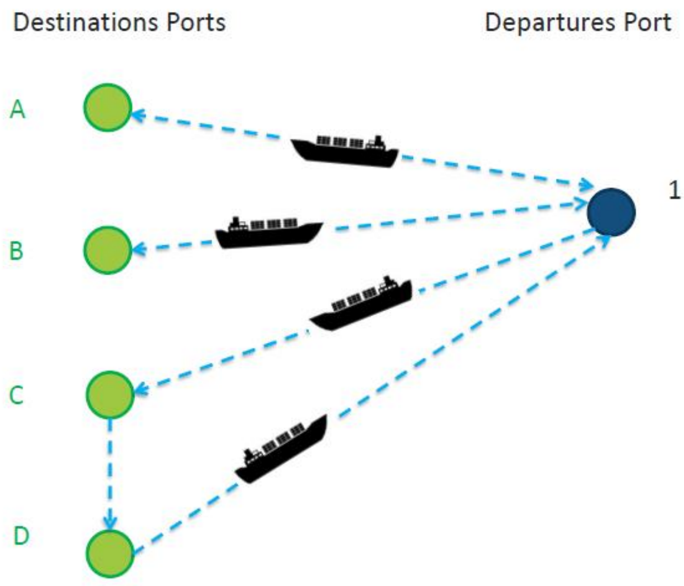

Figure 6 The optimal solution combines ports C and D with one triangle route (partial gas unloading)

4.2 Assessment of Volta platform – interface to the users

The optimization procedure will automatically set the input parameters for a certain number of designs in order to optimize the desired quantities (the percentage of ship usage, the total cost and the gas tariff estimation finally). Of course in this methodology it is also considered the possibility the same ship be used to transport gas to more than one destination whenever it is possible.

In order to facilitate the usage to the users, input and output parameters are provided by the web-based collaboration platform VOLTA of ESTECO. When the authorized user is logged in, he/she can fill the information related to design parameters of the scenario through the user interface. An example is provided in following figure 6.

The meaning of input parameters has been defined in chapter 2.2.

When the scenario parameters (including constant values and range of variation for the parameters which are to be optimized) are defined, the user can execute the scenario analysis, and as results a table will be obtained filled by the output parameters defined in section 2.2, which can be ordered by the gas tariff cost (allowing the selection of the optimal solution).

In addition, charts and reports can be retrieved for each scenario, as shown in figure 7.

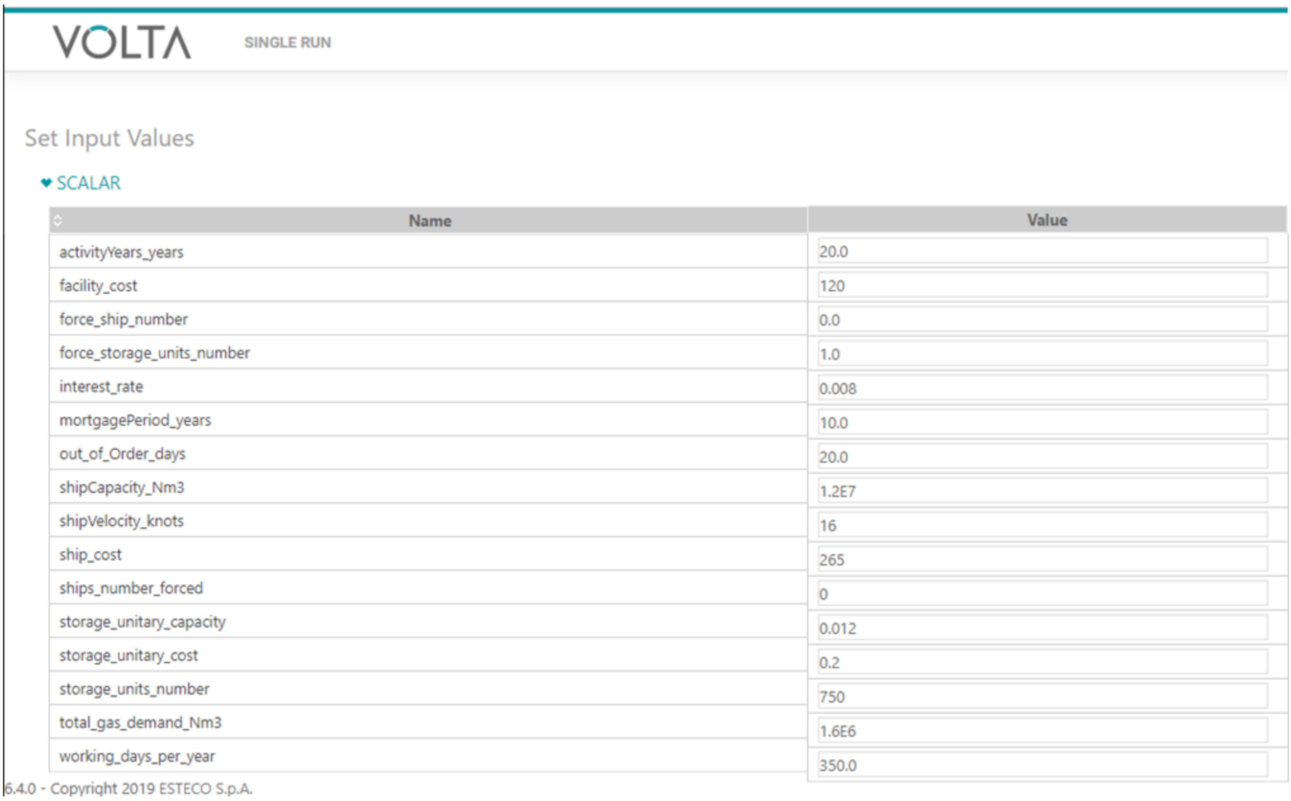

Figure 7 Web-based user interface in VOLTA –setup of input parameters

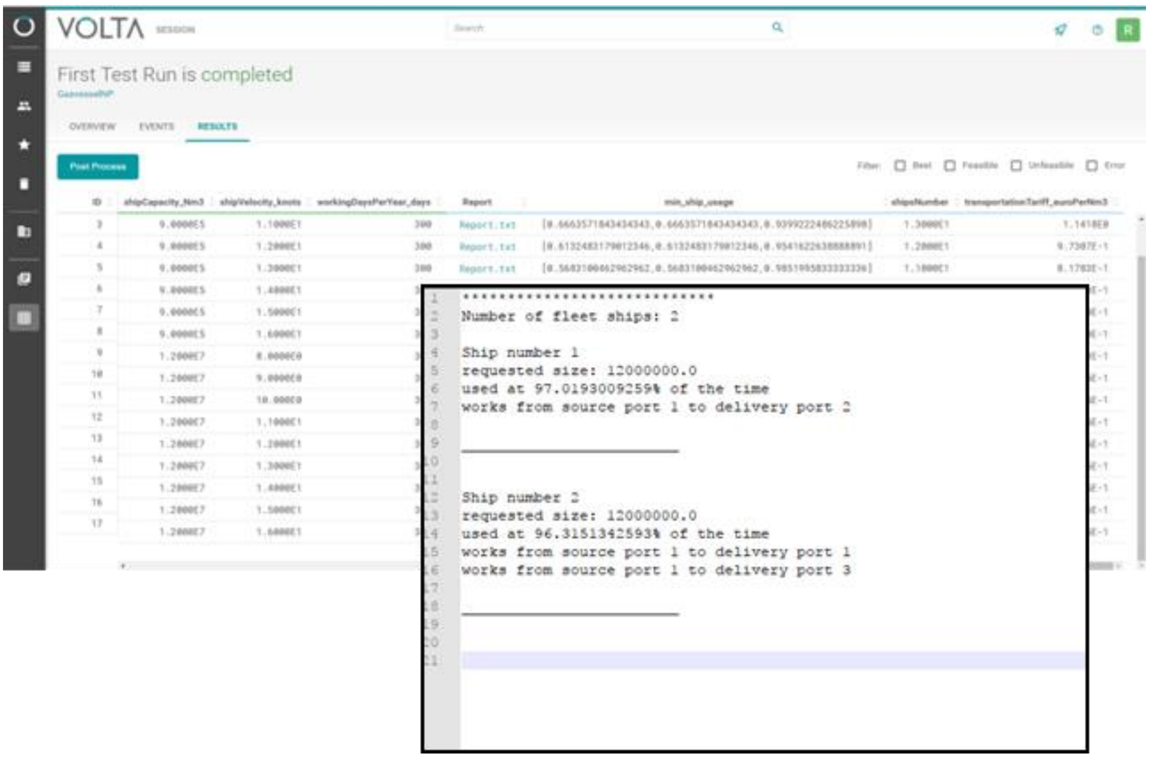

Figure 8 Example of Outcome of Decision tool platform

More in detail, the report file includes the following information:

- Number of ships fleet, it is the number of ships necessary to fulfil the gas requirement in the geographical area. The ship number is computed considering the number of trips necessary during one year, the port distances, the ship velocity and the maximum interval time between two ships arrivals;
- Ship size for each ship of the fleet.
- Ship usage, is a vector that reports for each ship the percentage of time the ship would be on mission over the entire working year
- Ship schedule, defining the source and delivery port number that the completes for each trip.

5 GAS TARIFF ESTIMATION

The following tables report the results of the application of Decision Support platform to the scenarios considered in this study. In total 8 scenarios are selected (3 for the East Mediterranean, 4 in Barents Sea and 1 for the Black Sea) by the Gasvessel consortium. Input parameters as defined in section 2.2 are reported as inputs for each scenario on the basis of the document WP7-Midstream Tariff from Navalprogetti (costs and benefits analysis), followed by the output results obtained by the application of the platform.

For every case, the upstream and downstream tariff are not competed at this stage (they depend on the conclusion of WP 6 activities), and estimated at the moment just on the basis of storage and port facilities investment costs.

The definitive outcome is instead related to the midstream costs, which is reported at the end of each table for each scenario.

5.1 East Mediterranean scenario

	EAST MEDITERRANEAN		
	CYPRUS-CRETE 1	CYPRUS-LEBANON 1	CYPRUS-EGYPT 5
Total gas demand (mmscmd)	1.4	3.70	16.95
Ship capacity (M m3) - 1ship	12	9	12
Ports distances (Nautical Miles)	400	120	285
Ship velocity (knots)	16	16	16
Working days per year	310	310	310
Activity years (years)	20	20	20
Mortgage period (year)	10	10	10
Interest rate (%) (legal Italy 2019)	0.8	0.8	0.8
Gas loading time (hours)	33	23	33
Gas unloading time (hours)	60	42	60
Operational time (hours) without sailing	10	10	10
Ship cost (M€) -1 ship	265	200	265
Ship OPEX cost - 1 ship per year	0.654	0.654	0.654
Storage unitary cost (M€) - 1 unit=12000 m3	0.2	0.2	0.2
Storage unit capacity (M m3)	0.012	0.012	0.012
Facilities cost (M€)	120	130	600
Facilities OPEX (M€) - per year			
Storage capacity (M m3) - minimal	8.925	13.875	97.9032
Storage capacity (M m3) - decided	9	13.9	14.5
Number of units - minimum	750	1158.333333	1208.333333
Number of units decided	750	1200	1210
Storage cost (M€)	150	240	242
Facilities cost (M€)	120	130	600

Total Upstream/Midstream costs (M€)	292.3944233	400.6886541	911.8374237
Gas Upstream/downstream tariff (€/m3) - incomplete	0.028610022	0.014834826	0.007369276
Nominal total gas delivered in life (M m3)	10220	27010	123735
Ships number - minimal	0.876	1.815	9.606
Ships number - decided	1	2	8
Coastal storage autonomy (day)	6.375	3.75	5.776
Ships cost (M €)	265	400	2120
Total Midstream costs (M€)	300.0597117	459.3369234	2400.477694
Gas Midstream tariff (€/m3)	0.02936005	0.01700618	0.019400151

For this scenario, it is to be noted how the storage capacity for Egypt is drastically reduced with respect to the computed minimum value, because as indicated in document WP7-Midstream Tariff, it is assumed that the spare storage can be used for 2 months per year. This means that in 20 years, the total use would be 40 months only.

On the other side, the number of ships decided for each scenario is rounded to the highest integer in order to fulfil the gas demand; only in the Egypt scenario it is rounded by defect (8 ships), considering an higher service (more than 310 days per year) to fulfil the request.

5.2 Barents Sea scenario

	BARENTS SEA			
	ALKE 1 Nyhamna	ALKE 2 Polarled	J. CASTBERG 1 Nyhamna	J. CASTBERG 2 Polarled
Total gas demand (mmscmd)	1.18	1.18	1.29	1.29
Ship capacity (M m3) - 1ship	9	9	9	9
Ports distances (Nautical Miles)	646	377	686	422
Ship velocity (knots)	16	16	16	16
Working days per year	310	310	310	310
Activity years (years)	20	20	20	20
Mortgage period (year)	10	10	10	10
Interest rate (%) (legal Italy 2019)	0.8	0.8	0.8	0.8
Gas loading time (hours)	33	33	33	33
Gas unloading time (hours)	60	60	60	60
Operational time (hours) without sailing	10	10	10	10
Ship cost (M€) -1 ship	200	200	200	200
Ship OPEX cost - 1 ship per year	0.654	0.654	0.654	0.654
Storage unitary cost (M€) - 1 unit=12000 m3	0.2	0.2	0.2	0.2
Storage unit capacity (M m3)	0.012	0.012	0.012	0.012
Facilities cost (M€)	70	70	70	70
Facilities OPEX (M€) - per year				
Storage capacity (M m3) - minimal	9.027	7.3868	10.1523	8.3721
Storage capacity (M m3) - decided	9.1	7.39	10.152	8.372
Number of units - minimum	758.3333333	615.8333333	846	697.6666667
Number of units decided	750	615	846	698
Storage cost (M€)	150	123	169.2	139.6
Facilities cost (M€)	70	70	70	70
Total Upstream/Midstream costs (M€)	238.2473079	209.0078655	259.0398002	226.9847079
Gas Upstream/downstream tariff (€/m3) - incomplete	0.02765815	0.024263741	0.027507678	0.024103718
Nominal total gas delivered in life (M m3)	8614	8614	9417	9417
Ships number - minimal	1.181	0.966	1.328	1.095
Ships number - decided	1	1	2	1
Coastal storage autonomy (day)	7.65	6.26	7.87	6.49
Ships cost (M €)	200	200	400	200

Total Midstream costs (M€)	229.6684617	229.6684617	459.3369234	229.6684617
Gas Midstream tariff (€/m3)	0.026662231	0.026662231	0.048777416	0.024388708

For this scenario, the number of ships is rounded normally to the highest integer, except for the case of the first route (Alke-Nyhamna), where the minimum number of ships (1.18) is close to the integer 1. There are not particular exceptions or notes related to the choice of storage units or other parameters.

5.3 Black Sea scenario

	BLACK SEA
	UKRAINE 1
Total gas demand (mmscmd)	6.3
Ship capacity (M m3) - 1ship	12
Ports distances (Nautical Miles)	578
Ship velocity (knots)	16
Working days per year	310
Activity years (years)	20
Mortgage period (year)	10
Interest rate (%) (legal Italy 2019)	0.8
Gas loading time (hours)	33
Gas unloading time (hours)	60
Operational time (hours) without sailing	10
Ship cost (M€) -1 ship	265
Ship OPEX cost - 1 ship per year	0.654
Storage unitary cost (M€) - 1 unit=12000 m3	0.2
Storage unit capacity (M m3)	0.012
Facilities cost (M€)	2000
Facilities OPEX (M€) - per year	10
Storage capacity (M m3) - minimal	45.99
Storage capacity (M m3) - decided	45.99
Number of units - minimum	3832.5
Number of units decided	3833
Storage cost (M€)	766.6
Facilities cost (M€)	2000
Total Upstream/Midstream costs (M€)	3196.068191
Gas Upstream/downstream tariff (€/m3) - incomplete	0.069494851
Nominal total gas delivered in life (M m3)	45990
Ships number - minimal	4.512
Ships number - decided	4
Coastal storage autonomy (day)	7.3

Ships cost (M €)	1060
Total Midstream costs (M€)	1200.238847
Gas Midstream tariff (€/m3)	0.026097822

For this scenario, midstream costs are aligned with the other scenarios. Preliminary data related to upstream and downstream costs are a bit higher than the other scenarios, basically due to the high value estimated by VTG for the facility costs (2000 M€). OPEX costs for facility maintenance are provided as well for this scenario (they are not yet available for the other cases).

6 CONCLUSIONS

The Decision Support Model developed in modeFRONTIER is a flexible workflow to calculate the CNG transportation tariff for any geologist scenario.

The model allows the end user to have an easy tool to estimate the CNG cost and then the gas tariff. The flexible modular concept and parametrization can explore different combinations, options, locations by adding or remove modules, inputs and outputs suitable for the specific case study.

Moreover the post process tools available in VOLTA design space can be helpful to analyzed data and results, in order to understand which is the most effective set of input parameters.

The modeFRONTIER optimization algorithms are used to locate the best option in an automatic way; the platform is made available to all the Gasvessel partners and published as a web service by the VOLTA architecture developed at Esteco.

In the present report, the platform has been applied to the scenarios decided by the partners for the analysis of WP3.2, but it is worth to note that the platform can be applied to any possible scenario of transportation, thanks to the versatility of the methodology. It is just necessary for the authorized user to specify the scenario details (as specified in the section 2 of this deliverable), and execute the analysis to get the updated results.

In addition, since at this stage of the project upstream and downstream costs are not available (these are definitive outcomes of WP 6), the results can be considered as definitive just for the midstream costs. Upstream and downstream costs are at this stage approximated by the available and not complete data (facility investments in the ports and storage costs). The platform is however set up to accept in input the complete parameters, therefore when data will be available also upstream and downstream costs will be available as output.