EUROPEAN GAS FLOW (EGF) MODEL

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This report refers to approaches for the European gas transmission network flows modelling. Since GTN's of European countries are closely related and have a strong influence on each other, for many problems it makes sense to consider the totality of these GTN as a whole.

Approaches in question are developed in order to create information and analytical system to solve various problems that refer to European countries GTN gas transport.

Investigations are carried out within the framework of scientific and technical collaboration between OAO Gazprom (Russia) and N.V. Nederlandse Gasunie (The Netherlands). The name of joint project is "European Gas Flow (EGF)".

European GTN flow modeling may have a variety of goals. The operational control objectives include:

- daily gas flows determination;
- existing gas flows optimization;
- gas flows rearrangement due to some GTN sections reconstruction, reduction of gas supplies by individual producers, some GTN sections capacity reduction.

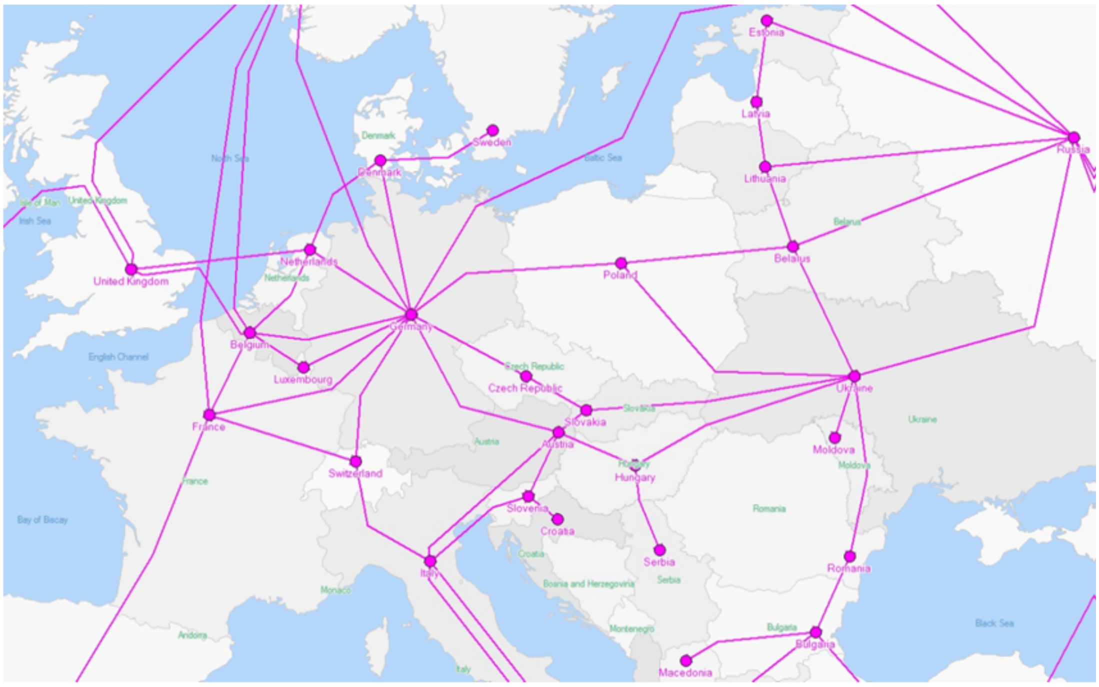
As well European GTN gas flows modelling can be executed for strategic management purposes, such as:

- existing pipelines throughput definition, including bottlenecks determining;

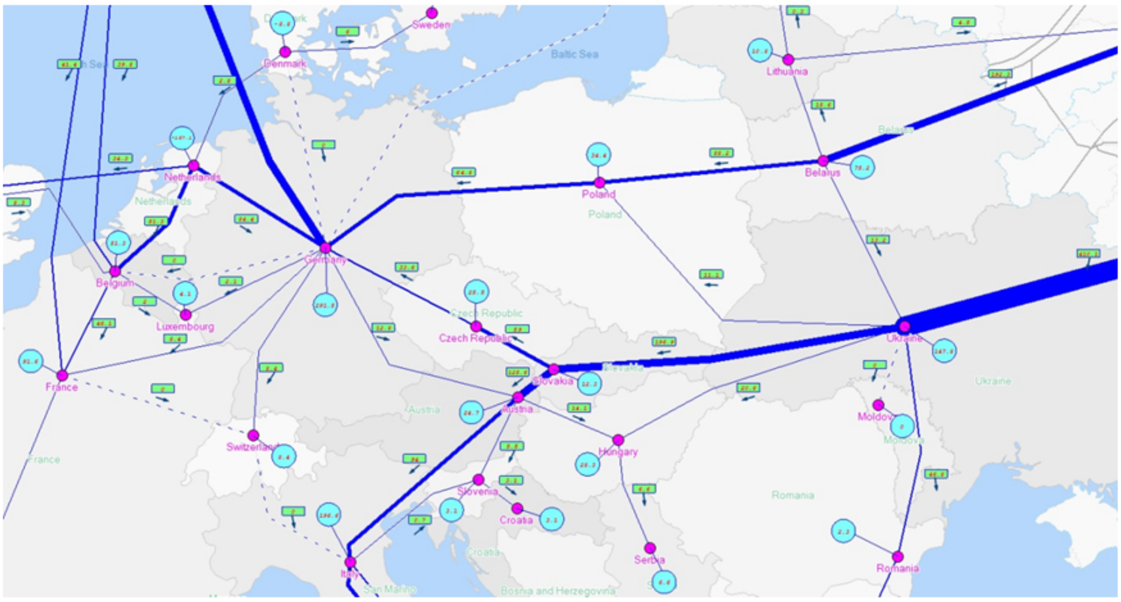
- stress tests to identify existing GTN capacities, considering for example extremely cold winter, pipeline accidents, reduction in supply;
- assessment of gas resources depletion and new production and LNG import facilities commission impact on gas flows in Europe;
- assessment of perspective transport and storage capacities impact on gas flows.

It's proposed to use a multilevel model for simulation of European GTN flows. Each level of model means the representation of the European GTN with a certain level of detail. Balance level is the simplest and most abstract description of the GTN. Flow level handles with separate sections of the GTN. Technological level contains the most detailed description of the GTN. Let's describe each level in more detail.

Balance level is represented by balance scheme of the European GTN. Balance scheme is a graph which nodes are European countries and arcs are flows from country to country. Each node of the graph is in fact a national GTN. A pair of nodes is connected by arc only if corresponding countries have GTNs connected with each other.

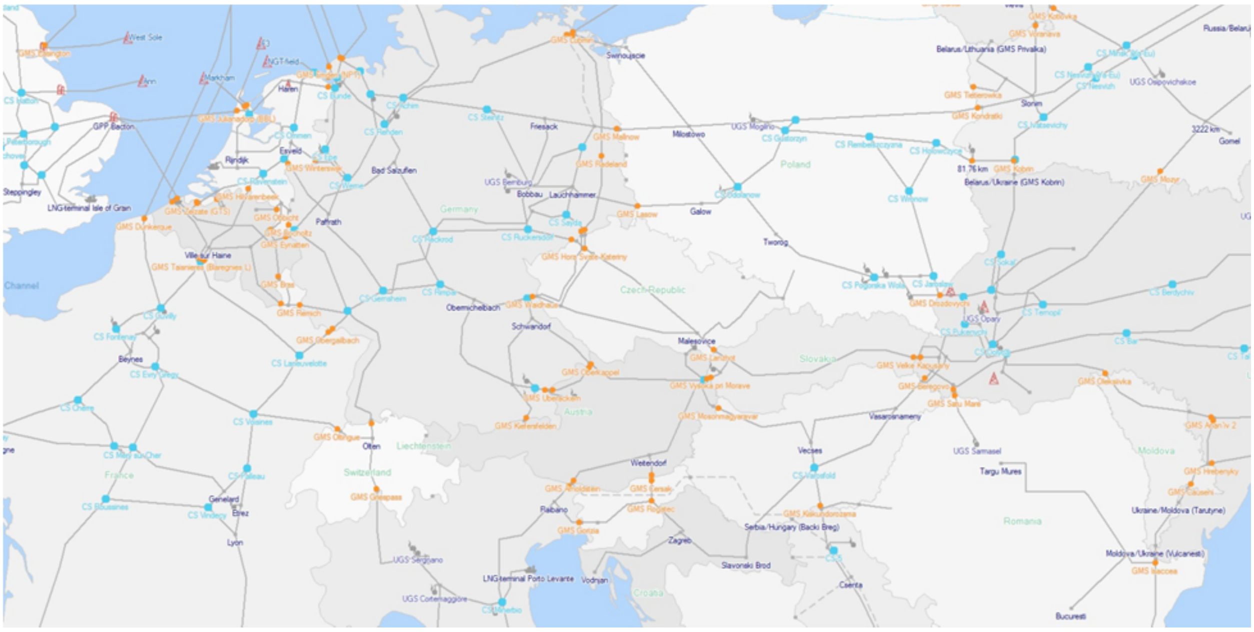


In the model this level serves to draw up the gas balance between European countries. At the same time a balance in each node (national GTN) have to be observed: the difference between imports and exports equals the sum of consumption, fuel gas for compressor needs, gas pipes stock change, injection into UGS reduced by withdrawal from UGS and production.

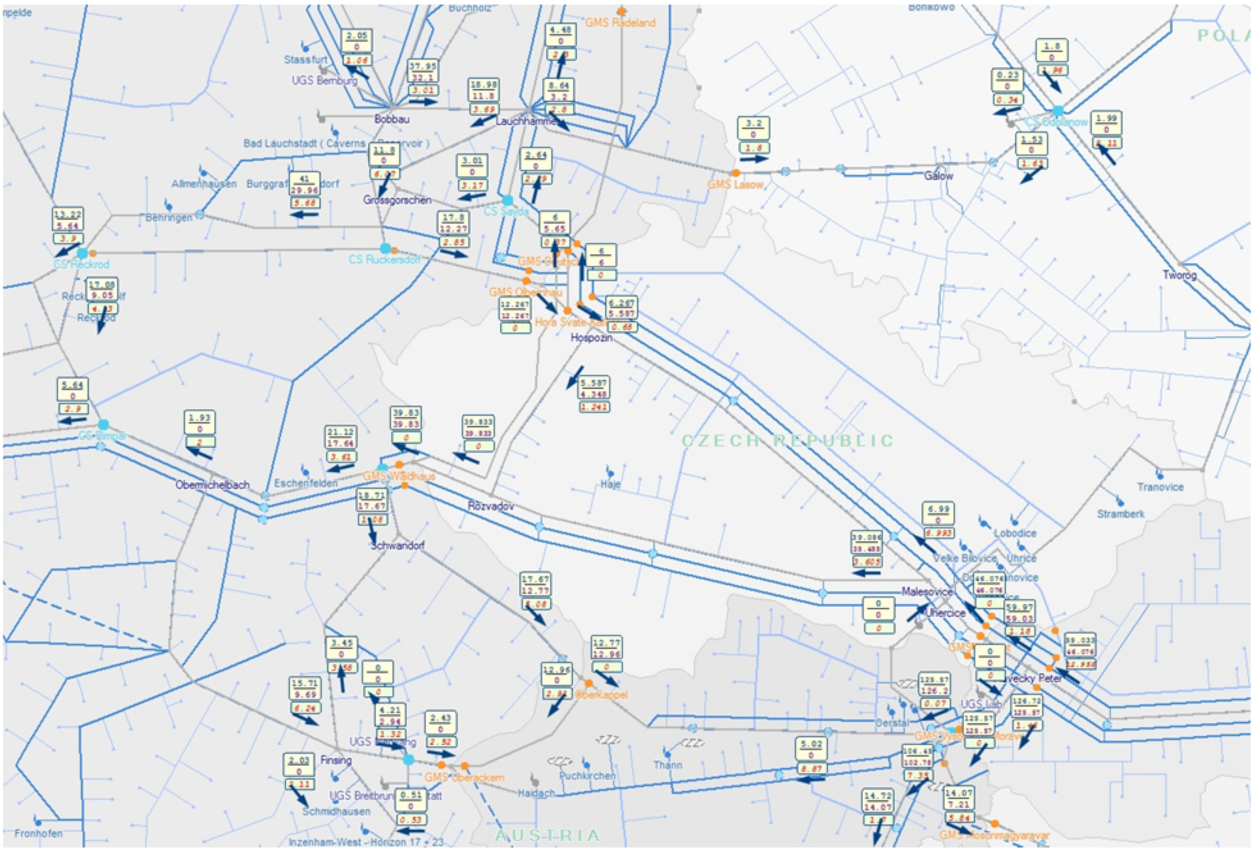


As already mentioned above, balance level is the simplest representation of the European GTN. It requires a minimal set of information to perform a calculation at this level, which is an advantage.

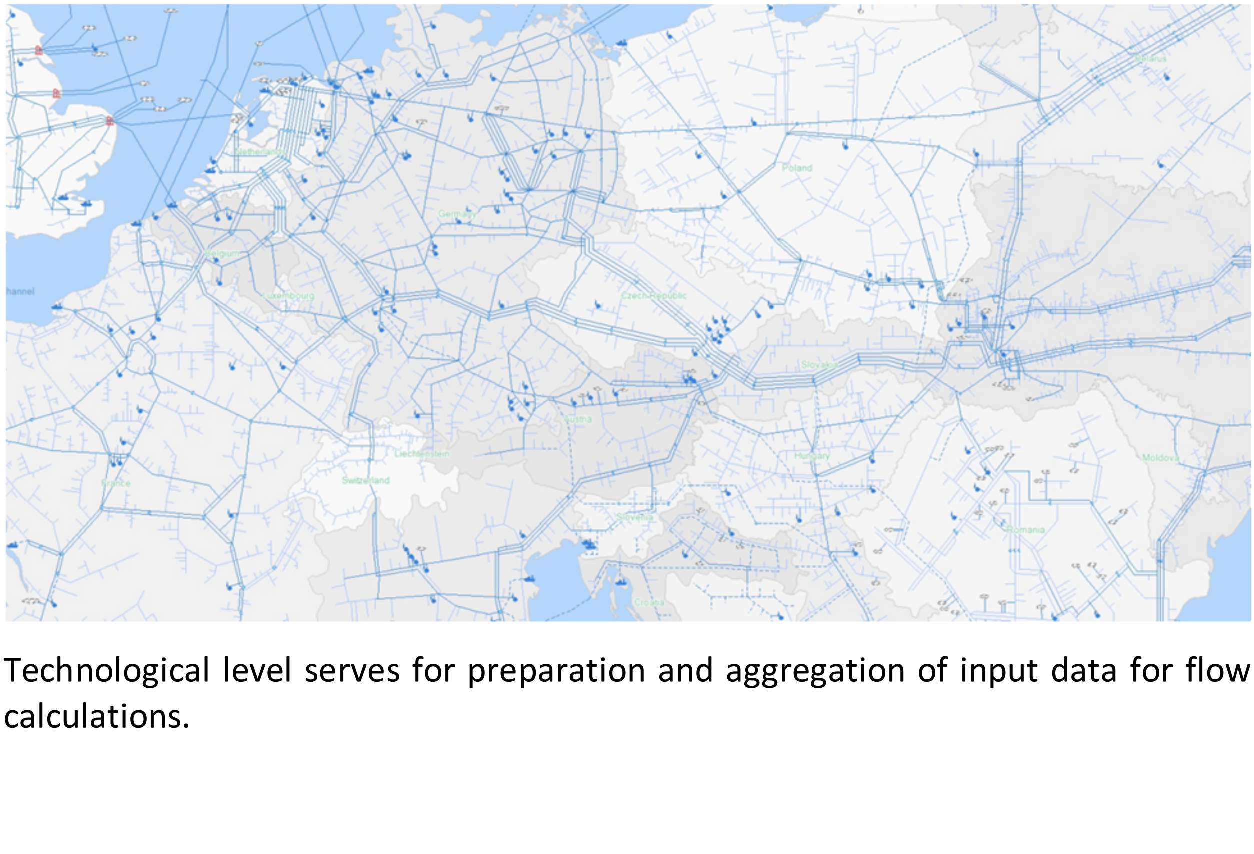
Flow level of the model gives more detailed description of the European GTN. It is represented by flow scheme graph. Its nodes are the diverging and merging points of major gas flows, production facilities, major UGSs, LNG terminals, cross border points. Graph arcs are the main sections of the GTN.



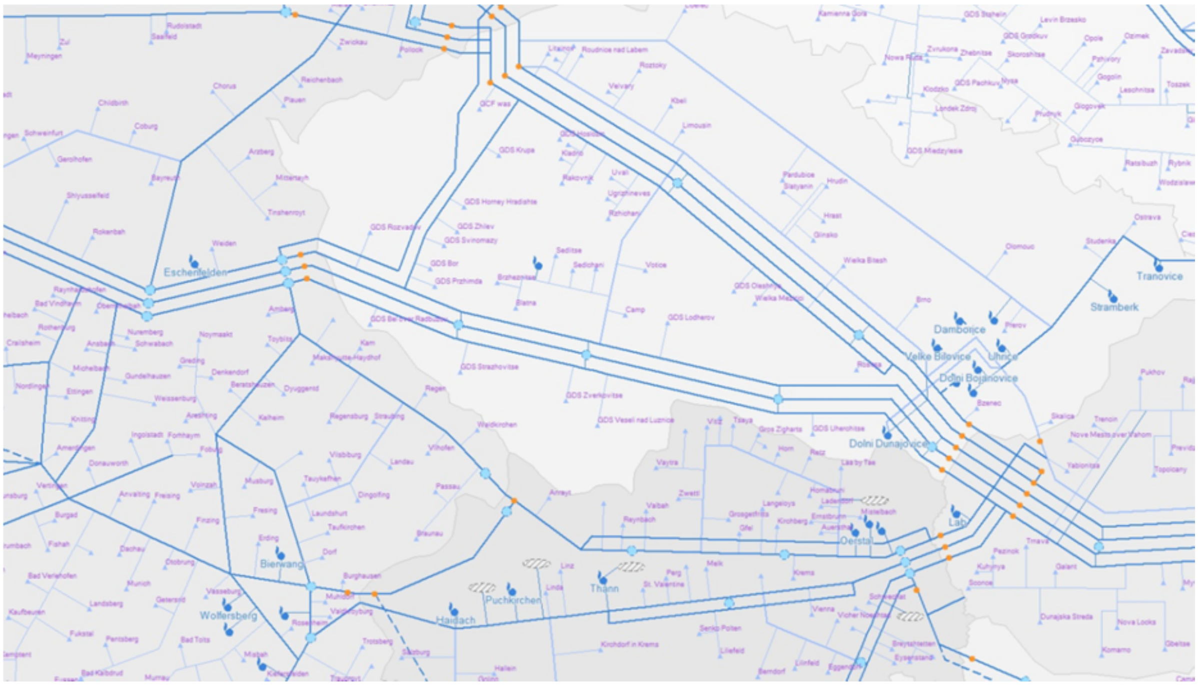
Flow level serves for flow simulation up to individual sections of the European GTN. The advantage of flow layer over the more simple balance layer is consideration of GTN topology and ability to consider GTN sections capacities while calculating.



Technological level of the model is represented by technological scheme. It provides the most detailed description of the European GTN. Individual objects of transmission infrastructure are the nodes of technological scheme: compressor stations, production facilities, underground gas storage, LNG-terminals, gas measure stations (GMS), gas distribution systems (GDS). Arcs of the graph are pipelines: trunk and distribution pipelines, branches, bypasses, process bypasses.



Technological level serves for preparation and aggregation of input data for flow calculations.



High detail of technological scheme allows evaluate data like:

- GTN section capacity;
- fuel gas value;
- available capacity;
- volume of gas stored in pipes.

The model is suit for solving different types of flow tasks: identification, optimization and simulation of gas flows. Flow identification is the basic task. The rest ones are based on its solutions. Moreover, identification is the most simple and demonstrative task.

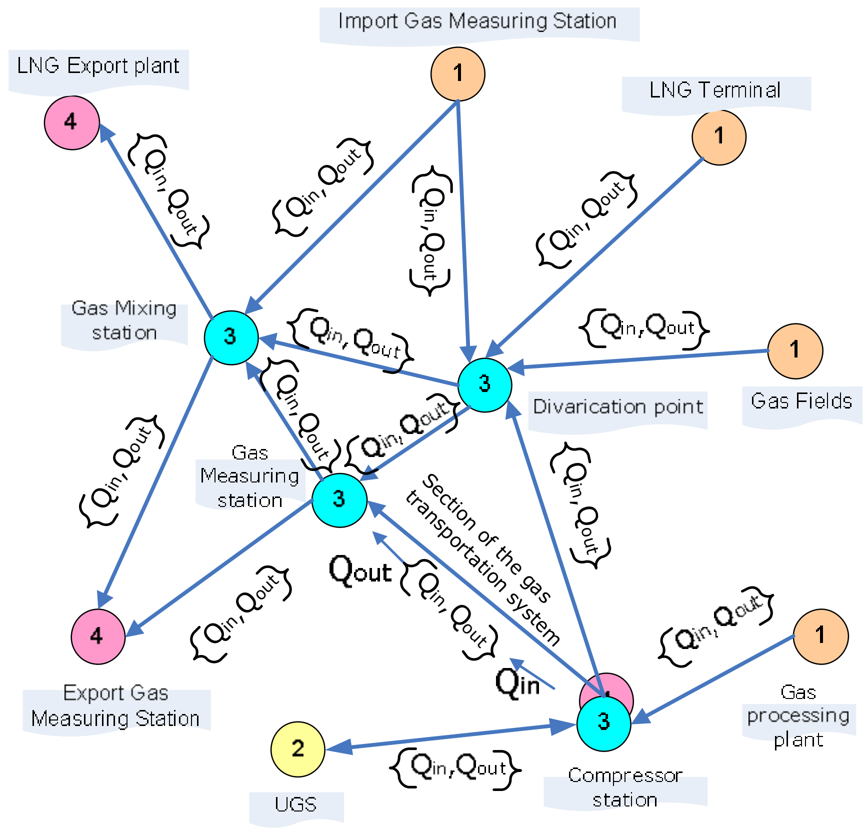
The flow identification task is stated as follows. Known:

- rates at the national GTN boundaries (pipeline gas exports and imports and LNG import);
- domestic production volumes;
- UGS injection/withdrawal rates (for each UGS);
- consumption of fuel gas for compressor needs;
- gas consumption volumes (for each GDS).

All these values are given for a certain period of time (day, month or year). Objective is to find flow values at the beginning and the end of each GTN section in a given time period. It should be noted hereby that we are not talking about the hydraulic calculations but about flow layer calculations only.

Identification problem in substance is to calculate the whole picture of actual flows in GTN while having information of GTN configuration and some GTN sections flow rates.

Flow identification can be solved as an optimization problem of mathematical programming. Constraints in this case are the balance equations for nodes and arcs, as well as restrictions on the quantity of flow. The optimization criterion consists of the optimization part and penalty functions. Depending on purpose of calculation the task may have various optimization criteria, such as achieving a minimum MTD, or minimum deviation from preset flows, or maximum gas reserves in pipes. Penalty functions will be discussed below.



For each point i balance equation: $\sum_j Q_{in}^{ji} = \sum_j Q_{out}^{ij}$

Criteria of optimization: $\sum_{i,j} Q_{in}^{ij} L_{ij} \rightarrow \min$

It’s proposed to build the model using open sources of information. First of all, such a choice is due to the lack of a unified database for European GTN objects that would contain all the necessary information for flow calculations. Typically such calculations require information like topology of the GTN, gas infrastructure facilities parameters, operational information, commercial information etc. Separate data sources provide only certain segments of the information required and they should be combined into united database to have the overall picture.

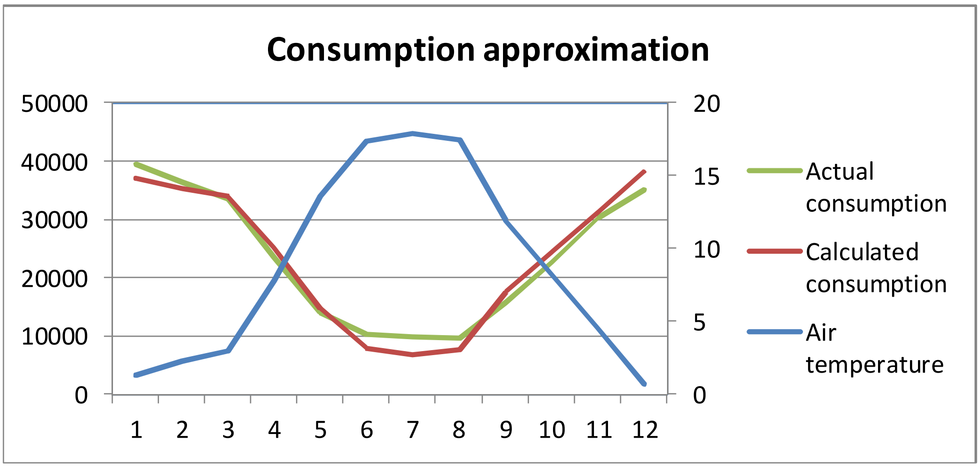
Open data sources are web sites of gas companies, their annual reports, information of European gas regulators and gas companies’ associations.

Using multiple sources of information causes problems like:

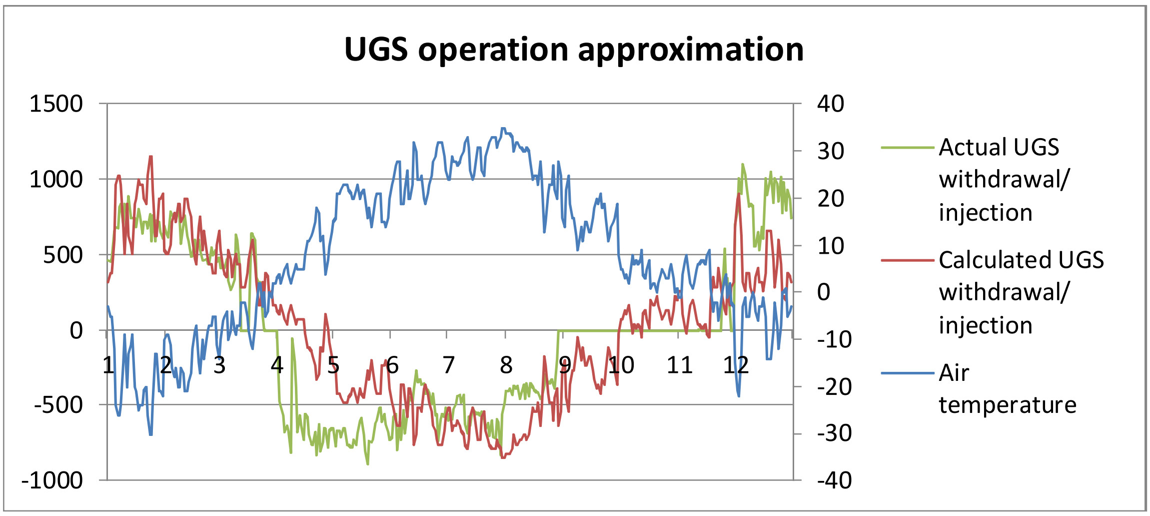
- Different national GTN operators publish different data sets, and there is no exhaustive published data for each country.
- Each source has its own data format.
- The data available from open sources is often aggregated and isn't detailed enough.

All this leads to the necessity of data pretreatment before performing calculations. Large amount of data have to be approximated by indirect information. Here are some examples of approaches to data approximation.

For a separate country the annual gas consumption value is often known. In case of calculating for a time period shorter than one year it's necessary to calculate consumption during this period. When doing so the unevenness of consumption during the year should be taken into account. To plot the consumption depending on day number during the year it's suggested to use gas consumption relation of air temperature. Such a statistical data could be easily found. Well known temperature and consumption curves for some countries are used to plot this relation.

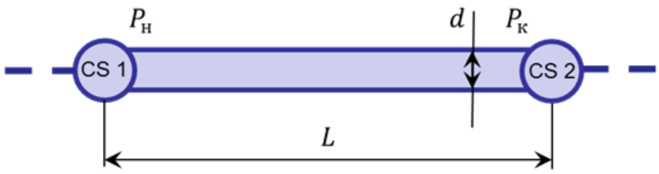


A similar method could be used for plotting the curves of injection and withdrawal on UGS depending on the day of the year.



Sometimes information of capacity is not available for a separate GTN sections. But there is information about pipes composing this section. It is proposed to use a simplified formula for determining capacity of pipeline based on its internal diameter and operating pressure. With knowledge of what pipes draw up the GTN section it's possible to estimate section capacity.

Trunk Pipeline



L – pipe section length [km]
d – pipe inner diameter [mm]
$P_н$ – section entry pressure [MPa]
$P_к$ – section exit pressure [MPa]

Pipeline technical capacity (with no route relief consideration) [mil. m³/day]

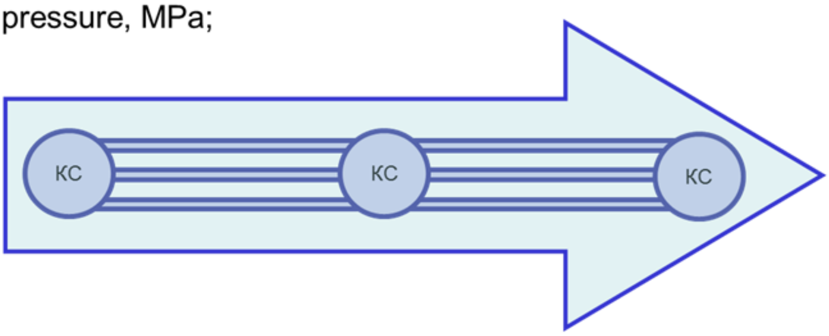
$$q = 3{,}32 \cdot 10^{-6} \cdot d^{2,5} \sqrt{\frac{P_н^2 - P_к^2}{\lambda \Delta T_{ср} Z_{ср} L}}$$

Pipeline capacity [mil. m³/day]

$$q = d^{2,6} \cdot P \cdot 10^{-7}$$

d – pipe inner diameter, mm;

P – working pressure, MPa;



Flow section capacity

$$q_{Участка\_ГТС} = \sum q_{МГ}$$

To calculate the fuel gas for compressor needs a simplified formula could also be used. Simplified formula gives the dependence of fuel gas consumption on compressor nominal power.

GPU fuel needs [thousand m³/h]

$$q_{TT} = q^o_{TT}\left(0{,}75\cdot\frac{N_H}{N^o_e} + 0{,}25\cdot K_{p_a}\sqrt{\frac{T_a}{288}}\right)\cdot K_{TT}\cdot K_{\bar{n}}$$

Fuel needs in nominal regime

Fuel needs in chosen regime

Fuel needs in idle regime

GPU technical condition amendment

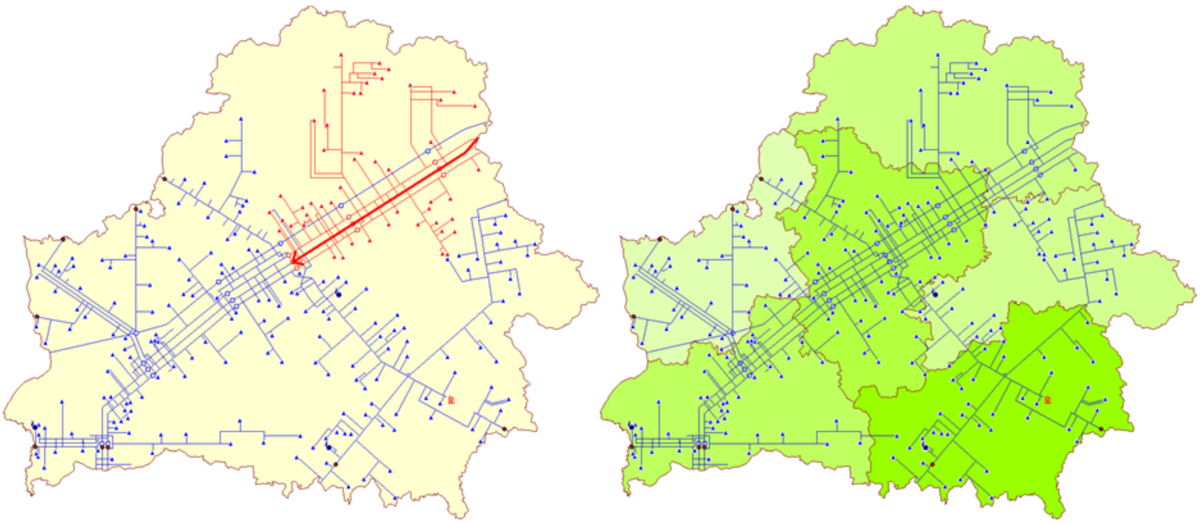
GPU fuel needs approximation simplified formula [thousand m³/h]

$$q_{TT} = 0{,}323\cdot N^o_e$$

CS fuel needs [mil.m³/day]

$$Q_{TT} = \sum q_{TT}\cdot 24\cdot 10^{-3}$$

For calculation of gas consumption for each GTN section various approaches could be employed depending on available data level of detail. The simplest approach is allocation of total domestic consumption value on GTN sections proportionally to their length. The most accurate one is to determine the consumption at each GDS and aggregate consumption by GTN sections with knowledge of what GTN section each GDS is connected to.



Population data by regions could be used for determining the consumption of GDS. Consumption of each region is considered to be proportional to the regional population share in the population of the whole country. Consumption of each GDS in the region is calculated by dividing the regional consumption by the number of GDSs in the region. As far as in the issue we calculate the consumption value by GTN sections, and large amount of GDSs are connected to each section, finally we get a fairly accurate value.

This method of consumption approximation can be improved if shares of consumption by sector are known (households, power and heat generation and industry). In this case three density maps by regions are needed: population, industry and CHP, to allocate demand on GDS.

In case initial data is not obtained ready for use for the calculation but it require be approximated from indirect information, it may get inconsistent. It may cause a solution of the optimization problem of mathematical programming couldn't be found. To avoid such a situation deviations from the approximated values are introduced in the mathematical model. Then penalty functions minimizing these deviations are added to the optimization criterion.

$$C = \tilde{C} + \Delta C$$

$\tilde{C}$ - initial (approximated) consumption value

ΔC - consumption deviation from approximated value

$$\sum \Delta C \rightarrow min$$

In conclusion the following could be stated:

- Multi-level model makes it possible to solve the problem with varying level of detail.
- The greater the level of detail, the more data is needed for calculations, and the more accurate result is obtained.
- The proposed approaches allow approximate missing data by use of indirect information.
- The proposed approaches can be improved or replaced with another.

It should be noted herein that a flexible approach to the creation of the model provide it with a wide range of applications. Such a model can serve as a tool for calculations both for the whole European GTN and for any separate national GTN. And while making calculations on the local GTN more detailed information can be added.