Gas Quality Tracking Supports Integration of Renewable Gases in the Gas Network

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An innovative solution for tracking gas qualities has been developed and is currently successfully being rolled out with a number of grid operators. The method includes a full uncertainty calculation based on a Monte-Carlo simulation. This ensures national metrology institutes recognize the use of calculated calorific values (CVs) and further properties in energy billing of end customers. The use of this method simplifies the injection of biomethane and hydrogen into gas grids by avoiding expensive alternatives such as installation of measurement equipment or CV adjustment through conditioning of the injected gases.

Introduction

Gas grids are set to make a major contribution to the decarbonization of our energy system. One of the most important tasks will be to integrate renewable gases such as biomethane or hydrogen from power-to-gas plants. Today a total of about 1 billion m³(n) (approx. 36 billion MJ) biomethane from approx. 200 biogas plants is being injected into the German natural gas network. The power-to-gas technology will contribute solving the problem of energy storage by using the huge storage capacity of the gas grid. The aim is to use surplus electricity from photovoltaic or wind farms to generate hydrogen by electrolysis and inject it into the gas network. Following commissioning of approx. 20 demonstration plants in Germany, construction of the first industrial scale plants is now underway in Brunsbüttel in Northern Germany (see also chapter 4.2) where the produced hydrogen will be injected into the grid of Schleswig-Holstein Netz. Similar developments towards a low carbon natural gas grid are observed in many countries in the world.

The described trend is welcome, as it will help to reduce climate-harming carbon dioxide emissions. On the other hand, the resulting increase in gas quality fluctuations is becoming a major challenge for grid operators, both in terms of gas appliances and the correct billing of the energy supplied. To meet these requirements, energy suppliers are increasingly turning to digital solutions. Gas quality tracking is an example of how this trend is playing out in the gas grid: Based on a software tool, all digital data available (i. e. grid topology, feed-in/consumption data, pressures) are used to accurately calculate the calorific values and further gas properties required for billing. This allows different gases to be fed into the grid in a flexible way without requiring extensive and costly measuring equipment.

Besides of facilitating the integration of renewable gases, gas quality tracking may of course also be applied for gas grids where different natural gases are injected; for example natural gases or shale gases from different sources or Liquified Natural Gases (LNG) from different origins.

Objective

Gas quality tracking based on flow simulation has been a known technique for quite some years now. However, the implementation for billing end customers was often difficult due to limited recognition by national metrological institutes; particularly in grids with poor measurement infrastructure.

The aim of this work is to develop a method for gas quality tracking which produces high accurate results and at the same time allows a reliable uncertainty determination. This way, compliance with national error limits can be verified in a transparent way. The uncertainty calculation based on a Monte-Carlo simulation which will be described in chapter 3.3 has been adopted in the revised ISO standard 15122, which is expected to be published in Mid 2018. This development will in future help to ensure metrological acceptance which has already been proven by a number of implementation projects.

Development of a new method for gas Quality Tracking

Method

The application of a gas quality tracking system requires detailed information on the grid topology (including pipeline length, pipe diameter and pipe roughness), calorific values or further gas quality properties at the entry points and volume flows at all entry and exit points. Additional data such as measured grid pressures may also be used in the calculation to enforce the determination of the volume flow through the grid. Calorific values at the entry points may be determined either by calibrated measurement instruments (such as process gas chromatographs) or by an upstream gas quality tracking system. Measured calorific values should be provided as hourly averaged values. Measured volume flows should be provided on an hourly basis. For exit points where no meters are available, the method described here uses standard load profiles to give a best possible estimation [1]. In addition, a special correction algorithm is applied to improve the quality of the volume flow at these exit points and to ensure that the total grid volume is balanced.

Based on the described input data, a complete flow simulation is carried out throughout the grid including the determination of flow speeds and travel times of the gas. In a second step, gas packages are then tracked backwards in time through the grid from their respective exit points to the entry points. This so-called 'back-propagation algorithm' makes it possible to identify the fractions of injected gases at each exit point, together with their transit times. Finally, the calorific values and further gas properties are determined for all exit points of the grid.

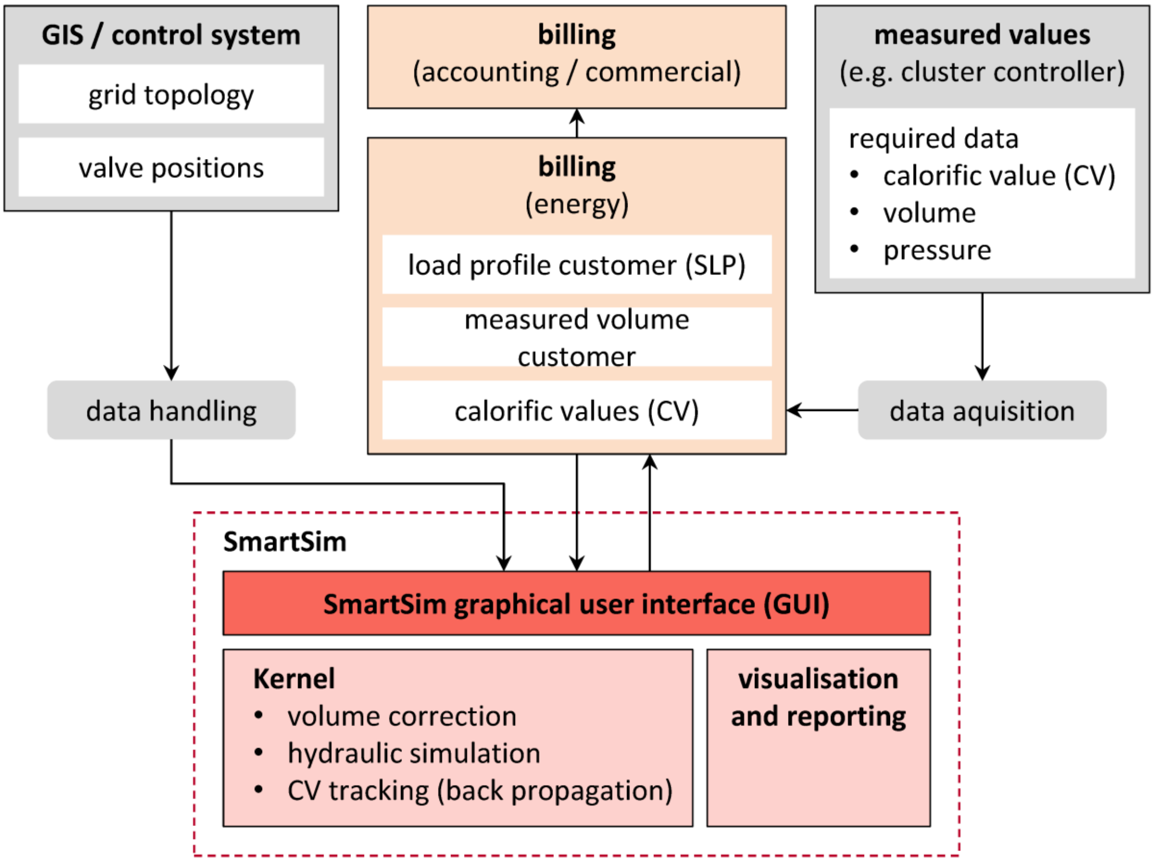

Figure 1: Data flow and software interfaces.

SmartSim Software

For an efficient implementation of the described method, a software tool known as SmartSim has been developed. On overview of the data flow and the interfaces to different IT-systems is illustrated in Figure 1. The calculation model was programmed in a discrete module - the SmartSim Kernel - which can be operated with a graphical user interface (GUI) (Figure 2). This kernel is based on newly developed algorithms for calculating hydraulic flow [2, 3]. The algorithms are characterized by a high degree of accuracy and very short calculation times, allowing even highly complex grids to be calculated within an acceptable timeframe. Calculation time is particularly important in connection with the time-consuming uncertainty calculation based on a Monte-Carlo simulation (see chapter 3.3) which is an integrate component of the software.

An interface for data import and export can be configured for different data and file formats (incl. XML, MSCONS, CSV), making connections to upstream or downstream IT systems straightforward. The user interface can be operated intuitively.

A software has been released 2015 and is currently rolled out with a number of grid operators as described in Chapter 4.

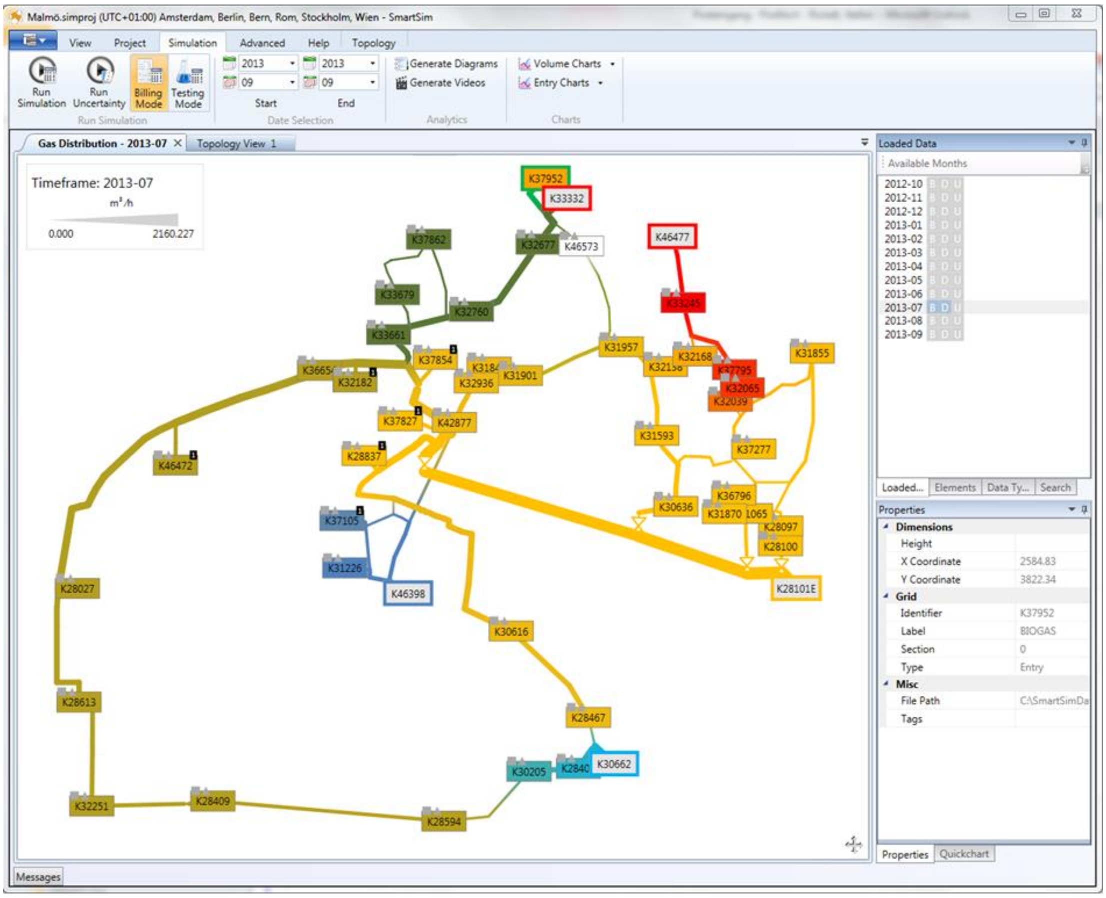

Figure 2: SmartSim Graphical user intervace.

Validation

Before applying a gas quality tracking system for billing end customers, calculation results have to be validated to ensure compliance with tolerance limits for calorific value. In the past, this has often been an obstacle, mainly because of lacking abilities to evaluate the uncertainty in a reliable way. With this work, for the first time, a complete uncertainty calculation has been implemented, which has already been recognized by several national metrology institutes.

In view of the complexity of a gas quality tracking system, an uncertainty calculation based on a conventional error propagation would be extremely difficult to apply. Therefore, the method adopted in this paper is based on a Monte Carlo simulation as described in Supplement 1 to the ISO Guide [4]. In this empirical method, a large number of calculation runs is carried out and the input variables are varied at random within the framework of their uncertainty. The calculation with unchanged input values is referred to as the reference scenario. For each scenario, the relative deviation, for example of the calorific value, is determined for each exit point with reference to the reference scenario. The resulting standard uncertainty is determined from the standard deviation of the relative deviations in the various scenarios. The extended uncertainty is then determined by multiplying the standard uncertainty by the extension factor k=2 (corresponding to a confidence level of 95%). The number of calculation runs must be sufficient to ensure that the calculated uncertainty is statistically well-founded. In the example simulation given in Figure 6, a total of 1600 simulations runs were carried out.

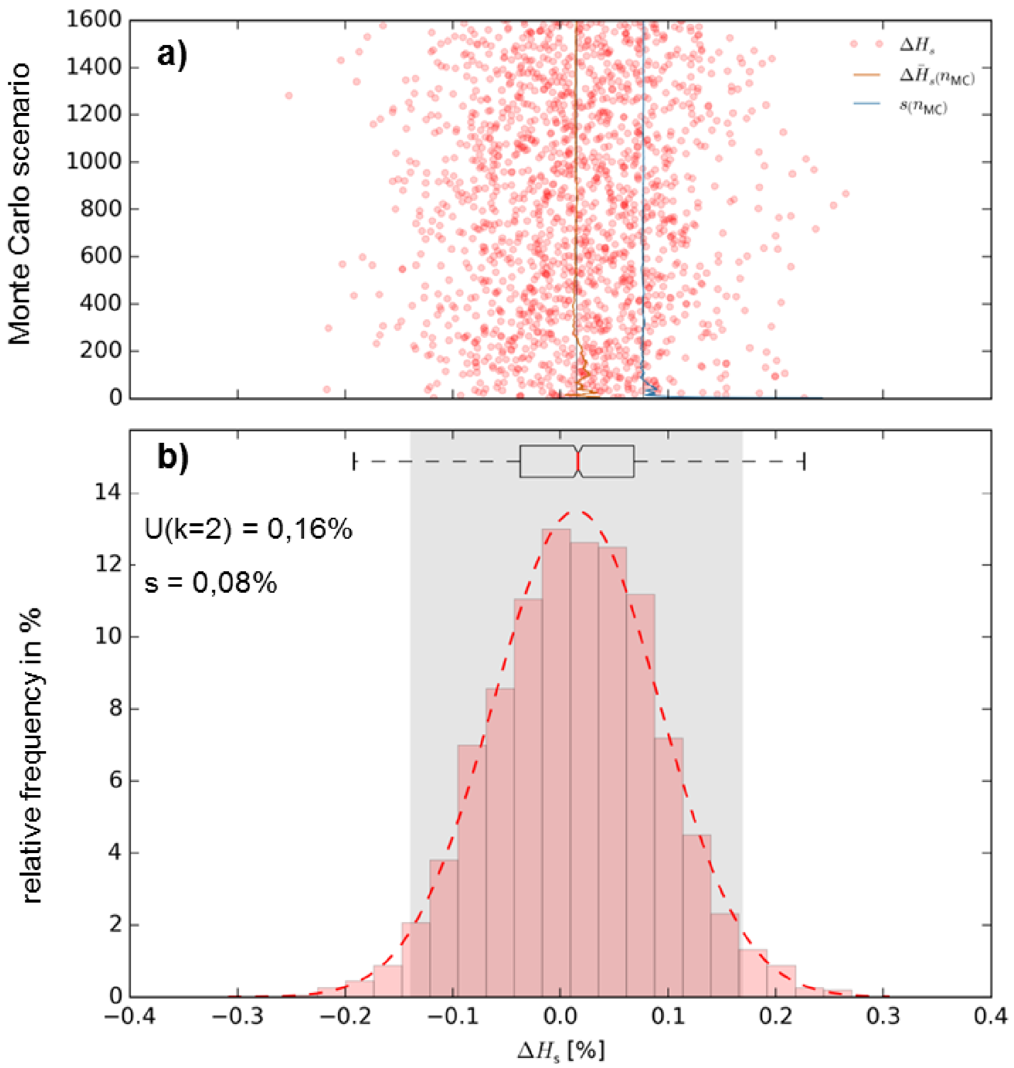

Figure 3: Graphical illustration of a Monte Carlo simulation. **a)** CV deviation for 1600 simulation runs compared to the reference scenario. **b)** Relative frequency distribution.

Calculated uncertainties should also be verified by comparison measurements using suitable gas quality measurement instruments (e.g. process gas chromatographs). Both remote mobile and locally fixed measurement instruments may be used. As an alternative, gas sampling techniques may also be applied. The suitable locations for measurement shall be selected in accordance with the expected flow situation. Measurements shall be performed preferably at exit points where gas quality fluctuations and mixtures of different gas qualities are to be expected. Those are usually the exit points where higher uncertainties are observed.

In order to evaluate the described method for determining the uncertainty, an extensive analysis has been made to compare calculated uncertainties with field test results. For this comparison, field tests with a mobile gas chromatograph (GC) in ten different grids at different time periods were considered. The duration of the tests was between 1 and 12 month. Figure 4 shows the results for the monthly averaged values. The diagram clearly shows, that uncertainties are predicted rather conservatively; in most cases uncertainties are by a factor of 5 or more larger than the observed experimental deviation. However, all calculated uncertainties are by a factor of 2 smaller than the tolerance of 1% required by German technical rules [5].

The described validation procedure will also be adopted in the revision of the ISO Standard 15122 (energy determination), which is expected to be published by mid 2018 [6]. Based on this, acceptance by national metrological institutes to use gas quality tracking for end user billing will certainly increase.

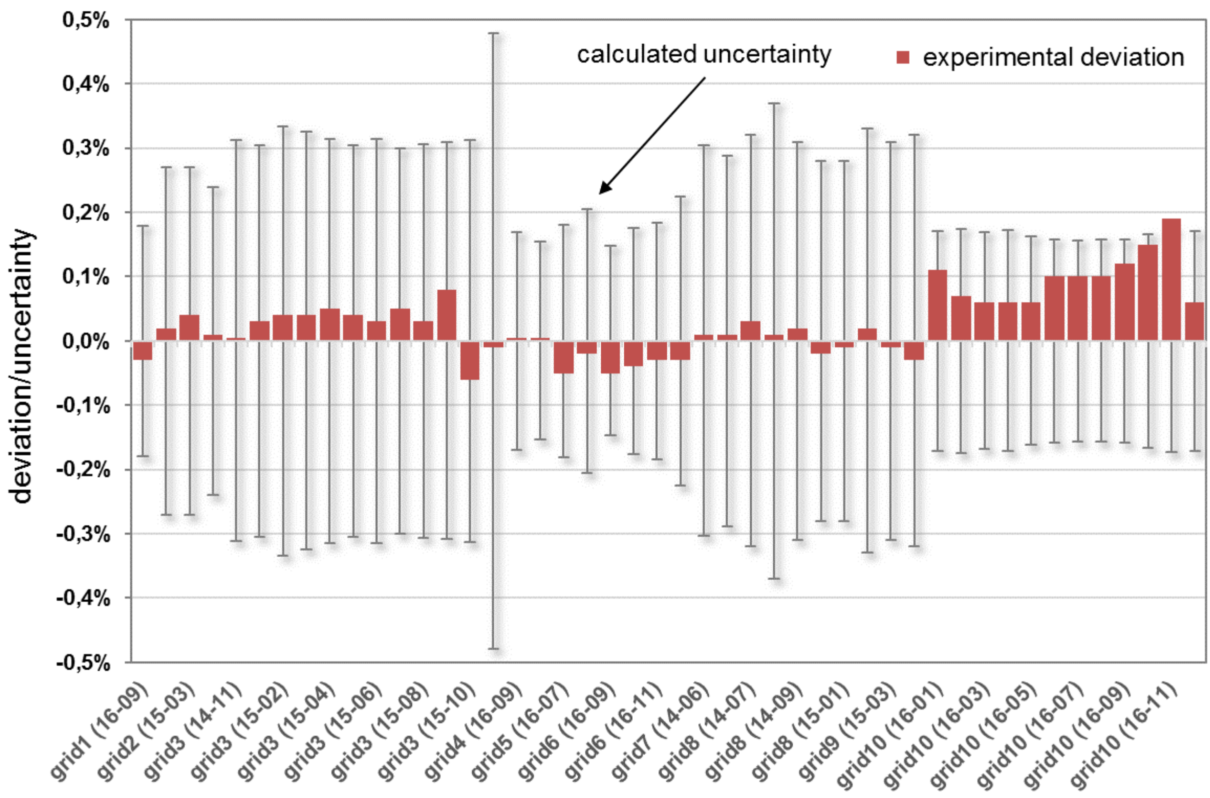

Figure 4: Comparison of calculated uncertainties with experimental deviations from different field tests (monthly mean). The baseline is the calculated CV from this work.

Implementation and approval

An implementation project is typically carried out in two project phases. In the first phase (prestudy) a grid analysis is carried out. This involves performing a complete grid simulation for a past time period (e.g. one year). If an automated data transfer is not yet possible, then the input data are in part manually edited. The results of the simulation reveal mixing and pending zones which are characterized by frequent changes in the gas quality. Based on these results it is possible to assess whether the CV can be tracked with sufficient accuracy or whether further measures have to be taken with regard to the grid's infrastructure (e.g. a different breakdown of grid sections/CV districts, or installing additional measuring instruments).

The second phase of the project involves carrying out a validation of the gas quality tracking system. National calibration authorities are usually involved at the start of this phase. The course of the validation process may be country-specific and therefore has to be conducted in accordance with the respective national requirements. However, key to an acceptance is the proof that error limits for the calorific value are met at all exit points of the grid. In Germany e. g. the limit is 1% during the validation phase and 2% during regular operation (for the averaged value over the billing period; usually 1 month).

Of course, a gas quality tracking system must also be checked at regular intervals during regular operation. This can be done either by carrying out a monthly Monte Carlo simulation or by regular testing with measurements (or both). In case of verification by measurement, often sample collectors are used. In this case, a sample that is collected over a certain period – usually 4 days – (with typically four samples per hour) is analyzed with a gas chromatograph and the representative CV for the sampling period is calculated from the analysis. This value is then compared with the calculated CV from gas quality tracking, which is also averaged over the sampling period. The number of tests will depend on the complexity of the grid. An annual test will suffice in most cases.

Examples of Applications

Since 2015 a software release known as “SmartSim” has been available and is currently rolled out with a number of grid operators. An overview of the ongoing projects in Europe together with the project status is given in Figure 5. By now the method is approved and in operation for more than fifteen grids in Germany, Denmark and Sweden. Approx. fifteen further projects are in a pre-study or validation phase. Most of these implementation projects have been initiated against the background of biogas injection. An example for this application is given in chapter 4.1. The first application in connection with the injection of hydrogen using the "power-to-gas" technology is described in chapter 4.2. Beginning of 2018, the first project outside Europe has been initiated. In the grid of the national Colombian grid operator TGI the SmartSim method will in future be used to track gases from different origins: Gases from national sources as well as from LNG terminals (see chapter 4.3).

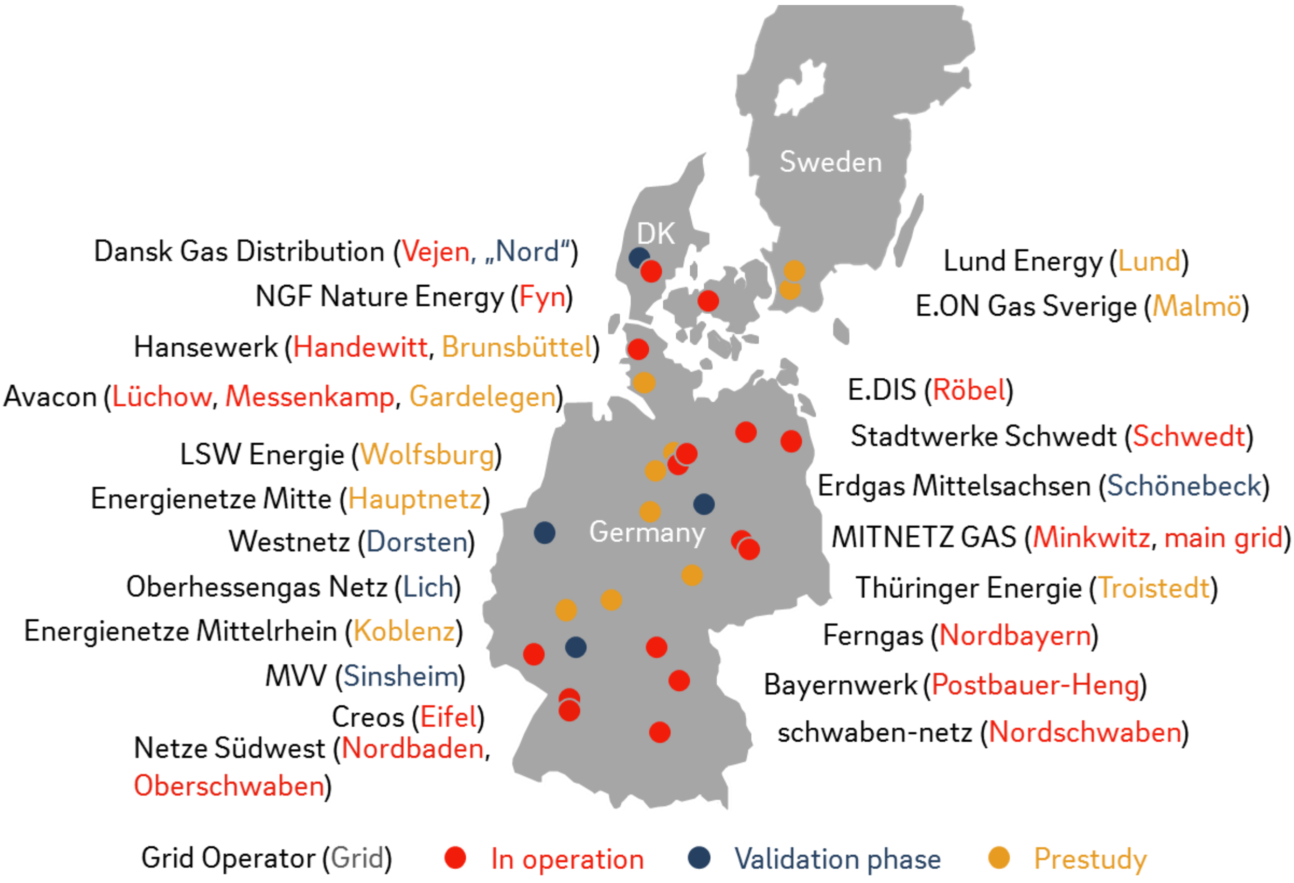

Figure 5: Overview of implementation projects in Germany, Denmark and Sweden (March 2017).

Example 1: Injection of biomethane in the grid of NGF (Denmark)

In Denmark, over the last few years, an increased number of biogas projects are under way where the upgraded biomethane is directly injected into the natural gas grid. This trend has been encouraged by incentives from the Danish government with the aim of decarbonizing the natural gas grid. As national regulation does not allow the conditioning of biomethane with propane to match the CV of the natural gas, the Danish gas grid operators require adequate solutions to handle different CVs in their gas networks.

As an example for a successful implementation, the project with NGF Nature Energy is described in the following. The grid of NGF comprises 4 natural gas and 4 biomethane entry points and a total of 486 exit points. The calorific values of ≈ 12,2 kWh/m³ (≈ 44 MJ/m³) for the natural gas and ≈ 11 kWh/m³ (≈ 40 MJ/m³) for the biomethane differ by more than 10 percent. An overview of the grid is given in Figure 6 together with a graphical presentation of the gas distribution for January 2017 as an example. In the summer time, the grid is sometimes entirely supplied with biomethane. During certain times, the biomethane has even to be recompressed to the upstream transmission grid.

Figure 6: NGF grid with eight feed-in gases (natural gases: red, yellow, orange, biomethane: different green colors) and their distribution in the grid (monthly mean January 2017).

A challenge of this project was that the gas quality tracking system had to be ready for billing when the first biomethane plant started operation beginning of 2016; only 12 months after the project start. This in turn meant, that a validation with a mobile gas chromatograph (GC) could not be done adequately before the system went in operation. However, before starting operation, the expected uncertainty could already be evaluated according to the method described in chapter 3.3. Figure 7 shows an uncertainty calculation for January 2017 as an example. For most of the exit points of the grid, the uncertainty below 0,5%. Higher uncertainties of up to 1,5% occur only temporarily in mixing zones between natural gas and biomethane in combination with low flow velocities.

The first field tests started in January 2016 and a second test phase has been completed in March 2016. A comparison between measured CVs and calculated values is demonstrated in Figure 8 for the second test phase (March 17-30). The mobile GC was installed at a location where a transition zone between biomethane and natural gas was expected, with CV fluctuations between 11,0 kWh/m³ (39,6 MJ/m³) and 12,2 kWh/m³ (43,92 MJ/m³) as it can clearly be seen from Figure 8. However, the diagram also confirms an excellent agreement of the calculated values with measurements. The deviation of the averaged CVs over the whole measurement period is -0,06 %.

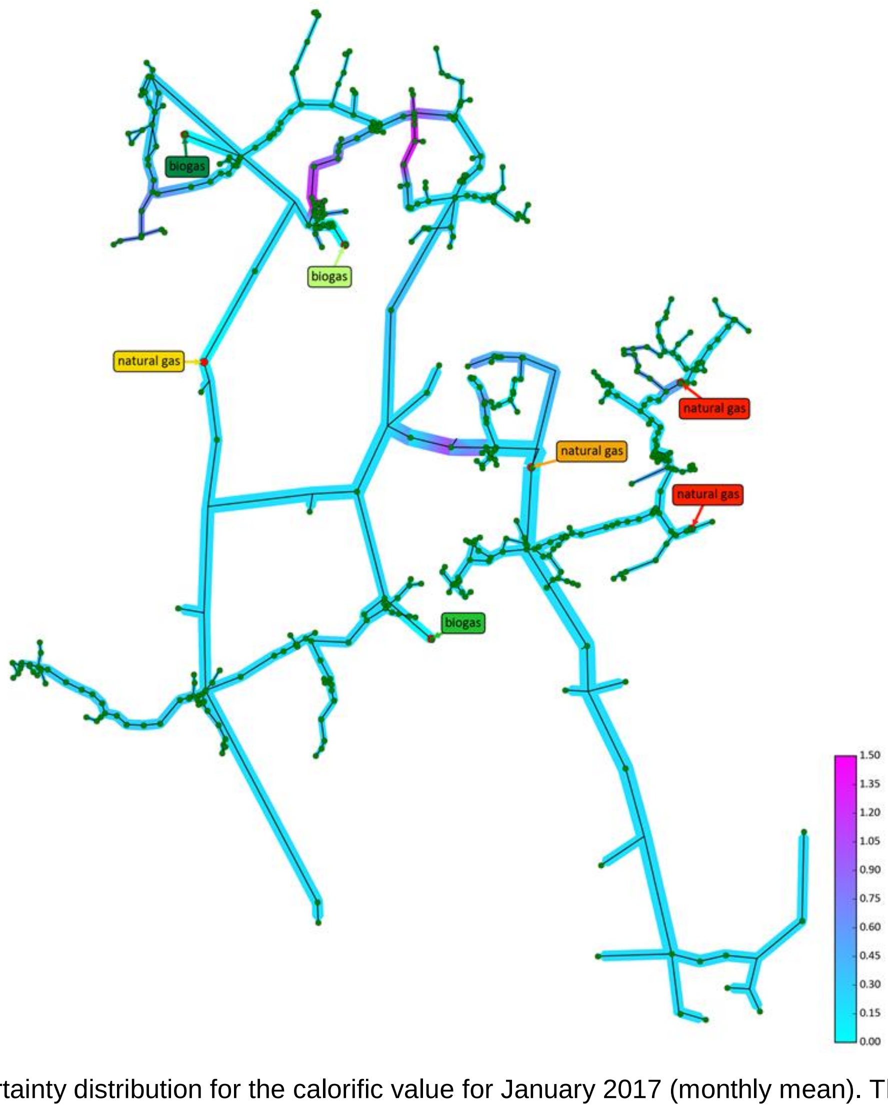

Figure 7: Uncertainty distribution for the calorific value for January 2017 (monthly mean). The colors represent the level of uncertainty between 0% (light blue) and 1,5% (pink)

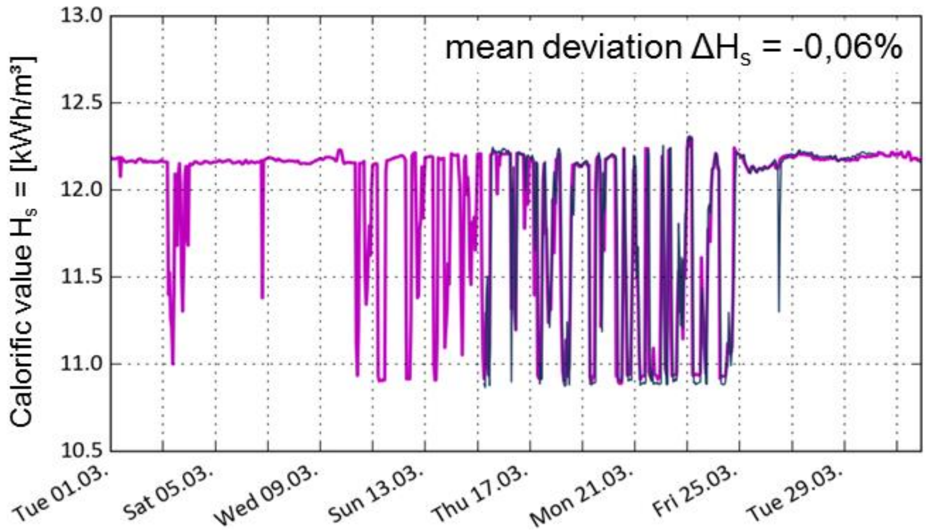

Figure 8: Comparison of calculated results (——) with measured values from a mobile gas chromatograph (——).

Example 2: Injection of hydrogen from a Power-to-Gas plant in the grid of Schleswig-Holstein Netz

The Power-to-Gas technology is expected to make a mayor contribution for the efficient use of renewable energy. Surplus energy e. g. from wind farms is used to produce hydrogen by electrolysis which is then directly injected into the natural gas grid. This way, the huge storage capacity of the existing natural gas infrastructure can be directly used (Germany as an example has approx. 500,000 km of pipelines and more than 20 billion m³ of working gas in storage facilities). This will help to transport and to store surplus or non-transportable renewable electricity and therefore costs for alternative solutions like construction of additional electricity lines or alternative energy storages can be avoided.

Up to now, the feasibility of the Power-to-Gas technology has been demonstrated in Germany in about 20 small scale pilot projects. With the project “Wind to Gas Südermarsch” [7] in Brunsbüttel, the first industrial scale Power-to-Gas plant is currently being constructed. In the first project phase, a 2,4 MW electrolyser producing up to 450 normal cubic meteres per hour (m³/h) is set up which is directly connected to a nearby windpark. In a second project phase, it is intended to extend the capacity to 1800 m³/h hydrogen. The hydrogen will then be directly injected into the grid of Schleswig-Holstein Netz. The grid is supplied by two natural gas and one biomethane injection and has 56 exit points to local city grids or industrial customers. It is expected, that the current hydrogen limit of 2 mol% will not be exceeded.

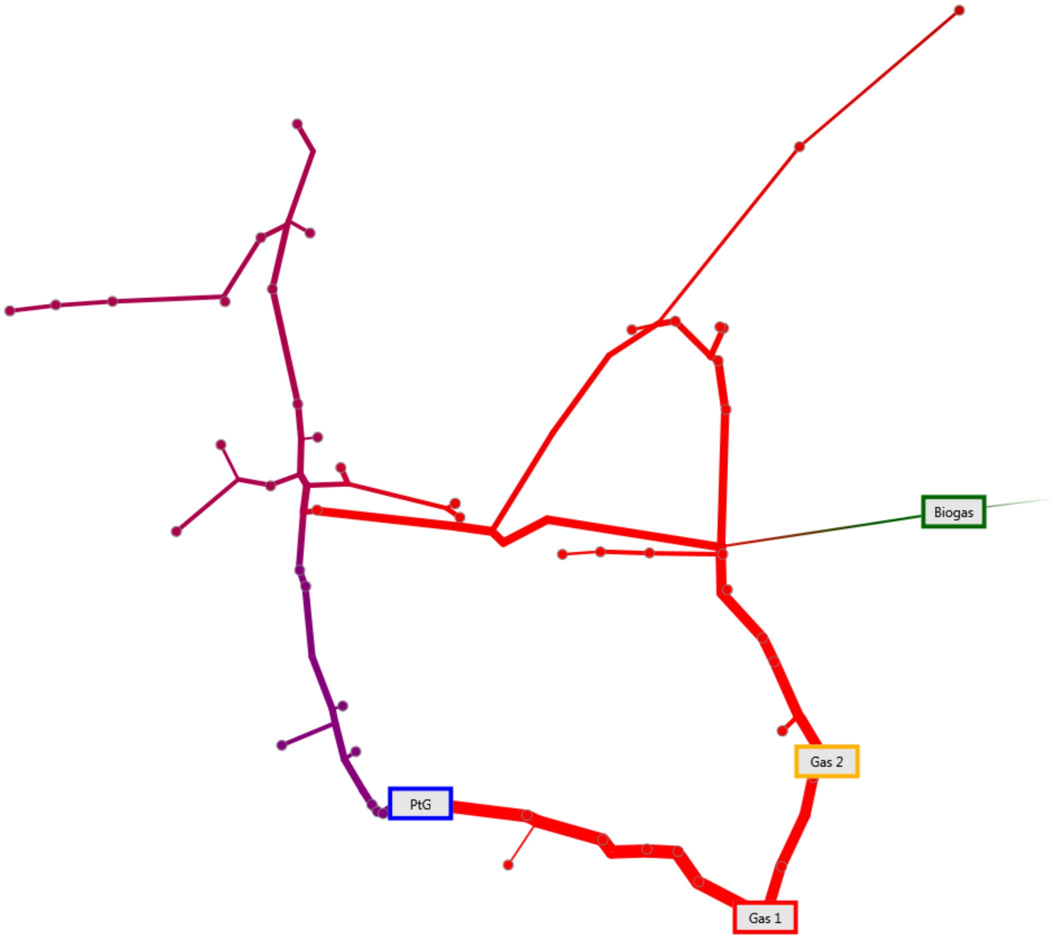

Figure 9: Simulation example for the grid of Schleswig-Holstein Netz with four feed-in gases (natural gases: red, orange, biomethane: green, hydrogen blue) and their distribution in the grid (monthly mean).

Since the volume based calorific value (CV) of hydrogen (approx., 12,7 MJ) is by a factor of 3 lower than the CV of natural gas, already small fractions of hydrogen will have a significant influence on the CV of the gas delivered to end customers. In Germany, technical rules require that a hydrogen concentration of more than 0,2 mol% must be determined with adequate measurement technique. To avoid the costly installation of gas chromatographs at all exit points of the grid, it has been decided to apply gas quality tracking to determine the correct CVs at all exit points. Currently the first project phase (prestudy) is under way. First simulation runs indicate consistent results so that it is expected that the second project phase (validation) will start soon.

Example 3: Injection of different natural gases/LNG in the grid of TGI (Colombia)

In a cooperation project between E.ON Metering (from April 2018 on SmartSim GmbH) and the Colombian Consultancy Firm Polygon Energy the SmartSim method is currently being implemented in the grid of TGI (Transportadora de Gas Internacional S.A. ESP), the largest grid operator in Colombia. TGI operates a transmission grid with a length of approx. 4,000 km and an annual capacity of 4 billion m³(n) which corresponds to more than 50 percent of the total natural gas consumption in Colombia. Currently the grid is fed from 9 different sources with varying CVs between 37,1 MJ/m³ and 42,8 MJ/m³. Colombia has a LNG Regasification Terminal at the Caribbean coast and plans to have an additional one at the pacific coast in the next 5 years. An overview of the grid and the main gas supply streams is given in Figure 10 [8].

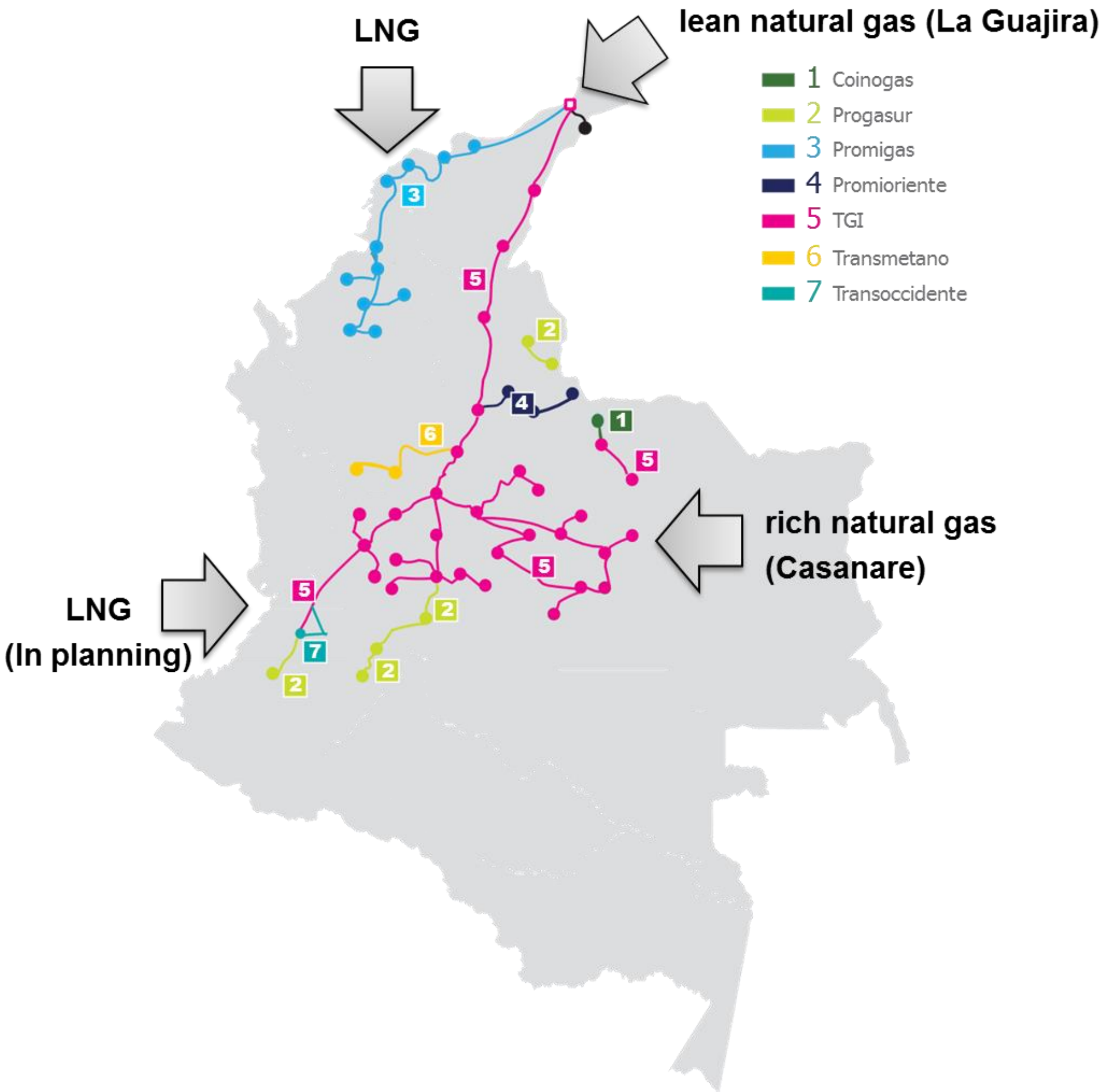

Figure 10: Overview of the Colombian gas transmission grid showing the grids of the seven national grid operators and the main gas supply streams.

The project has been contracted in January 2018 and is expected to be completed by end of 2018. This will facilitate to handle the variety of natural gas qualities and to determine the individual CV at each exit point of the grid based on a metrological accepted method.

Conclusion and Outlook

The new method for gas quality tracking has been successfully implemented and validated in a number of grids in Europe, mainly in connection with biomethane injection. Further projects – also outside Europe – are currently in preparation. Some of these new projects are also driven by the power-to-gas technology, where the method will help to simplify the injection of hydrogen and thus will avoid expensive measurement infrastructure.

In order to further increase the acceptance by national metrology institutes and to simplify the approval process, a detailed description of how to apply and how to validate a gas quality tracking system will in future be subject to the international standard ISO 15112. A revised ISO standard is expected to be published in mid 2018.

References

[1] J. Schenk, P. Schley and A. Hielscher: A New Method for Gas Quality Tracking in Distribution Grids. Gas for energy, 3 (2012), S. 34-42..

[2] A. Hielscher, C. Fiebig, R. Span, P. Schley and, J. Schenk: Gas Quality Tracking in Distribution Grids with SmartSim – A New Kernel for Flow Calculation. Proceedings of the International Gas Research Conference (IGRC), Copenhagen, September 17-19, 2014.

[3] S. Rickelt, P. Schley, A. Hielscher, C. Fiebig and J. Schenk: Gas quality tracking with SmartSim – Energy billing in gas grids with multipoint injection. Gas for energy, 2, 2016, p. 24-31.

[4] ISO/IEC, ISO/IEC Guide 98-3:2008/Suppl 1:2008: Evaluation of measurement data – Supplement 1 to the "Guide to the expression of uncertainty in measurement" – Propagation of distributions using a Monte Carlo method (98-3-1), 2008.

[5] DVGW technical rule G685, gas billing; DVGW-Arbeitsblatt G685, Gasabrechnung. November 2008, revised technical rule expected by mid 2018.

[6] ISO 15112, Energy Determination. International Standard, second edition 2011-07-15, revised standard expected by mid 2018.

[7] NEW 4.0 (Norddeutsche EnergieWende): http://new4-0.erneuerbare-energien-hamburg.de/de/new-40-blog/details/wind-to-gas-suedermarsch-plant-multi-megawatt-hybrid-speicherprojekt.html

[8] *Information sheet of the Colombian Gas Sector 2017, Promigas (Informe del sector gas natural 2017, Promigas):* http://www.promigas.com/Es/Noticias/Documents/Informe-Sector-Gas/Informe%20del%20Sector%20Gas%20Natural%20Colombia%202017.pdf