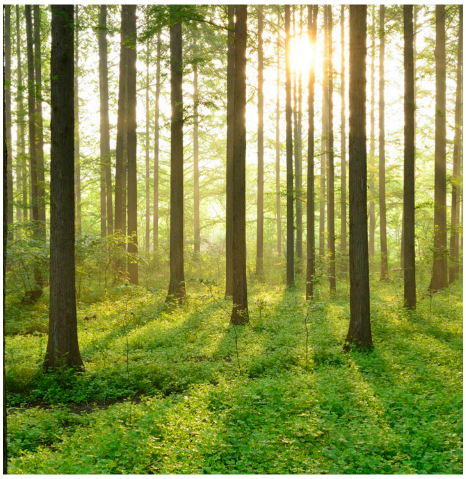
MEASURING AND ENSURING THE GAS QUALITY OF THE SWEDISH GAS GRID

REPORT 2016:325



ENERGY GAS TECHNOLOGY

Energiforsk

Measuring and ensuring the gas quality of the Swedish gas grid

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Authors' foreword

This project evaluated national standards from several European countries to address the issues with increasing variation of the gas quality in the Swedish gas grid arising from an increased content of gas from renewable sources.

The report has been produced by Lund University and the author is Laura Malek and Christian Hulteberg. Fredric Bauer is acknowledged for his invaluable help in finalizing the report.

The study was funded by the Swedish Energy Agency, through the Swedish Energy Research Centre and the Co-operation Program Energy gas technology, and E.ON Gas Sverige AB. The study had a reference/working group with the following members: Anna Gulin (E.On), Dan Lilja (E.On), Geir Sjöholm (Swedegas), Mattias Wesslau (Swedegas), Bernt Nymark (Kraftringen).

Sammanfattning

När mer förnybar gas produceras och exporteras till naturgasnätet uppstår en ny situation för nätoperatörerna, men i förlängningen även för kunderna, vad gäller mätning och säkerställning av gaskvaliteten på gasnätet. Den förnybara gasen idag produceras huvudsakligen via rötning, men innefattar även metan från termokemisk omvandling och vätgas via el som produceras i temporära överskott från sol eller vindkraft. Metan från skogsavfall demonstreras i Göteborg och den andra typen av förnybar vätgas demonstreras på många ställen, bland annat i Tyskland.

I denna framtida situation kommer det, till skillnad från dagens situation, att finnas ett mycket större antal inmatningspunkter på gasnäten. I Sverige har det historiskt bara funnits en inmatningspunkt i Klagshamn, där gasnätet når Sverige, vilket också reflekteras i hur gaskvaliteten bestäms i nätet idag. Men med en framtida situation med multipla inmatningspunkter på både transmissionsnät och distributionsnät uppstår ett behov av att kunna mäta och säkerställa kvaliteten på gasen som levereras till slutkund. Denna rapport försöker dra nytta av erfarenheter från andra europeiska länder där detta problem, i alla fall delvis, adresserats och försöka föreslå en rimlig väg framåt för det svenska gasnätet. De länder som legat till grund för studien är Tyskland, Danmark och Nederländerna samt en ISO-standard på området.

Informationen i det genomgångna materialet från andra länder kan delas in i fyra delar. Den första delen presenterar olika typer av gasnätskonfigurationer medan den andra delen går igenom olika aspekter av mätning så som mätfrekvens, mätnoggrannhet, precision och kalibrering. Den tredje delen beskriver olika metoder för allokering av värmevärde i olika nät medan den sista delen går igenom procedurer för kontroll av värmevärdesallokering.

Den tyska och danska standarden är relativt detaljerade med avseende på värmevärdesallokering medan den holländska standarden nämner det kortfattat. Den ISO-standard som finns ger ingen speciell information om själva utförandet utan konstaterar bara att det måste göras.

För att få till en bra metod för att mäta och säkerställa kvaliteten, framförallt med avseende på värmevärde, i det svenska gasnätet bör ett system för validering och övervakning av densamma utvecklas gemensamt av branschens parter. Dock måste en överblick av de framtida intressanta nättyperna först erhållas. Som en rekommendation skulle det svenska samarbetet följa den danska modellen där en tredje part är ansvarig för validering och säkerställande av kvaliteten.

Summary

When there is more renewable gas being produced, and exported to the natural gas grid, there is a new situation for the grid operators which, in extension, creates new circumstances with respect to measuring and ensuring the gas quality on the grid. The renewable gas is today mainly produced by anaerobic digestion, but near-term future sources may be methane from thermochemical conversion of lignocellulose and hydrogen produced from intermittent electricity stemming from wind and solar resources; indeed, the first type of gas is currently demonstrated in the Swedish context in Gothenburg and the second type in Germany.

In this future situation, there will, in contrast to today's situation, be a much larger number of feeding points to the grids. In Sweden, there has historically been only one feeding point, something that is reflected in the way the gas quality is currently determined in the grid. However, with more renewable gas on the grid, the quality of the grid has to be monitored in a more controlled and detailed manner. This report will try to draw upon the experience from other European countries where this problem has been addressed already and try to suggest a reasonable way forward for the Swedish gas grid. The countries assessed is Germany, Denmark and the Netherlands as well as the ISO standard on the subject.

The findings in the reviewed material from the countries listed above have been divided into four parts. The first part present different type of gas grid configurations. The second part present information regarding measuring procedures, including guidelines for measuring frequency, accuracy and calibration. The third part describe different methods for allocation of calorific value in different grids. The last part present procedures regarding control of allocated heating values.

The German and Danish standards are quite detailed with respect to allocation of heating value. The Dutch document reviewed mainly pertain to biogas feeding to the grid, allocation of heating value is mentioned briefly. Finally, the ISO standard is non-specific on deciding in allocation-method, it is more exemplary in nature.

Guidelines for validation and supervision of the calorific value in the Swedish gas grid should jointly be developed by the actors of the Swedish gas industry when a clear view of what different types of gas grids will be of interest is obtained. A suggestion is to follow the Danish model and assign to a third party the responsibility of validation and supervision.

List of content

1 Introduction

Natural gas is not one of the main energy sources in the Swedish energy system. It is however a very important energy source for many customers – industrial, residential, and others – in the southwestern part of the country. These customers rely on the ability of the grid to supply natural gas of high quality to meet the demand. The quality of the gas in the Swedish natural gas grid does show variations with time. Gas quality does in this context mainly refer to the calorific value (or heating value) of the gas, which in turn depends on its composition [1,2]. It is highly likely that these variations will become more frequent, and larger in amplitude in the future.

There are multiple factors contributing to current and future variations in the quality of the supplied gas. The main part of the gas in the Swedish transmission grid is Danish North Sea gas, a natural gas of high and relatively constant quality [3]. The Swedish natural gas grid was up until 2011 only supplied with North Sea gas but is today, due to declining production and periods of no production in Denmark, supplied with German gas via the Danish pipelines. This gas is of a lower quality, i.e. it has a lower calorific value, than the Danish North Sea gas. Due to increasing integration of the European natural gas grids and energy markets – which is one of the policy areas that are prioritized by the European commission as the Energy Union – as well as global international trade of natural gas, it is becoming increasingly plausible that Sweden will be provided by additional gas of varying quality produced in other European countries. Apart from pipeline connections to exporting countries, the Swedish gas grid can also be supplied with gas from shipping terminals for imported liquefied natural gas. In addition to the variations in the gas that is being imported, increasing volumes of domestically produced biogas and substitute natural gas (SNG) from biomass gasification, which both have different qualities compared to conventional natural gas, are being fed into the grid. The interest for power-to-gas technologies is also increasing, pointing to yet another possible, future source of gas that could find its way to the Swedish gas grid. All these supply options lead to variations in gas composition. Without adjustment, these variations will lead to a differentiated calorific value, which will depend on time and location, throughout the Swedish transmission and distribution grids.

These increasing variations pose a problem in quality control and debiting, an issue that is well known by the actors of the gas industry and which has previously addressed in several reports on behalf of Svenskt Gastekniskt Center (currently Energiforsk, the Swedish Energy Research Centre) and Energigas Sverige [1–3]. Swedegas also publishes real-time information about gas quality on their website to inform about the current status. End users can receive gas of different quality at different point in time and calorific value measurements and debiting must be adapted to these variations. To date there is no framework in place in Sweden that deals with calorific value control in grids with multiple feeding points of varying gas quality. Trading with natural gas in Sweden is primarily regulated in the Swedish law on natural gas (SFS 2005:403 [4]) and the specified regulations on measuring and reporting of traded natural gas (EIFS 2014:8 [5]). The Swedish gas industry has also adopted internal guidelines ("Gasmätning – Anvisningar för den svenska energibranschen" [6]) which however currently not adequately describe what methods for measurement and allocation of calorific values and what procedures for quality control are acceptable to use.

1.1 AIM

The aim of this report is to present (i) an overview of the literature on how to handle variations in gas quality in gas grids, (ii) how gas quality variations is being regulated and handled in other European countries, and (iii) discuss possible ways of dealing with these issues in Sweden.

This report presents results from the project "Measuring and ensuring the gas quality of the Swedish gas grid", which is a part of a collaboration within the Swedish gas industry aiming to develop a national regulatory framework for gas quality. The results from this report will serve as underlying material when developing the national regulatory framework regarding aspects such as determination of calorific value and quality control.

1.2 METHOD

Information regarding measurement methods and regulatory frameworks that already are in place in countries with gas grids with varying gas quality has been compiled and reviewed. Relevant agencies in multiple European countries were contacted and asked to provide information regarding regulations connected to varying calorific values. The reviewed material has been collected from Denmark, Germany, Netherlands, Sweden and current ISO standards.

The compiled information has been reviewed by a workgroup consisting of representatives from actors of the Swedish gas industry and academia. Representatives from E.ON, Kraftringen, Lund University, Swedegas and Öresundskraft participated in the work group. The purpose of the workgroup was to prepare a proposal for what changes and additions should be made to the current Swedish industry-wide gas measurement guidelines to accommodate for variations in gas quality.

1.3 DEMARCATIONS

No material from outside of Europe has been collected. Other natural limitations to the scope of the literature search has been language. The literature search has been limited to Swedish, English, Danish, German, Polish and Dutch.

No revision of the current guidelines and regulations has been made. The reviewed material has simply been compiled and solutions for the Swedish market are presented based on existing material.

2 Gas use and quality in Sweden

2.1 THE SWEDISH GAS GRID

The foundations to the Swedish gas grid were laid in 1985 [7]. It consists of a transmission grid that spans from Trelleborg to Stenungsund, about 600 km pipelines, and multiple distribution grids, in total about 2800 km pipelines, that supply numerous municipalities along the transmission grid with gas, Figure 1. About 37,000 Swedish costumers, of which 34,000 are residential, are supplied with energy for heating and cooking. The remaining costumers are industrial plants and district heating companies [7]. In addition to the gas grid, local distribution grids which are not connected to the transmission grid exist, e.g. in the city of Stockholm. More information about the Swedish gas grid can be found in Nelsson, 2011 [2].

Figure 1. Swedish gas grid [8]

Today, most the gas in the Swedish transmission grid is supplied from Denmark via one single feeding point in Klagshamn south of Malmö. This feeding point is believed to remain the only external feeding point for the foreseeable future. In addition to the external feeding, the transmission grid is also fed by gas from the gas storage in Skallen in Halland, by GoBiGas in Gothenburg and by Jordberga in Trelleborg. Also, a LNG terminal which might be used for suppling the transmission grid may be constructed in Gothenburg. The LNG facility is part of a future and more extensive project involving the construction of an LNG terminal at the Port of Gothenburg. The terminal will also be connected to the transmission grid to supply shipping, the transport sector and industry with LNG. On the distribution grid level, smaller amounts of biogas are also being mixed into the natural gas. The calorific value of the gas in the grid is currently being measured in Dragör in Denmark before entering Sweden, in Årstad in Halland, in Rävekärr south of Gothenburg and in Kålsered north of Gothenburg. These existing points of measurements will not be sufficient to predict an accurate calorific value for all end users when the expected variation in gas quality in the grid start to increase.

2.2 USE OF GAS IN SWEDEN

The Swedish gas grid currently transfers around 10-11 TWh natural gas annually, depending on the energy demand during winter [7,9]. This corresponded to about 2% of the total energy supply in Sweden. However, there are large regional differences that are dependent on the location relative to the gas grid. In municipalities in the south and west of Sweden which are connected to the gas grid, natural gas accounts for 20-25% of the primary energy supply [7,9]. This is at the same level as in the rest of Europe. Table 1 contains the total energy supply for Sweden 2014.

Table 1. Total energy supply in Sweden 2014 [10]

Commodity	TWh	%
Biomass	130	23%
Coal and coke	21	4%
Crude oil and oil products	134	24%
Natural gas, gasworks gas	9	2%
Other fuels	14	3%
Nuclear fuel	182	33%
Primary heat	5	1%
Hydropower	64	11%
Wind power	11	2%
Import-export of electricity	-16	-3%
Total	**555**	**100%**

Most of the gas consumed in Sweden is consumed in the region of the gas grid, but there are also smaller amounts of LNG being imported, mainly from Norway, to other regions. Figure 2 display the natural gas use by sector from 1983 up to 2014. At present day, the two largest areas of use for natural gas in Sweden are as fuel for electricity and heat production, and use in industry. The peak in 2010 is a result of investments made in gas-fired combined heat and power in combination with a cold winter. The third largest area of use is the residential and service sector where gas is used for heating and cooking purposes. The remaining two areas are as vehicle fuel in the transport sector and as raw material in industry (non-energy use).

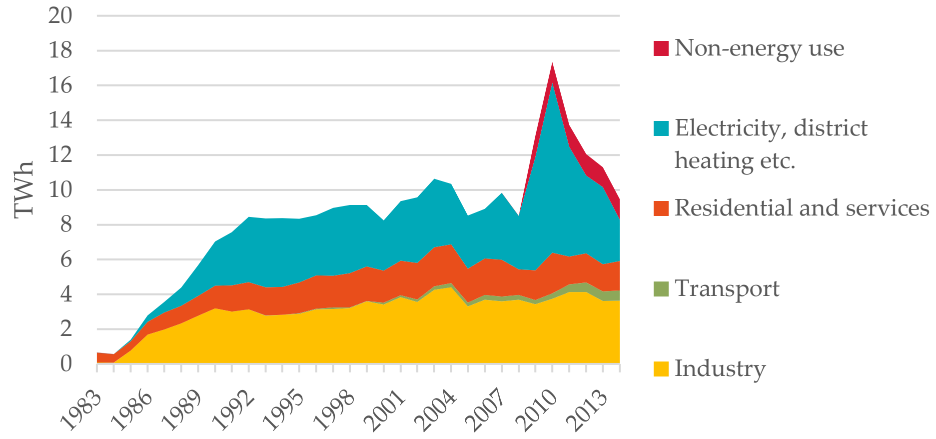

Figure 2. Natural gas use in Sweden by sector 1983-2014 [10]

Looking at projections made for 2016-2018 it is believed that the natural gas use will increase slightly as an increasing amount of companies in different sectors replace oil with natural gas [11].

2.3 VARIATIONS IN GAS COMPOSITION AND QUALITY

Variations in gas quality can arise due to production related and technical causes [1]. Production related variations are due to fluctuations in the gas field where the gas is produced, i.e. the composition of gas extracted from a certain field will change slightly. These variations occur over years and decades and do not cause any sudden, large variations in grid gas quality. The Danish gas, which constitutes the majority of the gas in the Swedish grid, has for example had a slightly decreasing content of methane and increasing content of heavier hydrocarbons (mainly ethane and propane) over the last 25 years. The average methane content over the last ten years has however been quite stable at around 90 % according to statistics from Swedegas. Technical variations however can be large and sudden and are what may affect end users both technically and economically. These variations may for example occur when gases produced at different gas fields are mixed in the grid, or when gas from a new source is being fed into the grid, e.g. German gas.

The composition of gas entering the Swedish gas grid is monitored and the statistics are made available by Swedegas. Knowledge of the composition allows for the quality of the gas entering the grid to be determined. Figure 3 shows the variations in gas composition and associated variations in calorific value as monthly averages over the five-year period from 2011-2015. As shown in the figure there are fluctuations in the gas composition, but no clear trend can be discerned over the five-year period.

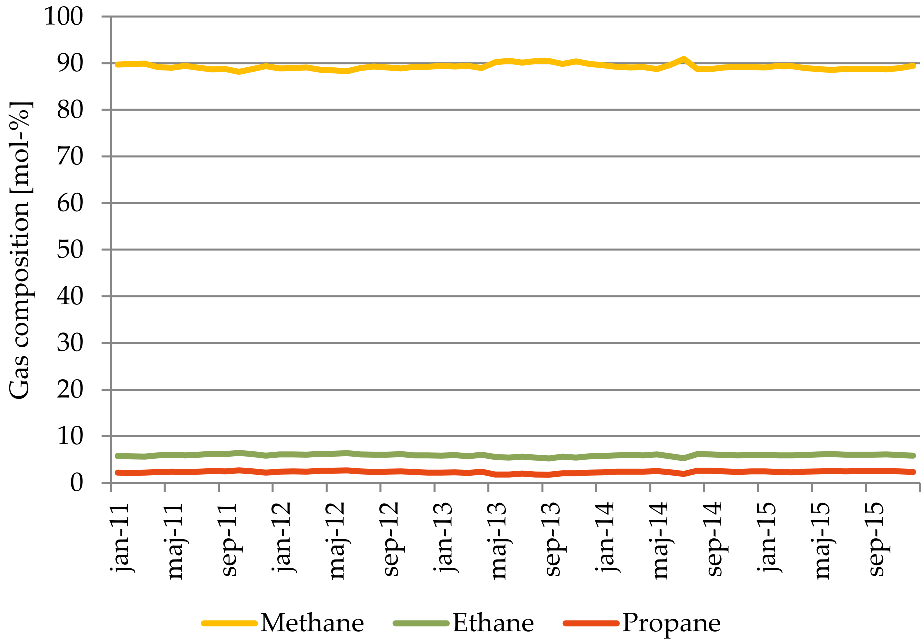

Figure 3. Gas composition over a five-year period. Data from Swedegas [12].

Figure 4 show the gas quality, i.e. higher heating value, varied over the year 2015 using available statistics for daily and monthly average values. This shows that although the variations in the gas composition may be small, these variations result in rapid changes in gas quality. The yearly average for 2015 was 12.155 kWh/Nm^3 with a standard deviation of 0.049 for the daily average values and 0.032 for the monthly average values, i.e. 0.40 % and 0.26 % for the daily and monthly averages respectively.

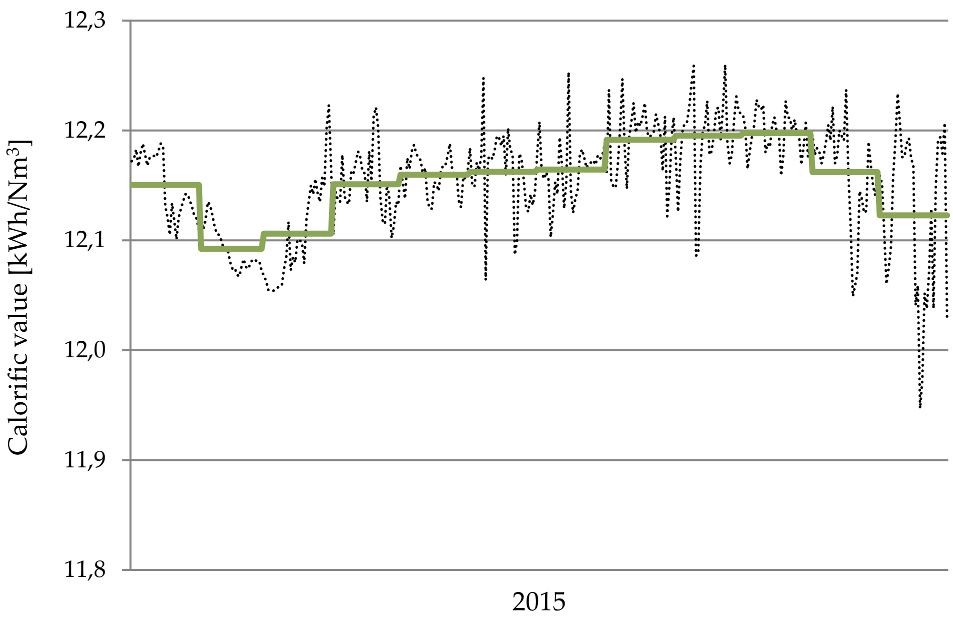

Figure 4. Variations in gas quality during 2015. Data from Swedegas [12].

Over the last couple of years, there has been an increase in the injection of upgraded biogas and SNG to the gas grid. Figure 5 displays the injection capacity by region for the years 2008-2015 [13–20].

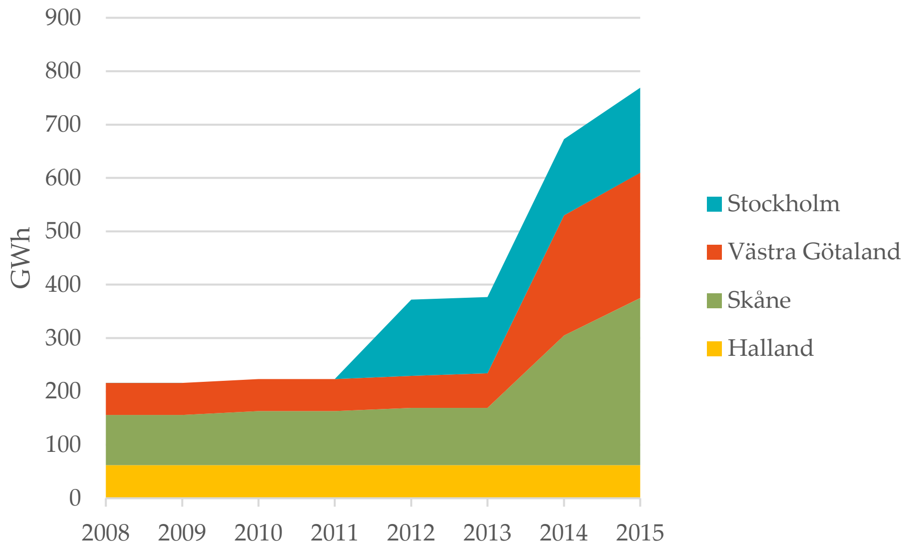

Figure 5. Injection capacity of upgraded biogas and SNG to the gas grid 2008-2015 [13–20]

Injection data before 2008 is not available and injection data for Stockholm is only available from 2012; please note that Stockholm is not connected to the main Swedish natural gas grid but a local grid. Important to note is that the reported figures only show injection capacity, not the actual injected volume at the time. The large increase in injection capacity that occurred in 2014 is due to the injection start for GoBiGas in Västra Götaland and Jordberga in Skåne. Injected volume compared to injection capacity is shown in Figure 6.

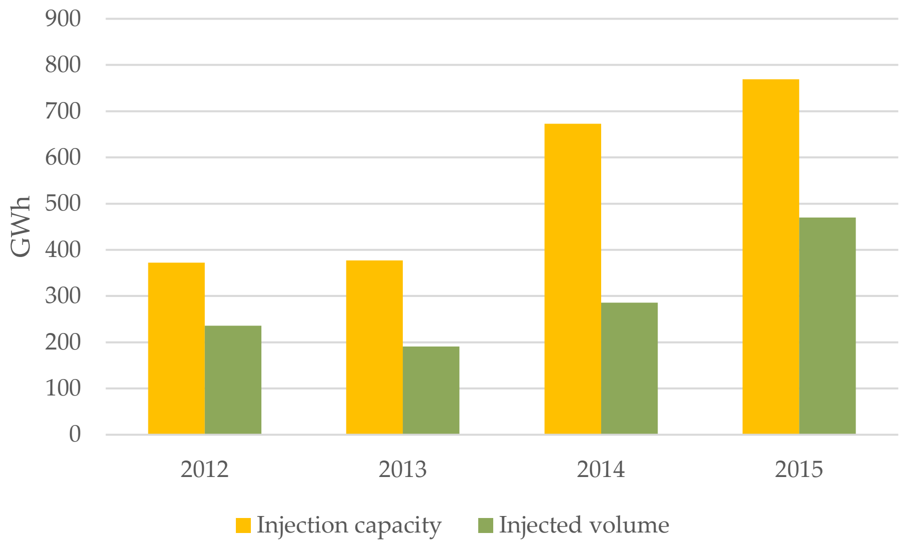

Figure 6. Injection capacity and injected volume of upgraded biogas and SNG to the gas grid 2012-2015 [17–20]

Currently SNG is only being injected on a transmission grid level. Biogas however is being injected both to the transmission grid and directly into distribution grids. Looking at the Swedish situation, GoBiGas is projected to deliver 160 GWh of SNG annually to the transmission net which will contribute to a significant change in gas quality around Gothenburg [3]. Similarly, the grids surrounding Jordberga will be affected by the annual production of 120 GWh of biogas from anaerobic digestion. In addition to these two inputs, there exist about 10 additional anaerobic digestion plants, which deliver biogas to local distribution grids. On a distribution-grid level, direct injection of biogas can lead to end users getting either pure biogas, pure natural gas or a mixture of both depending on location in the grid, gas consumption rate depending on season and production rate. The quality of the different gas streams is thus of great importance to avoid unjust debiting.

The quality of new gas sources differs from that of the conventionally used natural gas. Upgraded biogas that is being added to the gas grid consists of 97% methane and 3% inert gases. As previously mentioned, the natural gas that is being imported into Sweden contains higher hydrocarbons, which are not found in upgraded biogas and SNG. These higher hydrocarbons have a higher calorific value compared to methane, which leads to natural gas having a higher calorific value than upgraded biogas and SNG. Gas produced with power-to-gas technology consists either of hydrogen or pure methane [21], and thus also has a lower calorific value than the currently sourced natural gas.

One option to circumvent the issue of injecting gas of lower quality into the grid is to homogenize the calorific values by increasing the calorific value of upgraded biogas and SNG before injection. This is done by adding propane to the gas, a process known as propanation. This method is currently in use for all biogas in Sweden that is fed into the transmission grid [3]. The ideal situation would be to make real-time adjustment of the calorific value; however, this is rarely possible as different actors are responsible for the determination of the calorific value of the different gas streams. Instead, the calorific value of the upgraded biogas and SNG is adjusted to the monthly average of the previous month. Downsides to propanation are the extra costs incurred for the producers of biogas and SNG as well as the fact that the propane is fossil (at least at this time, renewable alternatives are in development), meaning that the potential for GHG reductions from biogas production is reduced. Implementing regulations for multiple feeding point grid with multiple gas qualities would open up the possibility to skip propanation.

2.4 ISSUES WITH VARIATION IN GAS QUALITY

Variations in gas quality may affect the end users both technically and economically. Possible technical complications in equipment running on natural gas due to variations in quality will not be covered in this report. However, the subject has previously been discussed in published reports [1–3]. It can be mentioned that no clear correlation between changed technical performance and gas quality could be found. The economic effect is considerably more tangible. The current debiting system is based on the amount of energy an end user has consumed. This amount is calculated as the product of gas volume that has been consumed by the end user and the monthly average calorific value that is assigned to the end user [3]. Quality variations in the grid means that the end user may receive gas of different quality during the same settlement period. Measurement and debiting has to be adapted to this possibility to avoid unjust debiting.

3 Earlier research

Even though the simulation of multiple feeding points of various grids are common practice, especially for electricity, indeed there are large government programs in several regions on this topic as well as commercial software developed [22–24].

The same approach with simulation of net-impact with respect to gas grids is not as well investigated. This is not to say that there is no simulations performed on gas grids, this is not the case. There are many papers dealing with different problems in natural gas handling as shown by a recent extensive literature review [25]:

1. Short term basis storage
2. Pipeline resistance
3. Compressor station modelling

The impact on gas quality with respect to multiple point injection is however a question that is increasing in relevance with increasing renewable content on the gas grid, as well as the entry of power-to-gas technology into the market. There are of course studied performed on this so called pooling problem [25,26] but it is mainly concerning general mixing of gases with varying quality and how to solve the problem from a mathematical standpoint. The mathematical model includes bilinear and multi-convex quadratic programming (quality) constraints [27,28].

There are studies on the combined optimization of different grids, e.g. natural gas and electricity (in particular with renewable electricity sources) [29,30]. In a paper by An et al. [31] the fundamental modelling of the natural gas grid was performed and, in the modelling work, also the transformation between gas and electricity (generators) were included. In the study, the modeling showed that considering both grids in the same model lead to social welfare maximization and that the power generation was sensitive to wellhead gas prices. However, this, and other, studies [29,31] are based on the steady-state Weymouth equations [25] that are unable to catch the dynamic effects in the grids causing changes on a less-than-one-day timescale. This is naturally mostly important when the natural gas grid used with gas turbines to cover mid-meridian electric demand.

The problem to date has however only been uni-directional, producing electricity from gas and how the variation in the electricity generation is influenced by the intermittent generation of renewable electricity. With the advent of more power-to-gas applications, there is a more complex situation as the new bi-directionality of the two energy vectors is also to be considered. To summarize the problem [32]:

"The grid could start receiving several different gases, whose properties variations (heating value, density) could significantly influence the management of the grid"

The injection of different qualities of gas at different points along the gas grid will cause issues. In particular, when there are large differences in properties between the various gases injected. This is best illustrated when injecting hydrogen in the gas grid. A study on injecting hydrogen on the Italian gas grid, as a power-to-gas play, was recently published by Guandalini et al. [32]. The study reveals that there is first of all an effect of the injection on the Wobbe index and the heating value, which is to be expected. However, what is more unexpected is the dynamic effects on the hydrogen concentration. This parameter, largely, depend on the user profile and out-take along the pipeline. In addition, the simulations performed in the paper shows that there is a need for moving away from traditional, volumetric measurement of the delivered gas and to base the measurement on energy instead.

As mentioned before, the quality of the gas on the grid has been calculated using simulation models in many instances. The transmission gas grid in Germany has had quality tracking using software for decades [33]. However, using quality tracking software for the distribution grid has until recently been difficult due to the much larger number of input/outputs in these grids, also there may be multiple feed-in points complicating the calculations further.

There are a few commercial software for sale with Simone [34] and PSIGanesi [35] being a well-used ones, as well as the SmartSim software developed by E.ON [36–38], which appears to be more suitable to distribution grid simulations. The purpose of the quality tracker is to ensure the correct debiting information to the end-user such that the bill reflects the received heating value of the gas. In designing and developing these software, an important parameter is to describe the theoretical user consumption profiles. These consumer profiles have been thoroughly researched by Hellwig and is used in many of the papers and publications on the qualification of quality tracker software [36,37,39].

Much of the current work is aimed at improving the software calculation routines and verifying the use of the SmartSim software with real-life examples [36–38]. Several grids in Germany, Denmark and Sweden have been investigated during the 2014-2016 timeframe and the deviations between the SmartSim software and actual grid composition has been measured. In some cases the software has been implemented [38].

As mentioned much attention has been put on the uncertainty of the calculations of the gas quality in different points in the grid using the quality trackers. Kessel and Sommer [33] evaluated the validity of a quality tracker which was based on the guidelines from ISO on uncertainty of measurement and in particular the 1st supplement focusing on propagation of distributions using Monte Carlo simulations [40,41]. Their findings are quite clear in that for the most part the quality tracker performs really well in describing the chosen (simulated) grid. By giving input ranges and distribution functions for a range of parameters (Table 2), the variations in quality in different nodes has been simulated.

Table 2. Specification of knowledge for input quantities [33]

Input	Knowledge precision	Distribution
Calorific value	< 1%	Normal
Source flow rate	< 2%	Rectangular
Drain flow rate	< 2%	Rectangular
Grid ref. pressure	< 5%	Rectangular
Temperature	0-15 °C	Rectangular
Length of pipes	< 10%	Rectangular
Diameter of pipes	< 5%	Rectangular
Roughness	< 50%	Rectangular

In some instances, the error was low (< 2.5%) and for a majority of the pipelines and flows the uncertainty was below 30%. However, in some cases, amplified by large diameter pipes with low flowrates, the errors may be as high as 300%. However, despite the errors in flowrate, the variation in the calorific value only varied by a maximum of 5% and the conclusion was drawn that the modelling was good enough for debiting purposes (with averages over 1 month), but that real measurements had to be performed to validate the model.

4 Findings from the comparative analysis

The findings from the reviewed material from other countries have been divided into four sections. In the first section, different types of gas grid configurations are presented. The second section contains information regarding measuring procedures, including guidelines for measuring frequency, accuracy and calibration. In the third section, different methods for allocation of calorific value in different grid types are described. Lastly, procedures regarding control of allocated heating values are presented. The Danish (Naturgasselskabernes kontrolmanual for allokering af brændværdi i distributionsnettet [42]) and German (Technische Regel Arbeitsblatt G 685 [43]) standards are quite detailed with respect to allocation of heating value. The Dutch document reviewed (Richtlijnen beheersprotocol groengas invoedingen [44]) mainly pertain to biogas feeding to the grid, allocation of heating value is mentioned briefly. Finally, the ISO standard (Natural gas - Energy determination ISO 15112:2011 [45]) is non-specific in deciding in allocation-method, it is more exemplary in nature.

4.1 GAS GRIDS

This section gives an overview of the configurations and strategies for calorific value allocation in both single and multiple feeding point distribution grids. The graphic symbols used when displaying gas grids are explained in Figure 7.

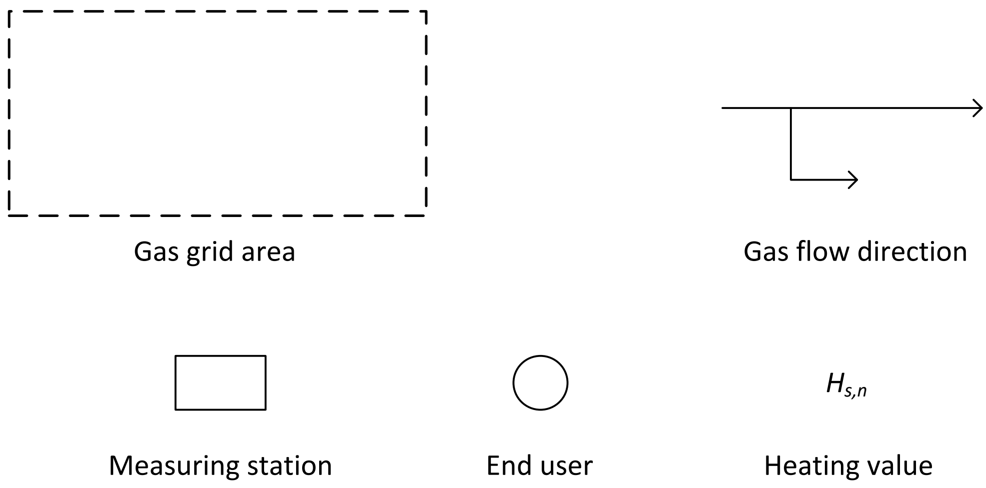

Figure 7. Gas grid graphic symbols

4.1.1 Distribution grids with single feeding point

Most common for distribution grids with only one feeding point is that the calorific value of the gas that has been determined before the transition from the transmission to the distribution grid is assigned to the entire distribution grid. There are, however, exceptions where multiple calorific values exist in a distribution grid with single point feeding.

The first exception is when an end user has access to equipment to measure the calorific value [42]. In this case that end user is assigned the self-measured calorific value regardless the value that is assigned to the remaining end users in the same distribution grid, Figure 8.

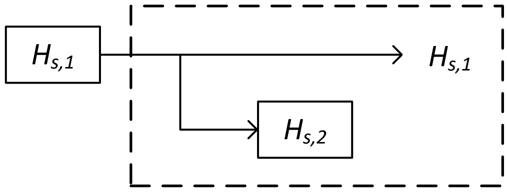

Figure 8. End user with calorific value measuring equipment

The second exception is when there locally in the distribution grid exists equipment to measure the calorific value [42]. In this case the distribution grid is divided into multiple zones where the zone upstream from the measuring equipment is assigned the calorific value determined before the transition from the transmission to the distribution grid and the zone downstream from the measuring equipment is assigned the locally measured calorific value, Figure 9.

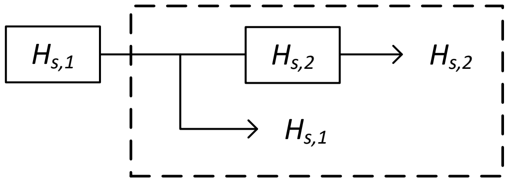

Figure 9. Grid with local calorific value measurement

4.1.2 Distribution grids with multiple feeding points

The task of allocating calorific values in a distribution grid gets increasingly complicated when the number of feeding points increase. This is especially true if the feeding points supply gas of different quality. There are two types of distribution grids with multiple feeding points.

In the first type of distribution grids with multiple feeding points the incoming gas is mixed before reaching the end users [45], Figure 10.

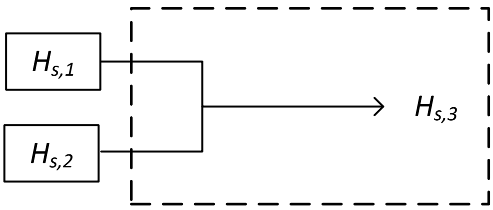

Figure 10. Gas grids with multiple feeding points with gas mixing before end users

Depending on how the feeding is configured it is sometimes possible to allocate a set calorific value for the entire distribution grid that coincides with one of the ingoing values. This can be done if transportation time within the grid is disregarded and the following criteria are met:

- Each individual feeding point has the capacity to supply the entire distribution grid independent of the others
- Only one feeding point at the time is in operation at any given moment
- The time span the different feeding points are in operation is being documented

If these criteria are not being met, then the calorific value for the distribution grid should be calculated or otherwise determined.

In the second type of distribution grids with multiple feeding points the incoming gas is not mixed before reaching the end users [42,43,45]. Mixing instead occurs at the end users, Figure 11. In this case, it is possible that some end users only are supplied by gas from one feeding point while other end users are located in a mixing zone.

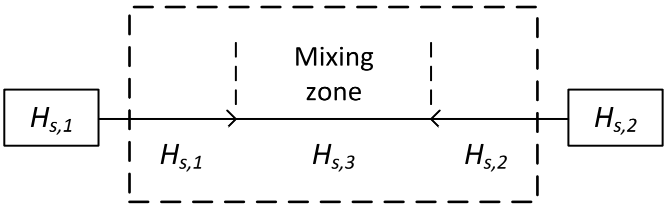

Figure 11. Grid with multiple feeding points and gas mixing at end users

It is possible to assign one calculated calorific value for the entire distribution grid but this should be avoided if incoming calorific values differ significantly from each other as it will lead to unjust debiting for some end users. Instead, in the case of large differences in incoming calorific values, the distribution grid should be divided into smaller calorific value zones where zones close to a feeding point is given the calorific value of that point and zones in mixing zones are given a calculated or otherwise determined calorific value. For very complex distribution grids with a great number of feeding points or large variations in incoming calorific value a state simulation tool known as a Quality Tracker (Section 4.3.3) should be considered.

4.2 MEASURING PROCEDURES

The general recommendations found in the reviewed material state that existing ISO standards and national regulations regarding measuring equipment and procedures are to be used if these types of documents are available. However, it is important to ensure that the entire national gas industry use the same standards and regulations as to avoid systematic differences in results between different actors. The most common method for determining the calorific value in Sweden is through gas chromatography but direct measurement is also used, see Section 4.3.1 for more information.

Examples of international standards that have been referred to in the reviewed material [45,46,44]:

- ISO 6974 1-6: Natural gas – Determination of composition with defined uncertainty by gas chromatography [47]
- ISO 6975:1997: Natural gas – Extended analysis – Gas-chromatographic method [48]
- ISO 6976:2016 Natural gas – Calculation of calorific values, density, relative density and Wobbe indices from composition [49]
- ISO 10715:1997 Natural gas – Sampling guidelines [50]
- ISO 15971:2008 Natural gas – Measurement of properties – Calorific value and Wobbe index [51]

In addition, there are several supporting ISO standards regarding calibration gases, evaluation of analytical systems, volume conversion, density, pressure and temperature, etc.

4.2.1 Measuring frequency

To obtain a representative calorific value several measurements within regular intervals have to be carried out. The obtained measurements are used to calculate a representative average for the settlement period, this to minimize the influence of possible outliers. Germany uses hourly measurements and the values are then used to calculate a daily average [43]. Monthly averages are then calculated from daily averages, monthly from daily, etc. Danish regulations specify that hourly measurements are to be used if available, otherwise daily measurements are used instead [42].

In the Dutch biogas manual it is specified that the Wobbe index of biogas should be measured on an hourly basis but do not mention any frequency for the calorific value [44]. No recommendations for measurement frequency is given in the ISO standard, however it is recommended that more frequent measurements should be performed the more the calorific value varies [45].

4.2.2 Measurement accuracy

Existing ISO standards contain specifications on what level of measurement accuracy is required for the standard to be valid. As all the national regulations that have been reviewed either build on or refer to ISO standards, it is safe to assume that the requirements on measurements accuracy found in the national regulations are based on the requirements set in these standards. As an example the maximally allowed deviation for calorific value measurement is set to ± 0.5% in Denmark while the Netherlands use ± 0.4%. These values are with high likeliness based on what accuracy can be reach when using ISO standards ISO 6974 and ISO 6976. The German standard contains nothing on measuring accuracy in the standard for the natural gas grid heating value allocation. There are however good recommendation for assessing error propagation in measurement and calculations provided by the joint Committee for Guides in Meterology, which are quite helpful in understanding this propagation problem in measurement [40,41].

4.2.3 Calibration

Existing ISO standards contain calibration procedures that must be fulfilled for the standard to be valid. The general instrument calibration procedure is to validate a known value of the parameter studied (calorific value, gas composition, etc.). If the measured value falls outside the maximally allowed deviation specified for the instrument, then a calibration of the instrument must be carried out whereupon a new value validation is performed. This procedure is repeated until the measured value falls within the maximally allowed deviation. The national standards are slightly more specific and the German standard mention calibration guidelines on page 10 (“Gesetz über das Mess- und Eichwesen (Eichgesetz – EichG)”) [43]. The Danish standard refers to the instrument manual, which may contain specifications for calibration [46]. The Dutch standard is the most demanding and say that P, T and volume flow instruments should be calibrated according to manufacturer instructions and that gas chromatographs should be validated/calibrated once a week [44].

4.3 ALLOCATION OF CALORIFIC VALUE

There are various methods available determination of calorific values viable to use when debiting end users. Which method to use mostly depends on the configuration of the affected gas grid and on what resources are available. This section gives a presentation of the various methods found in the reviewed material.

4.3.1 Direct measurement and gas chromatography

The calorific value of the gas can be determined either by direct measurement or by being calculated from the gas composition obtained by gas chromatography [45,44]. Both methods are carried out in accordance with existing ISO standards referred to in Section 4.2. Also, ISO standards regarding representative sampling and gas chromatography analysis are also of relevance when performing calorific value measurements. Calorific values that have been obtained by either of these methods can be used directly for debiting purposes in single feeding point grids, see Section 4.1.1.

It seems that gas chromatography is the preferred method; Denmark has a specific gas chromatography manual [46] and both the German and Dutch documents mention the use of ISO 6976. However, the Dutch document also state that additional methods for determining the calorific value are allowed as long as it can be proven that the method is accurate enough [44]. The ISO standard list multiple methods but do not give any recommendations on which one to use [45].

4.3.2 Flow-weighted calorific value

When multiple gas streams of different quality are mixed a flow-weighted calorific value can be calculated for the gas downstream from the mixing point. The flow-weighted calorific value is calculated using the calorific values ($H_{s,n}$) and flows (Q_n) of the incoming gas streams according to:

$$H_s = \frac{\sum_{i=1}^{n} H_{s,i} \cdot Q_i}{\sum_{i=1}^{n} Q_i}$$

This method to determine the calorific value can be used to allocate calorific values to grids with multiple feeding points (Section 4.1.2). However, this method should only be used for simpler grids as the risk of unjust debiting increases with increasing grid complexity. More complex grids should be divided into smaller calorific value zones to increase allocation accuracy. Below follows two examples.

Example 1: Gas grid with two feeding points and one calorific value zone [42,45]

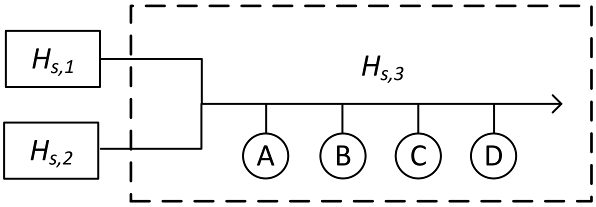

Figure 12. Gas grid with two feeding points and one calorific value zone

The grid is fed by two feeding points with different calorific values simultaneously. As mixing of the gas streams takes place before reaching the end users a flow-weighted calorific value can be assigned to the entire grid. The flow-weighted calorific value is calculated as:

$$H_{s,3} = \frac{H_{s,1} \cdot Q_1 + H_{s,2} \cdot Q_2}{Q_1 + Q_2}$$

Example 2: Gas grid with two feeding points and three calorific value zones [42,43,45]

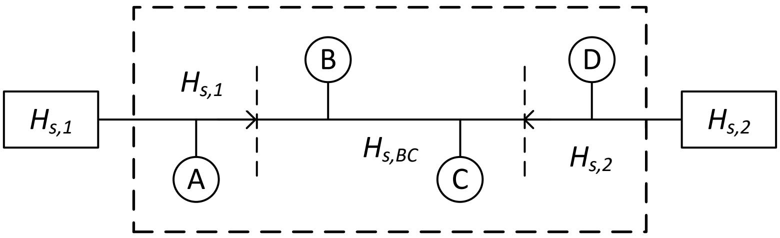

Figure 13. Gas grid with two feeding points and three calorific value zones

In the case where an end user is located close to a feeding point where the flow in the grid significantly exceeds the consumption of the end user, it can safely be assumed that the calorific value for the end user coincides with the calorific value of the feeding point. In this example end user A receives gas with the calorific value $H_{s,1}$ provided that $Q_1 >> Q_A$ and the corresponding reasoning applies to end user D. For end users B and C however a flow-weighted calorific value has to be calculated according to:

$$H_{s,BC} = \frac{H_{s,1} \cdot (Q_1 - Q_A) + H_{s,2} \cdot (Q_2 - Q_D)}{(Q_1 - Q_A) + (Q_2 - Q_D)}$$

4.3.3 Quality Tracker

A Quality Tracker (QT) is a state reconstruction tool that allows the user to calculate calorific values at any point in a gas grid using incoming calorific values, gas volume flows and standard load profiles for end users [45,52]. QT have been used in e.g. Germany to track the calorific value in transmission grids for several years and new QT systems that can be applied on distribution grids have recently been developed. A detailed description can be found in [52]. This tool is especially useful in complex grids where the accuracy of the flow-weighted calorific value is insufficient such as grids with several feeding points, with large variations in flow and/or incoming calorific values and in grids where there for some reason is not possible to measure the calorific value. Examples of model input are found in Table 3.

Table 3. Specification of knowledge for input quantities

Input information	**Data source**
Calorific values at entry points	Measured values (verified)
Normal volumes at entry points	Measured values (verified)
Normal volumes at exit points	Measured values (RDM customers); SLP data corrected on the basis of volume balance*
Network pressures	Pressures measured at representative points
Topology data (such as line lengths, line diameters, surface roughness)	Data obtained from network operator

*RDM customers: customers with recorded demand measurement. SLP customers: customers whose energy consumption is determined using standard load profiles

At this current time there is no detailed documentation available regarding the use of QT. QT is mentioned in the Danish regulations and in ISO 11512 but no further information in given. The German standard DVGW Arbeitsblatt G685 however is under revision and the new edition will also include regulations regarding the use of QT.

According to DONG in Denmark there is currently no regulations in place for the use of QT [53]. However, the Danish system is well on its way to submit a proposition for the implementation of QT regulations where the underlying information for the proposition has been obtained from Germany. The proposition will demand that controls of the calorific value shall be carried out annually at representative checkpoints where the QT calorific value is compared to a measured one. In both Denmark and Germany the maximal allowed deviation between measured and calculated calorific is set to 2%, see Section 4.4.1 for more information. Additional controls of the calorific value will be carried out when larger changes are made to the grid. Large changes are changes in gas flow larger than 10% and grid reconstruction where the physical length of the pipes change with more than 10% [53].

4.3.4 No determination of calorific value in grids with multiple feeding points

There are scenarios for grids with multiple feeding points where no determination of the calorific value in the grid is needed. Looking at grid configuration, the scenario of a grid with multiple feeding points were mixing of the gas takes place before reaching the end users but where each individual feeding point has the capacity to supply the entire distribution grid independent of the others, described in Section 4.1.2, is on example where no new calorific value determination has to be performed locally. Another example is grids with multiple feeding points where mixing of the gas takes place at the end users but where there exists zones where some end users clearly only receives gas from one feeding point based on volume flows. These zones can be assigned the calorific value of their correspondent feeding point, see Section 4.3.2, Example 2.

Additional situations where determination of calorific value might be considered unnecessary due to the relations of the incoming gas qualities and volumes exists. One example is when the incoming calorific values do not differ significantly from each other. In this case it might be acceptable to use the lower calorific value for debiting in the entire grid. Another example is when a local biogas producer occasionally delivers a small volume of biogas with a low calorific value to a significantly larger gas flow. In this case the impact of the added biogas volume is small enough to be disregarded and the calorific value of the larger gas flow is used for debiting.

Regardless what grid configuration or gas feeding scenario is under consideration a sensitivity analysis should be carried out to estimate what variation and/or deviation in calorific value might be expected. If the variation and/or deviation is deemed to be insignificant then the option of not determining new calorific values continuously may be considered.

4.3.5 Absent calorific value

Due to various reasons, e.g. faulty measurement equipment or ongoing service, it may occasionally occur that no calorific value is measured or delivered to a grid during a limited period of time. The German regulations and ISO 11512 state that a substitute calorific value may be used or is required for debiting during these periods [45,43]. Neither the Danish nor the Dutch regulations contain information regarding substitute calorific values. Substitute calorific values should only be used if no correctly operating measuring equipment is available and all involved gird actors agree that it should be implemented. Also, according to ISO 11512, all affected end users must be informed of that a substitute calorific value is in use and should also be informed of what method was used to determine it [45].

Methods for determining substitute calorific values

There are different suggested methods for how to determine a substitute calorific value. Different methods might be more appropriate to use depending on situation and length of the period when the substitute calorific value is to be used. Suggested methods are:

- Redundant measuring equipment

- Calorific values from up or down stream located measuring equipment
- Interpolation between last know and newest calorific value measurement
- Reuse of latest calorific value
- Comparison with historic values from similar period

4.4 CONTROL

In addition to measuring and allocation strategies there is also a need for control procedures to ensure that the end users are indeed debited for the correct calorific value. This entail regular periodic control of allocated calorific values, especially in grids with multiple feeding points.

4.4.1 Allowed deviation

When applying the flow-weighted calorific value to a grid it is important to ensure that no end users are at a constant advantage or disadvantage by receiving gas with a significantly higher or lower calorific value than the calorific value allocated to the grid. Of special interest is to protect end users close to the feeding point with the lowest calorific value.

Both Germany and Denmark have introduced maximal limit for how much the flow-weighted calorific value is allowed to deviate from incoming calorific values, the so called “2% limit”. This limit means that the flow-weighted calorific value may be used for debiting provided that it does not deviate with more than ± 2% from the average calorific value for the settlement period of any of the incoming feeding points (Germany [43]) or lowest average incoming calorific value for the settlement period on a yearly basis (Denmark [42]).

The German “2% limit” is based on what demands historically have been placed on measuring equipment. In Denmark, the limit is based on calculations of different gas mixing scenarios of Danish and German gas [42,54]. However, these calculations do not take measurement uncertainty on site into account.

Example 3: Control of 2% limit (Germany) [43]

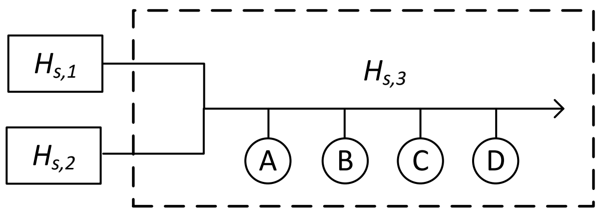

Figure 14. Gas grid with two feeding points and one calorific value zone

The flow-weighted calorific value $H_{s,3}$ has been calculated according to Example 1 (Section 4.3.2). Next, a control is carried out to determine if the calculated calorific value deviated more than ± 2% from incoming average calorific values.

$$\frac{H_{s,3} - H_{s,1}}{H_{s,3}} \cdot 100 \leq \pm 2\,\%$$

$$\frac{H_{s,3} - H_{s,2}}{H_{s,3}} \cdot 100 \leq \pm 2\,\%$$

Example 4: Control of 2% limit (Denmark) [42]

The flow-weighted calorific value $H_{s,3}$ has been calculated according to Example 1 (Section 4.3.2). Next, a control is carried out to determine if the calculated calorific value deviated more than 2% from the lowest incoming monthly average calorific value.

$$\frac{H_{s,3} - H_{s,low}}{H_{s,\mathrm{low}}} \cdot 100 \leq 2\,\%$$

If the difference exceeds 2%, a spread s is calculated based on the daily average calorific values that were used when calculating the monthly average. If s is less than 2% a correction is made to the lowest incoming average calorific value with a maximum of (2 – s)% and the new corrected calorific value is used for debiting. If s instead exceeds 2% the lowest incoming average calorific value is used for debiting.

4.4.2 Validation

Among the reviewed national regulations, only the Danish regulation thoroughly describe a process for regular validation of calorific values used for debiting [42]. In Denmark an annual control of the allocated calorific values is carried out by the Danish organization DGC. The validation process is the same regardless of type of end users or size of gas volume flows but differs between single feeding point and multiple feeding point grids. For grids with a single feeding point the control is carried out for, in the specific grid, a representative group of end users and the error is calculated on an energy basis. For grids with multiple feeding points the Danish “2% limit” (Section 4.4.1) is used and the control is carried out for all feeding points.

DGC performs all controls of the gas quality of Danish gas grid. Energinet.dk delivers daily and monthly average calorific values for all M/R stations in the transmission grid, while various distribution grid owners delivers the same information for all feeding points for the respective grid. Data has to be delivered to DGC at latest 10 working days after the turn of the month and DGC report their control results to the various net owners 20 working days after the end of the settlement period that is under revision. If the measured calorific values falls outside the accepted accuracy limit, the control frequency is increased from annual to monthly basis. In the case that the error persists over a period of six months, the grid owner is obliged to develop an action plan to resolve the error.

4.4.3 Compensation due to incorrect debiting

There are no specific guidelines presented in the reviewed material for how to handle situations where incorrect debiting has occurred. The Danish regulations concerning the "2% limit" (Section 4.4.1) prevents that end users are debited for a higher calorific value than they have received [42]. Nothing is however mention regarding incorrect debiting due to systematic errors in measurements or the use of substitute calorific values. The German national regulations addresses incorrect debiting in conjunction with the use of substitute calorific values but only establishes that a correction should be made to the invoice based on the correct calorific value [43].

5 Discussion

There are many aspects to consider when developing a national regulatory framework for gas grids with multiple feeding points. The ensuing variations in gas quality does raise questions regarding equipment performance, calorific value allocation, quality control, debiting and responsibility. This report has presented earlier research on the topic together with how the issue is being dealt with in selected European countries (Denmark, Germany, Netherlands). Several important issues have been identified for how to move forward with the issue of varying gas sources and qualities in the Swedish system.

5.1 LESSONS FROM THE LITERATURE

Understanding how to efficiently operate gas grids is an important topic in the research literature since some time. Recently issues regarding the relation between use of gas, power, and heat have become more important as the dependency on intermittent renewable energy sources has increased. Advanced methods have been developed for how to analyze and optimize the operation of gas grids, but less attention has been given to issues of gas quality variations, maybe because this has not yet become an important issue in regions with the highest demand for natural gas.

5.2 DEALING WITH GAS QUALITY VARIATIONS

Using propanation of gases to balance the gas quality has several drawbacks, which are inevitable. It is directly a barrier for introducing more renewable energy, e.g. biogas, as the currently available propane is fossil, and is an indirect barrier as it adds to the cost for producers of renewable gases. It is also only a consistent way of handling gas quality variations as it relies on the largest incoming flow of gas to have a reliable quality, an assumption that in itself is being challenged.

Calculating flow-weighted calorific values is a well-documented and used method, but has its limitations in terms of acceptable variations and errors. Variations here relate to the actually allowed changes in the quality that is being transmitted, which may be set by technical specifications, and errors relate to the difference between measured values and calculated ones. In an increasingly complex grid with many gas sources, risks will become higher that both variations and errors increase beyond acceptable limits.

Quality tracking tools are advanced calculation tools that allows for the system in its entirety to be simulated and the quality to be determined by the simulations. Acceptable errors and variations must be determined also in the case of implementing a QT system, but this type of tool allows for higher precision and thus reduced risk of unacceptable errors. Although QT systems have been implemented and used for some time, they are still seemingly not well regulated. As the operation of a QT system will require resources it remains to be determined at which levels and grids this type of system should be implemented in, and how to share the costs.

5.3 OPTIONS FOR SWEDEN

The implementation of QT may be an interesting course of action, but the current lack of regulations surrounding it is of concern depending on implementation date. Especially the question of how to validate and preform periodic controls is of essence.

Whether the “2% limit” used in Denmark and Germany can be considered a reasonable limit for the Swedish system has to be evaluated based on the demands placed on measuring equipment in Sweden. An estimation or sensitivity analysis of what gas qualities can be expected has to be performed before a limit is set. This survey must take grid configurations into consideration.

The workgroup suggests that error propagation should be taken into consideration when deciding upon what limit should be set as the allowed deviation between measured and true calorific value in Sweden. By using measured calorific value data and error specifications of measuring equipment that is currently in use it is possible to assess what error can be expected in the process of calorific value allocation. Error propagation only accounts for the errors generated during measurement and conversion, not errors connected to varying gas quality.

Guidelines for validation and supervision of the calorific value in the Swedish gas grid should jointly be developed by the actors of the Swedish gas industry when a clear view of what different types of gas grids will be of interest is obtained. A suggestion is to follow the Danish model and assign a third party the responsibility of validation and supervision. One third party that could be of interest to involve is the Swedish national accreditation body SWEDAC.

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MEASURING AND ENSURING THE GAS QUALITY OF THE SWEDISH GAS GRID

With the advent of more renewable gas in the Swedish natural gas grid, there is also more variations in quality expected. This renewable gas can stem from several sources, for example methane from anaerobic digestion and via thermochemical conversion of lignocellulosic material or indeed hydrogen from intermittent production of wind and solar power.

These gases have different properties than the gas on the grid and it is important to ensure that the measuring and assessment of the gas quality, and thus the debiting of the customers, is performed correctly.

This report uses other European countries national standards as examples on how this problem has previously been solved and discuss the implication of variations of gas quality on the Swedish natural gas grid.