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Dave Lander Consulting Limited
Registered in England and Wales, No 06725912 94 Sudeley, Dosthill, Tamworth, Staffordshire B77 1JU
tel: +44 (0)7901 510 905
e-mail: dave@davelanderconsulting.co.uk

ACCURACY OF CV DETERMINATION SYSTEMS FOR CALCULATION OF FWACV

1 BACKGROUND

Energy billing of domestic gas consumers is generally based on the actual volume of gas consumed, converted to a volume at reference conditions of temperature and pressure. The resultant *quantity*[1] of gas is then converted to energy by multiplying it by a *representative*[2] calorific value (CV). Generally, the representative CV applied by gas suppliers is the average of daily values provided by National Grid for each charging area, or Local Distribution Zone (LDZ), over the billing period of the consumer. The conversion of actual volume to volume at reference conditions and the determination of daily charging area CVs is governed by the Gas (Calculation of Thermal Energy) Regulations 1996 and Amendment 1997 ("the Regulations").

Volume conversion is performed by gas suppliers by use of national fixed factors that account for variation of temperature and pressure of gas in the meter. These factors are provided in the Regulations and are based on principles and methods originally used by British Gas Corporation prior to privatisation of the UK gas industry.

Daily charging area CVs are calculated by National Grid from determinations of daily CVs for all relevant inputs to, and relevant outputs from, a particular charging area. The methodology for calculating daily charging area calorific values is prescribed in the Regulations and permits either use of "lowest source" or "flow weighted average" approaches. Flow Weighted Average Calorific Value (FWACV) has been the method of choice by the then Transco, and now the four Gas Distribution Networks, since the amendment to the Regulations in 1997 which permitted its use.

FWACV is calculated from daily CVs calculated for individual relevant inputs to and outputs from a particular charging zone, which in turn are based on individual determinations of CV made by gas transporters using instruments that have been approved by Ofgem. The location and manner of determination of CV is formally prescribed through Letters of Direction from Ofgem to the gas transporter. The Letter of Direction requires the use of instruments that are approved by Ofgem and this approval is formally given by Ofgem to the gas transporter through the use of a Letter of Approval. Currently two types of instrument are approved by Ofgem: a combustion calorimeter manufactured by Cutler Hammer and two variants of the gas chromatograph manufactured by Daniels Industries Ltd ("the Danalyzer").

There is no agreed specification for the required performance of instruments for determination of CV, although custom and practice has led to the use of certain criteria for initial and regular performance evaluation of gas chromatographic systems:

a) Error in CV determined by the instrument when presented with gases of different composition.

b) Repeatability of the composition determined by the instrument when presented with gas of constant composition.

The criterion for acceptable error in CV is generally for error to be no more than +/- 0.1 MJ/m^3. Initially this criterion was applied for four hypothetical test compositions agreed with Ofgem. However, with increased PC power, use of Monte Carlo (MC) methods has been used to determine error for a large (typically tens of thousands) set of hypothetical compositions. This approach has been taken to align performance evaluation with some of the more advanced concepts of error and uncertainty in use by the natural gas metrology community.

The criterion of Maximum Permissible Error of +/- 0.1 MJ/m^3 is historical and dictated by Danalyzer performance, rather than any notion of fairness to or impact on the domestic consumer for whom the

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[1] Because the volume of a gas increases and decreases with increasing temperature and pressure, respectively, it does not define a quantity of gas. Instead actual volume is converted to a volume the gas would have occupied, had it been at reference conditions of temperature and pressure. The volume at reference conditions can be considered a quantity. The UK gas industry has adopted ISO reference conditions of 15^{o}C and 1.01325 bar.

[2] The term *representative* is used here to refer to the gas that is taken to represent that consumed in a particular charging area over a particular billing period.

CV determination is principally directed. As a result, in 2006 Ofgem requested a view on the impact of this criterion on the domestic consumer and in 2006 a National Grid report[3] set out a methodology for assessing and quantifying its impact.

In late 2011 Ofgem instigated the setting up of the EMIB Review Panel[4] under the stewardship of the Joint Office of Gas Transporters with the aim of addressing the outstanding technical and commercial barriers thought to the injection of biomethane into gas distribution and transportation systems. One such barrier is the cost associated with CV determination devices (CVDDs) and the question of the appropriate level of accuracy of CVDDs and in particular those associated with biomethane injection (the flows of which inevitably represent a relatively small fraction of the energy flowing into a charging area, even under the most optimistic of future scenarios).

The work carried out in 2006 and reported in MPR071 has therefore been updated to address the issue of small flows of biomethane (or any other gas, for that matter) into charging areas and the impact of different levels of CV determination accuracy on the consumer. This report describes both the original work published in 2006 and the recent work carried out for EMIB.

2 METHODOLOGY FOR ASSESSMENT OF IMPACT OF CVDD INSTRUMENT ACCURACY

The approach taken in assessing impact is based on the principles and recommendations developed by the Marcogaz Energy Measurement Working Group[5]. Essentially the process sets out the bias and uncertainty in bias for all component parts that together make up the determined quantity of energy. Bias is defined here as the mean of a distribution of errors of a series of determinations.

Biases for each component part are combined by arithmetic addition, whereas uncertainties in biases are combined by addition in quadrature. These components are described in turn below:

> Atmospheric pressure. The correction factor in the Regulations assumes an atmospheric pressure of 1013.25 mbar. For the UK [6] mean monthly atmospheric pressure from 1987 to 1996 was estimated to be described by a distribution with mean 1015.20 mbar and a standard deviation of 1.15 mbar, so the bias in atmospheric pressure is taken to be -1.85 mbar, with a standard uncertainty in bias of 1.15 mbar.
>
> Meter pressure. The correction factor in the Regulations assumes meter pressure regulator is set at a pressure of 21 mbarg. IGE/GM/8 Part 1 specifies an accuracy of 7.5% (preferred) or 10% (limit) of set gauge pressure for domestic meter regulators with an inlet gauge pressure of between 21 and 100 mbar. Bias in meter gauge pressure is therefore taken to be zero, with a standard uncertainty in meter pressure of 1.21 mbar ((0.1 x 21)/√3). The divisor √3 is employed to convert upper and lower bounds for a uniform distribution into standard uncertainty, in accordance with Marcogaz and GUM[7] guidance.
>
> Altitude. The correction factor in the Regulations is based on a nominal altitude of 66m above sea level. In practice the correction factor is based on the use of an altitude adjustment to pressure of -8.114 mbar. This value is derived from Table in Part 1 the Regulations (height above sea level band >65.0, ≤67.5m), which in turn is derived from an altitude of 67.5m in the formula that was in use by British Gas prior to the Regulations coming into force:
>
> pressure deduction = altitude in metres * 0.120208
>
> The value 0.120208 is the altitude correction factor. For the UK [4] mean altitude was estimated to be described by a distribution with mean 67.16 m and a standard deviation of 54.55 m, so the bias in altitude is taken to be +0.34 m, with a standard uncertainty in bias of 54.55 m.

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[3] "Accuracy of CV determination systems for calculation of FWACV". National Grid Measurement and Process Report MPR071. October 2006.

[4] Ofgem Review Group on Energy Market Issues for Biomethane Projects

[5] "Guidance note on energy determination: implementation of certain principles presented in relevant standards." Marcogaz, October 2006.

[6] L.M.Wallis. "Examination of environmental factors affecting gas metering accuracy". BG Technology Report R2278 April 1998.

[7] PD 6464-3:1995: General Metrology – Guide to the expression of uncertainty in measurement (GUM)

The value of altitude correction factor (0.120208 mbar/m) was in use by British Gas prior to the Regulations coming into force. This value is assumed to have zero bias and a standard uncertainty of 0.0012 mbar/m (10%).

Temperature. The correction factor in the Regulations assumes a gas temperature of 12.2 ^{o}C. For the UK [4] mean monthly atmospheric pressure from 1987 to 1996 was estimated to be described by a distribution with mean 11.9 ^{o}C, with a half-range of 11.2 ^{o}C, so the bias in gas temperature is taken to be +0.3 ^{o}C, with a standard uncertainty in bias of 6.47 ^{o}C (11.2/√3).

Representative CV. Bias in representative CV and its uncertainty are governed by bias and uncertainty associated with the FWACV, which is in turn dependent upon: variation in daily CV of all sources of gas into the charging area, the bias and uncertainty in bias in the CVDD at the relevant inputs and outputs to the charging area (the CVDD is in most cases a Danalyzer), and the bias and uncertainty in bias in the daily volume measurement equipment at the relevant inputs and outputs to the charging area. Bias and uncertainty in bias in representative CV was estimated for North West LDZ daily volumes and daily CV seen in 2005, using combinations of accuracy for CVDD and daily volume measurement system. The details and methodology are given in Section 3.

Actual calorific value. Whilst the representative CV is used for consumer billing a consumer may actually receive gas of CV up to 1 MJ/m3 lower than that used for billing. The representative CV may therefore be in error (from an individual consumer's perspective) by up to 1 MJ/m3. The bias in actual CV is therefore assumed to be zero with a standard uncertainty in bias of 0.577 MJ/m3 (1/√3).

3 BIAS AND UNCERTAINTY IN BIAS IN REPRESENTATIVE CV

Representative CV is the average of each daily FWACV calculated over the billing period. Bias in representative CV will depend upon how the bias in FWACV varies over that time and for simplicity this is assumed to be constant across the billing period. In the absence of a capped FWACV, bias in FWACV is assumed to be zero and hence bias in representative calorific value is assumed to be zero. This assumption is valid so long as the measurements of calorific value and daily volumes are unbiased, i.e., they show a distribution of errors that are centred about zero. Uncertainty in error in representative calorific value will depend on the uncertainty in daily FWACV values and how strongly the daily FWACV values are correlated. If the FWACV values were uncorrelated, the uncertainty in bias in representative calorific value would be smaller than that of the FWACV by a factor of about the square root of 91 for a 13-week (91day) billing period. Clearly some components of FWACV are strongly correlated (e.g., Danalyzer performance over a billing period is relatively constant) and so the most conservative estimate of uncertainty in bias in representative CV is to assume it is that of the daily FWACV.

The bias and uncertainty in bias of the daily FWACV was calculated using Monte Carlo (MC) methods with a Microsoft Excel spreadsheet model of a sample charging area using design offtake flowrate data from those of National Grid's North West LDZ. Inputs to the FWACV calculation are assumed to be as set out in Table 1.

The uncertainties in the above inputs are of two "types": measurement uncertainty8 associated with instrumentation (uncertainty in biases in daily volume and calorific value), and uncertainty associated with variation (geographical, seasonal) in the daily volumes and calorific values themselves.

All MC calculations were performed using the Gas Tools Excel Add-in supplied by GL Noble Denton Ltd. Figure 1 shows a screenshot from the Excel model.

[8] The uncertainty in measurement of calorific value assumed above is, strictly speaking, only that associated with distribution of error in calorific value for all possible concentrations of gas within the approval range of a Danalyzer. There is an additional source of uncertainty associated with the repeatability of the Danalyzer and the uncertainty in composition of the calibration standard. Typically this amounts to a standard uncertainty of around 0.025 MJ/m^3, which should be added in quadrature. However the additional uncertainty is small in comparison and was ignored for the purpose of this study.

Table 1: Input values to the FWACV calculation and their uncertainties

Input	Description	Value	Uncertainty	Distribution
Vd(i)	Daily volume at the *i*th offtake	Mid-range design value	Half-range design value	Uniform
Cd(i)	Daily average CV at the *i*th offtake	39.5 MJ/m^3	2 MJ/m^3	Uniform
E(Cd(i))	Error in daily average CV at the *i*th offtake	0 MJ/m^3	0.05 MJ/m^3 0.10 MJ/m^3 0.20 MJ/m^3	Uniform
E(Vd(i))	Error in daily volume at the *i*th offtake	0 MJ/m^3	1% 4%	Uniform

4 RESULTS

4.1 BIAS AND UNCERTAINTY IN BIAS IN FWACV

The inputs to the MC modelling studies are distributions of errors in measured values for daily volume and calorific value that are centred at zero (i.e., are unbiased). The outputs from the studies are a distribution of errors in FWACV values that are centred at zero and uncertainty was calculated from these output distributions resulting from combinations of uncertainty in bias in daily average CV and uncertainty in bias in daily volume.

Bias and uncertainty in FWACV was estimated for different combinations of NTS offtake metering and CV measurement accuracy, the extremes in which correspond to the situation like that prevalent in 2006 (accuracy of CVDD 0.1 MJ/m^3; accuracy of offtake metering around 4%) and an idealised "highest accuracy" situation (accuracy of CVDD 0.1 MJ/m^3; accuracy of offtake metering around 1%). The resulting standard uncertainties in FWACV are shown in Table 2 below, expressed as relative %:

Table 2: Standard uncertainty in bias in FWACV, u(bias(FWACV), relative %

a(E(Vd))	a(E(CV))		
	0.05 MJ/m^3 (0.125%)	0.10 MJ/m^3 (0.25%)	0.20 MJ/m^3 (0.5%)
1%	0.0352%	0.0695%	0.1377%
4%	0.0473%	0.0762%	0.1418%
Note: a(Vd) and a(CV) are the assumed uncertainties in daily volume and a(CV) respectively, expressed as half-range values (uniform distribution).			

4.2 IMPACT ON DOMESTIC CONSUMERS

The output from the domestic energy uncertainty calculations set out in Section 3 is a mean and standard deviation for the distribution of possible errors in energy estimated for the domestic consumer. The distribution arises from combination of the distributions associated with sources of uncertainty or distributions of error. The output distribution is centred close to zero (-0.008%) because the input distributions, with the exception of the atmospheric pressure and altitude correction factors assumed in the Regulations, are themselves centred close to zero i.e., they are unbiased (or assumed to be so in the case of flow and CV measurement – see Section 5).

Tables A1-A6 in Appendix A detail the results of Cases 1-6, corresponding to combinations of accuracy assumptions for offtake flow measurement and CV determination. The results are summarised below:

Table 3: Expanded* uncertainty in bias in domestic consumer energy billing

a(E(Vd))	a(E(CV)), MJ/m^3 (£ pa**)		
	+/- 0.05	+/- 0.10	+/- 0.20
+/- 1%	5.816% (£58.16)	5.817% (£58.17)	5.822% (£58.22)
+/- 4%	5.816% (£58.16)	5.817% (£58.17)	5.822% (£58.22)

*Assuming a coverage factor k=2, corresponding to a probability of around 95%

** Based on an average bill of £1000 pa

The above expanded uncertainties in error in energy correspond to a probability level of around 95%, so under current custom and practice (maximum permissible error in CV determination +/- 0.1MJ/m^3 i.e., Case 3 in Appendix A) around 95% of domestic consumers' bills will be in error by no more than +/- 5.817%. The effect of errors in energy billing is for some consumers to gain (through under-estimation of bill) at the expense of others (whose bill is over-estimated), so around 2.5% of the domestic population are over- or under-billed by around £58 pa.

The above uncertainties are dominated by domestic metering issues, rather than issues associated with offtake measurement (daily volume or calorific value). Under current custom and practice (Case 3 in Appendix A), uncertainty in representative CV contributes 0.06% of the total variance in the energy bill. The variation in CV of the gas that could actually be received by a consumer represents an additional 25% of variance in the energy bill. The remaining 74.71% of the variance is associated with consumers' metered volume and its conversion of to reference conditions of volume and temperature. Figure 2 shows how each source of uncertainty contributes to the total variance (Case 3 in Appendix A).

The choice of a coverage factor of k=2 (corresponding to a probability level of 95%) is a pragmatic one, normally associated with general commercial or measurement uncertainty. A higher probability level might be considered to be more appropriate, in view of the size of the domestic population (2.5% still corresponds to around 0.5 million consumers). Because of this, level of impact is also shown in Tables A1-A6 for 0.1% of the population (around 20,000 consumers). At this level, current custom and practice results in 0.1% of the population over-charged by £89.07 pa or under-charged by around £90.69. The asymmetry arises from the slight bias in the distribution of errors (mean -0.081%). The uncertainty in bias in representative CV contributes around £2.15 pa of this cross-subsidy.

4.3 IMPACT OF BIOMETHANE INJECTION

None of the estimates in 2006 of bias and uncertainty in bias of FWACV in Table 2 anticipated injection of relatively small quantities of biogas into charging areas and so additional estimates were made using the original MC model, but with a small (3% of daily charging area volume) flow of biomethane into the charging area. Table 4 below shows the results obtained:

Table 4: Additional values for biomethane injected for the FWACV calculation and their uncertainties

Input	Description	Value	Uncertainty	Distribution
Vd(b)	Daily volume of biomethane injected into the LDZ	240,000 m3/d	60,000 m3/d	Uniform
Cd(b)	Daily average CV of biomethane injected into the LDZ	39.5 MJ/m^3	0.5 MJ/m^3	Uniform
E(Cd(b))	Error in daily average CV of biomethane injected into the LDZ	0 MJ/m^3	1.0 MJ/m^3 10 MJ/m^3	Uniform
E(Vd(b))	Error in daily volume of biomethane injected into the LDZ	0 MJ/m^3	3%	Uniform

The measurement of CV for biomethane was assumed to have relatively large uncertainty (1 MJ/m^3 and 10 MJ/m^3) and the measurement of volume was assumed to have an uncertainty of 3%.

The impact of the biomethane injection on the standard uncertainty in error in FWACV was found to be extremely small. For Case 3 (uncertainty in GCV determination at NTS offtakes 0.1 MJ/m^3, uncertainty in volume determination at NTS offtakes 1%) the standard uncertainty in error in FWACV changed from 0.0695% (see Table 2) to 0.0687% and 0.0848% when uncertainty in error in daily average CV for the biomethane injected was 1 MJ/m^3 and 10 MJ/m^3, respectively. The slight decrease in error for the 1MJ/m^3 case is within the natural variation expected for these Monte Carlo methods.

The slight increase in uncertainty in bias of FWACV resulting from allowance for biomethane injection results in a slight increase in the uncertainty in bias in the domestic consumer bill. For Case 3 above, the expanded uncertainty in bias in domestic consumer energy billing increased from 5.817% to just 5.818%.

5 DISCUSSION

5.1 DOMESTIC METERING

Uncertainty in domestic consumer energy billing arises from several sources and leads to cross subsidy from consumers whose bills are over-estimated to those whose bills are under-estimated. The dominant source of this cross-subsidy is associated with conversion of the actual volume of gas metered at consumers' premises in accordance with the fixed factors specified in the Regulations and in particular the assumptions about temperature of gas metered in domestic premises. In effect, those consumers whose gas is consistently cooler than 12.2 oC are under-charged, whilst those whose gas is consistently hotter are over-charged. This cross-subsidy could in principle be reduced by direct temperature correction at the meter (over 60% of total variance) or direct temperature/pressure correction at the meter (over 65% of total variance), or through adoption of LDZ-specific fixed factors. Technically, the greatest reduction would be through volume conversion at the domestic meter, but this would require investment in new metering technology for the domestic meter population. This might be regarded as an unjustifiable expense in its own rights, but it should be noted that installation of smart metering is planned for the UK economically anyway, so the marginal cost of volume conversion is what requires economic test and not the full cost of new meters. Both volume conversion and LDZ-specific fixed factors would require modification of consumer billing systems (not without significant cost) and both would of course require amendment to the Gas (Calculation of Thermal Energy) Regulations.

5.2 ACCURACY IN REPRESENTATIVE CV

Uncertainty in representative CV is only a minor contributor (less than 0.1% of variance) to cross-subsidy between consumers. The dominant source of uncertainty is not the CV determination itself, but the variation in the gas actually received by different consumers within a given charging area

(25% of total variance). Reducing this source of uncertainty could be achieved most effectively by CV determination at the domestic meter, or less effectively by reduction in the size of charging area. Similar arguments to that for domestic metering above apply, i.e. marginal cost of CV determination at the meter (using inferential methods, such as speed of sound determination) and the need for billing system and regulatory changes.

The only other means of reducing uncertainty in representative CV is through adoption of higher accuracy standards for CV determination or volume metering at entry to charging areas. Although it may be possible to achieve better accuracy with modern CV determination instrumentation, the overall impact on consumer billing would be insignificant.

There may in fact be some merit in relaxing accuracy standards for CV determination or volume metering at entry to charging areas if this could open up lower capex/opex options for CV measurement instrumentation, such as micro-gc or inferential devices. This approach would be especially applicable for low volume flows such as inter-LDZ flows, small NTS offtakes and injection of biomethane and other non-conventional sources of gas. Because the impact of CVDD accuracy on domestic energy billing is insignificant, the appropriate MPE should be decided by consideration of other regulatory issues (such as monitoring of compliance with the GS(M)R if shared duty is being practiced), or normal commercial factors for sale of energy

A key assumption in this study was that the CV and flow measurements were unbiased, i.e., the distribution of errors was centred at zero. In practice individual instruments will demonstrate some bias and for gas chromatographs will reflect how well the composition of the calibration standard employed matches the distribution of compositions of gases that might be presented to individual instruments. An additional criterion for CV determination instrumentation is therefore recommended, based on the mean error in CV for the gases likely to be (or actually) presented to the instrument. (The MPE is based any possible gas composition within the approval range of the instrument.) For current custom and practice (Case 3 – Appendix A) changing bias in representative CV from zero results in the following change in cross-subsidy at the 0.1% level of the population:

Table 5: Impact of bias in CV measurement instrumentation

	Mean Error in CV, MJ/m^3			
	0.00	0.01	0.05	0.10
Overall (all sources of uncertainty:				
0.1% of consumers under-charged* by:	£90.69	£90.43	£89.42	£88.15
0.1% of consumers over-charged* by:	£89.07	£89.32	£90.33	£91.60
Representative CV only:				
0.1% of consumers under-charged* by:	£2.15	£1.89	£0.88	£0.38
0.1% of consumers over-charged* by:	£2.15	£2.40	£3.41	£4.68
*Based on an average bill of £1000 pa				

Note that the impact shown in Table 5 assumes that FWACV is biased by the stated amount, which would require all CV instruments to be bias in the same direction by the same amount. Whilst gas chromatographs employ calibration standards of the same composition, they unlikely to be presented with gases of the same composition at the same time, so individual biases will probably differ in direction and magnitude. The assumptions in Table 5 are therefore pessimistic; however a maximum bias error criterion of around +/- 0.01 or +/- 0.05 MJ/m^3 might be appropriate for CV determination instrumentation.

6 CONCLUSIONS

1) Current custom and practice is for CV determination equipment to meet a requirement that (absolute) error in CV should not exceed 0.10 MJ/m^3. This requirement results in insignificant impact on the domestic consumer as the dominant factor is associated with fixed factors for conversion of actual domestic metered volume to reference temperature and pressure.

2) Some relaxation in Maximum Permissible Error (MPE) may be appropriate, particularly in low volume applications, such as biomethane injection, for which the anticipated daily volumes are so low as to make CV determination accuracy insignificant in respect of impact on the domestic consumer. The appropriate MPE should be decided by consideration of other regulatory issues (such as monitoring of compliance with the GS(M)R if shared duty is being practiced), or normal commercial factors for sale of energy.

3) In addition to MPE, a formal performance specification for CV determination devices should include a maximum bias shown by CV determination devices with gases that the instrument (or family of instruments) is likely to see.

APPENDIX A – CALCULATIONS OF ESTIMATES OF ERROR AND UNCERTAINTY IN ERROR IN ENERGY DETERMINATION FOR THE DOMESTIC CONSUMER

Tables A1-A6 below illustrate the estimation of bias and uncertainty in bias in domestic consumer billing using the methodology outlined in Section 2. Impact is interpreted by converting the uncertainty in energy billed to a cost assuming an average quantity of energy consumed of 20,000 kWh pa and an average price of gas of 5 p/kWh, which equates to an average energy bill of £1000.

Table A1: Summary of uncertainty in energy determination - Case 1

u(E(GCV))		0.125%
u(E(Vd))		1%
Tb	K	273.15
Pb	mbar	1013.25
Z/Zb		1
Coverage factor		2

MCS modelling results for u(bias(FWACV)):

a(Vd)	a(GCV), %		
	0.125%	0.250%	0.500%
1%	0.0352%	0.0695%	0.1377%
4%	0.0473%	0.0762%	0.1418%

	Units	P	meanP	bias(P)	bias(P)/P	u(bias(P))	u(bias(P)/P)	variance	% total variance
atmospheric pressure	mbar	1013.25	1015.20	-1.95		1.15			
meter pressure	mbarg	21.00		0		1.21			
altitude	m	67.50	67.16	0.34		54.55			
altitude correction factor	mbar/m	0.12		0		0.0012			
Pressure (combined)	mbar	1026.14		-1.91	-0.186%	6.77	0.66%	0.0043%	5.14%
Temperature	K	285.35	285.05	0.30	0.105%	6.47	2.27%	0.0514%	60.73%
Actual billing period volume	m3	100.00		0	0.000%		0.87%	0.0075%	8.87%
Converted billing period volume	**m3:E**	**96.94**			**-0.081%**		**2.51%**	**0.0632%**	**74.75%**
Actual CV	MJ/m3:E	39.50		0	0.000%	0.577	1.46%	0.0213%	25.24%
FWACV	MJ/m3:E	39.50		0	0.000%		0.04%	0.0000%	0.01%
Energy	**MJ**	**3829.21**			**-0.081%**		**2.91%**	**0.0846%**	

Overall:

Bias in domestic consumers' bills	-0.081%		(or -£0.81 pa)
Standard uncertainty in bias in domestic consumers' bills	2.908%		(or £29.08 pa)
Expanded uncertainty in bias in domestic consumers' bills	5.816%	assuming k=2	(or £58.16 pa)

0.10% of the population have a bias of -9.07% or less (or -£90.67 pa)
0.10% of the population have a bias of 8.90% or more (or £89.05 pa)

FWACV accuracy:

Standard uncertainty in bias in domestic consumers' bills arising from representative CV uncertainty	0.035%		(or £0.35 pa)
Expanded uncertainty in bias in domestic consumers' bills arising from representative CV uncertainty	0.070%	assuming k=2	(or £0.70 pa)

0.10% of the population have a bias of -0.11% or less (or -£1.09 pa)
0.10% of the population have a bias of 0.11% or more (or £1.09 pa)

Table A2: Summary of uncertainty in energy determination - Case 2

u(E(GCV))		0.125%
u(E(Vd))		4%
Tb	K	273.15
Pb	mbar	1013.25
Z/Zb		1
Coverage factor		2

MCS modelling results for u(bias(FWACV)):

a(Vd)	a(GCV), %		
	0.125%	0.250%	0.500%
1%	0.0352%	0.0695%	0.1377%
4%	0.0473%	0.0762%	0.1418%

	Units	P	meanP	bias(P)	bias(P)/P	u(bias(P))	u(bias(P)/P)	variance	% total variance
atmospheric pressure	mbar	1013.25	1015.20	-1.95		1.15			
meter pressure	mbarg	21.00		0		1.21			
altitude	m	67.50	67.16	0.34		54.55			
altitude correction factor	mbar/m	0.12		0		0.0012			
Pressure (combined)	mbar	1026.14		-1.91	-0.186%	6.77	0.66%	0.0043%	5.14%
Temperature	K	285.35	285.05	0.30	0.105%	6.47	2.27%	0.0514%	60.73%
Actual billing period volume	m3	100.00		0	0.000%		0.87%	0.0075%	8.87%
Converted billing period volume	**m3:E**	**96.94**			**-0.081%**		**2.51%**	**0.0632%**	**74.74%**
Actual CV	MJ/m3:E	39.50		0	0.000%	0.577	1.46%	0.0213%	25.23%
FWACV	MJ/m3:E	39.50		0	0.000%		0.05%	0.0000%	0.03%
Energy	**MJ**	**3829.21**			**-0.081%**		**2.91%**	**0.0846%**	

Overall:

Bias in domestic consumers' bills	-0.081%		(or -£0.81 pa)
Standard uncertainty in bias in domestic consumers' bills	2.908%		(or £29.08 pa)
Expanded uncertainty in bias in domestic consumers' bills	5.816%	assuming k=2	(or £58.16 pa)

0.10% of the population have a bias of -9.07% or less (or -£90.67 pa)

0.10% of the population have a bias of 8.91% or more (or £89.05 pa)

FWACV accuracy:

Standard uncertainty in bias in domestic consumers' bills arising from representative CV uncertainty	0.047%		(or £0.47 pa)
Expanded uncertainty in bias in domestic consumers' bills arising from representative CV uncertainty	0.095%	assuming k=2	(or £0.95 pa)

0.10% of the population have a bias of -0.15% or less (or -£1.46 pa)

0.10% of the population have a bias of 0.15% or more (or £1.46 pa)

Table A3: Summary of uncertainty in energy determination - Case 3

u(E(GCV))		0.250%
u(E(Vd))		1%
Tb	K	273.15
Pb	mbar	1013.25
Z/Zb		1
Coverage factor		2

MCS modelling results for u(bias(FWACV)):

a(Vd)	a(GCV), %		
	0.125%	0.250%	0.500%
1%	0.0352%	0.0695%	0.1377%
4%	0.0473%	0.0762%	0.1418%

	Units	P	meanP	bias(P)	bias(P)/P	u(bias(P))	u(bias(P)/P)	variance	% total variance
atmospheric pressure	mbar	1013.25	1015.20	-1.95		1.15			
meter pressure	mbarg	21.00		0		1.21			
altitude	m	67.50	67.16	0.34		54.55			
altitude correction factor	mbar/m	0.12		0		0.0012			
Pressure (combined)	mbar	1026.14		-1.91	-0.186%	6.77	0.66%	0.0043%	5.14%
Temperature	K	285.35	285.05	0.30	0.105%	6.47	2.27%	0.0514%	60.71%
Actual billing period volume	m3	100.00		0	0.000%		0.87%	0.0075%	8.87%
Converted billing period volume	**m3:E**	**96.94**			**-0.081%**		**2.51%**	**0.0632%**	**74.72%**
Actual CV	MJ/m3:E	39.50		0	0.000%	0.577	1.46%	0.0213%	25.23%
FWACV	MJ/m3:E	39.50		0	0.000%		0.07%	0.0000%	0.06%
Energy	**MJ**	**3829.21**			**-0.081%**		**2.91%**	**0.0846%**	

Overall:

Bias in domestic consumers' bills	-0.081%		(or -£0.81 pa)
Standard uncertainty in bias in domestic consumers' bills	2.908%		(or £29.08 pa)
Expanded uncertainty in bias in domestic consumers' bills	5.817%	assuming k=2	(or £58.17 pa)

0.10% of the population have a bias of -9.07% or less (or -£90.69 pa)

0.10% of the population have a bias of 8.91% or more (or £89.07 pa)

FWACV accuracy:

Standard uncertainty in bias in domestic consumers' bills arising from representative CV uncertainty	0.070%		(or £0.70 pa)
Expanded uncertainty in bias in domestic consumers' bills arising from representative CV uncertainty	0.139%	assuming k=2	(or £1.39 pa)

0.10% of the population have a bias of -0.21% or less (or -£2.15 pa)

0.10% of the population have a bias of 0.21% or more (or £2.15 pa)

Table A4: Summary of uncertainty in energy determination - Case 4

u(E(GCV))		0.250%
u(E(Vd))		4%
Tb	K	273.15
Pb	mbar	1013.25
Z/Zb		1
Coverage factor		2

MCS modelling results for u(bias(FWACV)):

a(Vd)	a(GCV), %		
	0.125%	0.250%	0.500%
1%	0.0352%	0.0695%	0.1377%
4%	0.0473%	0.0762%	0.1418%

	Units	P	meanP	bias(P)	bias(P)/P	u(bias(P))	u(bias(P)/P)	variance	% total variance
atmospheric pressure	mbar	1013.25	1015.20	-1.95		1.15			
meter pressure	mbarg	21.00		0		1.21			
altitude	m	67.50	67.16	0.34		54.55			
altitude correction factor	mbar/m	0.12		0		0.0012			
Pressure (combined)	mbar	1026.14		-1.91	-0.186%	6.77	0.66%	0.0043%	5.14%
Temperature	K	285.35	285.05	0.30	0.105%	6.47	2.27%	0.0514%	60.70%
Actual billing period volume	m3	100.00		0	0.000%		0.87%	0.0075%	8.87%
Converted billing period volume	**m3:E**	**96.94**			**-0.081%**		**2.51%**	**0.0632%**	**74.71%**
Actual CV	MJ/m3:E	39.50		0	0.000%	0.577	1.46%	0.0213%	25.22%
FWACV	MJ/m3:E	39.50		0	0.000%		0.08%	0.0001%	0.07%
Energy	**MJ**	**3829.21**			**-0.081%**		**2.91%**	**0.0846%**	

Overall:

Bias in domestic consumers' bills	-0.081%		(or -£0.81 pa)
Standard uncertainty in bias in domestic consumers' bills	2.909%		(or £29.09 pa)
Expanded uncertainty in bias in domestic consumers' bills	5.817%	assuming k=2	(or £58.17 pa)

0.10% of the population have a bias of -9.07% or less (or -£90.69 pa)

0.10% of the population have a bias of 8.91% or more (or £89.07 pa)

FWACV accuracy:

Standard uncertainty in bias in domestic consumers' bills arising from representative CV uncertainty	0.076%		(or £0.76 pa)
Expanded uncertainty in bias in domestic consumers' bills arising from representative CV uncertainty	0.152%	assuming k=2	(or £1.52 pa)

0.10% of the population have a bias of -0.24% or less (or -£2.35 pa)

0.10% of the population have a bias of 0.24% or more (or £2.35 pa)

Table A5: Summary of uncertainty in energy determination - Case 5

u(E(GCV))		0.500%
u(E(Vd))		1%
Tb	K	273.15
Pb	mbar	1013.25
Z/Zb		1
Coverage factor		2

MCS modelling results for u(bias(FWACV)):

a(Vd)	a(GCV), %		
	0.125%	0.250%	0.500%
1%	0.0352%	0.0695%	0.1377%
4%	0.0473%	0.0762%	0.1418%

	Units	P	meanP	bias(P)	bias(P)/P	u(bias(P))	u(bias(P)/P)	variance	% total variance
atmospheric pressure	mbar	1013.25	1015.20	-1.95		1.15			
meter pressure	mbarg	21.00		0		1.21			
altitude	m	67.50	67.16	0.34		54.55			
altitude correction factor	mbar/m	0.12		0		0.0012			
Pressure (combined)	mbar	1026.14		-1.91	-0.186%	6.77	0.66%	0.0043%	5.13%
Temperature	K	285.35	285.05	0.30	0.105%	6.47	2.27%	0.0514%	60.61%
Actual billing period volume	m3	100.00		0	0.000%		0.87%	0.0075%	8.85%
Converted billing period volume	**m3:E**	**96.94**			**-0.081%**		**2.51%**	**0.0632%**	**74.59%**
Actual CV	MJ/m3:E	39.50		0	0.000%	0.577	1.46%	0.0213%	25.18%
FWACV	MJ/m3:E	39.50		0	0.000%		0.14%	0.0002%	0.22%
Energy	**MJ**	**3829.21**			**-0.081%**		**2.91%**	**0.0847%**	

Overall:

Bias in domestic consumers' bills	-0.081%		(or -£0.81 pa)
Standard uncertainty in bias in domestic consumers' bills	2.911%		(or £29.11 pa)
Expanded uncertainty in bias in domestic consumers' bills	5.822%	assuming k=2	(or £58.22 pa)

0.10% of the population have a bias of -9.08% or less (or -£90.76 pa)
0.10% of the population have a bias of 8.91% or more (or £89.14 pa)

FWACV accuracy:

Standard uncertainty in bias in domestic consumers' bills arising from representative CV uncertainty	0.138%		(or £1.38 pa)
Expanded uncertainty in bias in domestic consumers' bills arising from representative CV uncertainty	0.275%	assuming k=2	(or £2.75 pa)

0.10% of the population have a bias of -0.43% or less (or -£4.26 pa)
0.10% of the population have a bias of 0.43% or more (or £4.26 pa)

Table A6: Summary of uncertainty in energy determination - Case 6

u(E(GCV))		0.500%
u(E(Vd))		1%
Tb	K	273.15
Pb	mbar	1013.25
Z/Zb		1
Coverage factor		2

MCS modelling results for u(bias(FWACV)):

a(Vd)	a(GCV), %		
	0.125%	0.250%	0.500%
1%	0.0352%	0.0695%	0.1377%
4%	0.0473%	0.0762%	0.1418%

	Units	P	meanP	bias(P)	bias(P)/P	u(bias(P))	u(bias(P)/P)	variance	% total variance
atmospheric pressure	mbar	1013.25	1015.20	-1.95		1.15			
meter pressure	mbarg	21.00		0		1.21			
altitude	m	67.50	67.16	0.34		54.55			
altitude correction factor	mbar/m	0.12		0		0.0012			
Pressure (combined)	mbar	1026.14		-1.91	-0.186%	6.77	0.66%	0.0043%	5.13%
Temperature	K	285.35	285.05	0.30	0.105%	6.47	2.27%	0.0514%	60.61%
Actual billing period volume	m3	100.00		0	0.000%		0.87%	0.0075%	8.85%
Converted billing period volume	**m3:E**	**96.94**			**-0.081%**		**2.51%**	**0.0632%**	**74.59%**
Actual CV	MJ/m3:E	39.50		0	0.000%	0.577	1.46%	0.0213%	25.18%
FWACV	MJ/m3:E	39.50		0	0.000%		0.14%	0.0002%	0.22%
Energy	**MJ**	**3829.21**			**-0.081%**		**2.91%**	**0.0847%**	

Overall:

Bias in domestic consumers' bills	-0.081%		(or -£0.81 pa)
Standard uncertainty in bias in domestic consumers' bills	2.911%		(or £29.11 pa)
Expanded uncertainty in bias in domestic consumers' bills	5.822%	assuming k=2	(or £58.22 pa)

0.10% of the population have a bias of -9.08% or less (or -£90.76 pa)
0.10% of the population have a bias of 8.91% or more (or £89.14 pa)

FWACV accuracy:

Standard uncertainty in bias in domestic consumers' bills arising from representative CV uncertainty	0.138%		(or £1.38 pa)
Expanded uncertainty in bias in domestic consumers' bills arising from representative CV uncertainty	0.275%	assuming k=2	(or £2.75 pa)

0.10% of the population have a bias of -0.43% or less (or -£4.26 pa)
0.10% of the population have a bias of 0.43% or more (or £4.26 pa)

Figure 1: Example spreadsheet model used to estimate error and uncertainty in error in FWACV

NWLDZ Model for Danalyzer Approval

Volumes and compositions

Daily volume	Site	Description	daily volume, m^3(st) design	daily volume, m^3(st) mid	daily volume, m^3(st) half-range	flow distribution	ggcv mid	ggcv half-range	ggcv distribution
1	AUDLEY NW	Official offtake	1366000	683000	683000	u	39.5	2	u
2	BLACKROD	Official offtake	26620000	13310000	13310000	u	39.5	2	u
3	ECCLESTON	Official offtake	2812000	1406000	1406000	u	39.5	2	u
4	HOLMES CHAPEL	Official offtake	2339000	1169500	1169500	u	39.5	2	u
5	ICI RUNCORN	Official offtake	1700000	850000	850000	u	39.5	2	u
6	LUPTON	Official offtake	2662000	1331000	1331000	u	39.5	2	u
7	MALPAS	Official offtake	120000	60000	60000	u	39.5	2	u
8	MICKLE TRAFFORD	Official offtake	2880000	1440000	1440000	u	39.5	2	u
9	PARTINGTON	Official offtake	0	0	0	u	39.5	0	u
10	PARTINGTON	Official offtake	0	0	0	u	39.5	0	u
11	PARTINGTON OFFTAKE	Official offtake	10800000	5400000	5400000	u	39.5	2	u
12	SALMESBURY	Official offtake	13310000	6655000	6655000	u	39.5	2	u
13	SHELLSTAR/KEMIRA	Official offtake	1500000	750000	750000	u	39.5	2	u
14	WARBURTON	Official offtake	13500000	6750000	6750000	u	39.5	2	u
15	WESTON POINT	Official offtake	2661000	1330500	1330500	u	39.5	2	u

calorific values, volumes and energies

Daily volume	Site	Description	true ggcv MJ/m^3(st)	true daily energy MJ	true volume m^3(st)	ggcv errors e(ggcv) MJ/m^3(st)	ggcv errors u(e(ggcv)) MJ/m^3(st)	ggcv errors dist	e(volume) m^3(st)
1	AUDLEY NW	Official offtake	39.50	26978500	683000	0	0.1	u	0
2	BLACKROD	Official offtake	39.50	525745000	13310000	0	0.1	u	0
3	ECCLESTON	Official offtake	39.50	55537000	1406000	0	0.1	u	0
4	HOLMES CHAPEL	Official offtake	39.50	46195250	1169500	0	0.1	u	0
5	ICI RUNCORN	Official offtake	39.50	33575000	850000	0	0.1	u	0
6	LUPTON	Official offtake	39.50	52574500	1331000	0	0.1	u	0
7	MALPAS	Official offtake	39.50	2370000	60000	0	0.1	u	0
8	MICKLE TRAFFORD	Official offtake	39.50	56880000	1440000	0	0.1	u	0
9	PARTINGTON	Official offtake	39.50	0	0	0	0.1	u	0
10	PARTINGTON	Official offtake	39.50	0	0	0	0.1	u	0
11	PARTINGTON OFFTAKE	Official offtake	39.50	213300000	5400000	0	0.1	u	0
12	SALMESBURY	Official offtake	39.50	262872500	6655000	0	0.1	u	0
13	SHELLSTAR/KEMIRA	Official offtake	39.50	29625000	750000	0	0.1	u	0
14	WARBURTON	Official offtake	39.50	266625000	6750000	0	0.1	u	0
15	WESTON POINT	Official offtake	39.50	52554750	1330500	0	0.1	u	0

		true	measured	MC error	offset	base error		u(error)	
LDZ daily energy	MJ	1624832500	1624832500	1000000000	1000000000	0	0.00%	4734416.25	0.29%
LDZ daily volume	m3(st)	41135000	41135000	20000000	2.00E+07	0	0.00%	116043.889	0.28%
FWACV	MJ/m3(st)	39.50	39.50	40	40	0	0.00%	0.02743977	0.07%

Figure 2: Breakdown of variance in energy bill