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Executive Summary

In January 2014, Ofgem engaged the technical support of Dave Lander Consulting Ltd with the aim of addressing two key aspects of consumer metering:

a) Improving the understanding of the accuracy of determination of thermal energy within the Gas (Calculation of Thermal Energy) Regulations (GCOTE, "the Regulations") and the impact domestic gas consumers.
b) Assessing the consumer impact of a relaxation of the accuracy of Calorific Value Determination Devices (CVDDs) that are used to determine the calorific value (CV) of biomethane injected into gas distribution systems.

Two studies were carried out. The first study aimed to establish the accuracy of the volume conversion factor employed in the Regulations, whether this value is appropriate to ensure overall energy cost is recovered, and the degree to which consumers are under- or over-billed.Mean error in energy determination was estimated at three levels of granularity: for GB as a whole, for each charging area (LDZ) and for each of 2564 UK postal outcodes.

The second study aimed to establish how the accuracy of CVDDs affects the accuracy of the billing CV and the impact of any relaxation of such accuracy on consumers' bills.

For both studies impacts were estimated for a single year and, because of constraints regarding availability of data, the particular year chosen was 2011.

Conclusions

Accuracy of consumer billing

1) For GB as a whole mean error in annual energy during 2011 is estimated to be

   -0.238% ±0.019%

   Note: unless specified otherwise in this report, uncertainty is expressed as an expanded uncertainty with an associated probability of around 95%. In the example above, therefore there is a 95% probability that the mean error in annual energy lies between -0.257% and -0.219%.

2) For GB as a whole, the mean error in daily energy during 2011 is estimated to be

   +0.6% ±3.6%

   The uncertainty of ±3.6% represents largely the variation in geographical and meteorological factors seen across GB.The reduction in mean error in daily energy compared with mean error in annual energy arises because individual daily errors tend to be negative during autumn/winter (when gas consumption is higher) and positive during spring summer (when gas consumption is lower). The reduction in uncertainty arises because the seasonal variation is removed.

3) Use of a single fixed factor necessarily results in under-billing and over-billing of groups of consumers. At the outcode level, under-/over-billing in 2011 is estimated to vary from

   -1.569% ±0.021% (for PE11) to +2.477% ±0.016% (for BD6).

Assuming an average gas bill of £750 p.a., the extremes in this range are equivalent to under-billing of £11.77 p.a. and over-billing of £18.58 p.a. For most consumers error in annual bill falls between these two extremes.

4) Use of an alternative single fixed volume conversion factor would have corrected the mean error, but at the expense of increased over-billing (and decreased under-billing) of some consumers.
5) Use of volume conversion factors specific to individual LDZs would have reduced the width of the distribution of errors in annual outcode energy, but largely by reducing the degree of under-billing. Over-billing would have remained largely unchanged.
6) Use of volume conversion factors incorporating mean height at each outcode would reduce the width of the distribution of errors in annual outcode energy.

Accuracy of biomethane Calorific Value Determination Devices

1) Expanded uncertainty of daily charging area CV is conservatively estimated to be currently around ±0.08 MJ/m^3, or 0.2%.
2) The contribution of biomethane CV determination accuracy on the future accuracy of billing CV depends on the size of the biomethane injection site; the number of biomethane injection sites and the CV of the biomethane (compared with the FWACV[1]).
3) The following values of Maximum Permissible Error (MPE) for biomethane CVDDs are suggested:

   For site flows of up to 100,000 m^3/day an appropriate MPE for biomethane CVDD is ± 1.0 MJ/m^3.

   For site flows of up to 250,000 m^3/day an appropriate MPE for biomethane CVDD is ± 0.7 MJ/m^3.

   The impact of use of these values on uncertainty in error in annual energy is expected to be negligible. The impact in terms of application of CV capping[2] is expected to be small.

4) Although the above thresholds have been developed for biomethane, they could be applicable to any low-volume injection site, injecting either conventional or non-conventional gases.

[1] Most consumers are billed on the basis of the average CV of gas delivered into a charging area over a specified charging period. This charging area CV is calculated by averaging the each daily charging area CV over each day of the charging period. Each daily charging area CV is calculated by averaging the CV of each gas supplied to the charging area, weighted by the proportion of total daily gas flow represented by each individual gas supply. This daily charging area CV is called the Flow-Weighted Average CV, or FWACV.
[2] The Regulations cap the value of the daily charging area CV to no more than 1 MJ/m^3 greater the lowest daily average CV for each gas supplied to the charging area on each gas day.

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Introduction

In January 2014, Ofgem engaged the technical support of Dave Lander Consulting Ltd with the aim of addressing two key aspects of consumer metering:

a) Improving the understanding of the accuracy of determination of thermal energy within the Gas (Calculation of Thermal Energy) Regulations ("the Regulations") and the impact domestic gas consumers.
b) Assessing the consumer impact of a relaxation of the accuracy of CV determination devices (CVDDs) that are used to determine the calorific value[3] of biomethane injected into gas distribution systems.

The two aspects are clearly linked; estimating the impact of relaxation in accuracy of energy determination requires quantification of the accuracy under the current arrangements.

The study carried out builds on previous work carried out in two previous studies:

a) The activities of CEN TC 234 Working Group 5 “Energy Determination”, which is developing a European standard covering the determination of energy in a number of applications, including domestic, commercial and industrial metering, custody transfer metering and gas sales metering. WG5 in turn has sought to utilise principles developed by a Marcogaz Expert Group (“Energy Determination”) and work reported by the International Organisation of Legal Metrology (OIML) on gas metering.
b) The activities of the UK Energy Market Issues for Biomethane Group (EMIB). EMIB was instigated by Ofgem in late 2011 under the stewardship of the Joint Office of Gas Transporters with the aim of addressing any remaining technical and commercial barriers perceived for the injection of biomethane into gas distribution and transmission systems.

Overview of Domestic energy billing in Great Britain

The following is a simplified explanation of domestic energy billing in Great Britain. Appendix A provides a more detailed description.

Consumers are billed on the amount of energy that they use and energy consumption is determined by estimating the quantity of gas metered at the premises and multiplying this by its calorific value (CV).

The volume of a given amount of gas varies with temperature and with pressure and so the quantity of gas is, by convention, expressed as the volume that it would have occupied at a reference temperature and pressure. For GB these “reference conditions” are 15°C and 1013.25 mbar. For the majority of domestic and commercial gas consumers, converting actual metered gas volume to a volume at GB reference conditions is achieved by multiplication by a Volume Conversion Factor (VCF). The value of the VCF is prescribed in the Regulations as a fixed factor, equal to 1.02264. This value was chosen based on estimates of the average temperature and pressure of gas throughout the year so that the overall cost of energy is recovered. Most consumers’ meters will experience different average temperature and pressures from those assumed for the UK as a whole. Some consumers will be under-billed (through experiencing colder temperatures and/or higher pressures

[3] Calorific value of natural gas is the heat emitted when a unit quantity is burnt under agreed reference conditions. In the UK volumetric calorific values are employed, i.e. the CV is the heat emitted when one cubic meter of gas is burnt. See ISO 6976:1995 for a more complete discussion of calorific values of natural gases.

on average) whilst others will be over-billed (through experiencing higher temperatures and/or lower pressures on average).

The first study therefore aims to establish the accuracy of the VCF and in particular whether this value is appropriate to ensure overall energy cost is recovered, and establishing the degree to which consumers are under- or over-billed. For clarity, this study is called the Accuracy of Consumer Billing study.

The calorific value is determined each day, for all consumers in each of 13 charging areas (or Local Distribution Zones – LDZs) and the consumer is billed on the average of each daily charging area CV within a charging period (typically quarterly for domestic consumers). Daily charging area CV is in turn calculated from the CV of all gas flows into each charging area. The CV determinations are made each day by the four Gas Distribution Networks using CVDDs and so the accuracy of the gross CV used to calculate consumers' energy bill (the Billing CV) will depend on the accuracy of the CVDDs employed.

The second study therefore aims to establish the impact of a relaxation in the accuracy of CVDDs used to determine the CV of biomethane supplies injected into gas distribution systems upon theaccuracy of the Billing CV. For clarity, this study is called the Accuracy of biomethane CVDDs study.

Part 1 - Accuracy of Consumer Billing study

General Approach

A mathematical model of consumer billing was developed. This model is based on models used earlier to support the EMIB investigations and the work of CEN TC 234 WG5 that examine the sources of error and uncertainty in all of the inputs that make up the consumer's gas bill. However, whereas previous models were developed for GB as a whole and in the long-term, the model for this study was expanded by adopting much finer levels of granularity (i.e. the size of the group of consumers examined). The finest level of granularity chosen was the UK outcode[4].

The model estimates the error in the energy determined for a group of consumers on each day of 2011. Three groups of consumers are considered: GB as a whole, the 13 charging areas (LDZs) and the 2564 outcodes assessed in this study. Information on number of consumers (strictly-speaking numbers of Meter Point Reference Numbers or MPRNs) was provided by Xoserve.

Error in determined energy is defined here as the daily energy estimated for each outcode based on an assumed actual daily gas volume, corrected using the VCF prescribed in the Regulations, minus the energy estimated for each outcode using a VCF calculated for the daily average gas temperature and pressure for that outcode, i.e.

$$E(daily\ outcode\ energy) = Daily\ outcode\ energy\ (VCF = 1.02264) - Daily\ outcode\ energy\ (VCF\ calculated\ from\ T, P)$$

Where $E(daily\ outcode\ energy)$ is the error in the daily energy calculated for each outcode.

The basic output from the model is therefore 365 estimates of error in daily outcode energy for each of 2564 outcodes. The uncertainty of each estimate in error was also estimated in accordance with the Guide to the Expression of Uncertainty in Measurement[5].

Details of the Consumer Billing Model are provided in Appendix B.

An overview of the results of the Consumer Billing Study is provided in the following sections. Appendix C provides more detailed results from the modelling study.

Consumer billing at the GB level of granularity

For GB as a whole, the mean relative error in daily billed energy during 2011 is estimated to be

+0.6% ± 3.6%

The maximum and minimum errors in GB daily energy are shown in Table 1, below.

Table 1: Maximum and minimum error in GB daily energy

Group	minimum E(GB daily energy)	maximum E(GB daily energy)
GB	-5.57%	+4.71

[4] The UK postcode is hierarchical; the top level being postcode area and comprises 1 or 2 alpha characters, e.g. "GU" or "B". The next level is postcode district, e.g. "GU1" or "B77" and is commonly known as the "outcode".
[5] Joint Committee for Guides in Metrology. JCGM 100 – Evaluation of measurement data – Guide to the expression of uncertainty in measurement

Figure 1 illustrates how error in daily energy and energy consumption varied throughout the year. During the winter months (when energy consumption is greater), error in GB daily energy was negative, whereas during the summer months (when energy consumption is lower), error in GB daily energy was positive.

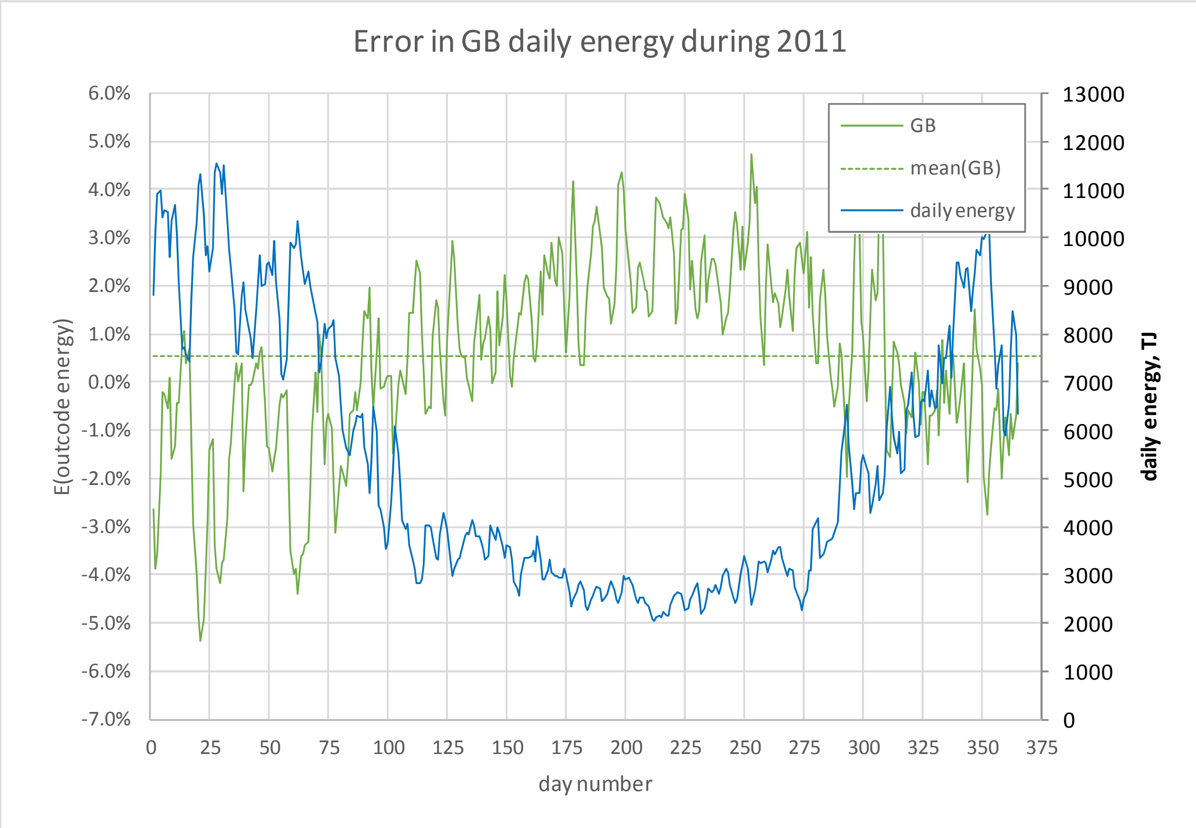

Figure 1: Error in GB daily energy during 2011

Seasonal variation in daily energy, associated with variation in temperature and barometric pressure, can be removed by considering annual energy, rather that daily energy.

For GB as a whole, the relative error in annual energy in 2011 is estimated to be

-0.238% ±0.019%

The error is smaller and negative than the mean daily energy because, in effect, the errors in daily energy during autumn/winter are given greater weighting (i.e. more energy is consumed) than those during spring/summer.

The uncertainty in error in annual energy is less than that for daily energy because the variance associated with seasonal variation in temperature and pressure is removed (negative errors in daily energy during autumn/winter are offset by positive errors in spring summer).

Consumer billing at the LDZ level of granularity

Table 2 summarises the annual LDZ energy, error in annual LDZ energy and uncertainty in error in annual LDZ energy for each LDZ.

Error in annual LDZ energy varied from -0.916% ±0.020% (for East Anglia LDZ) to +0.554% ±0.017% (for North Thames LDZ).

Table 2: Annual energy, error in annual energy and uncertainty in annual energy for GB and each LDZ

Group	energy TJ/y	E(energy) TJ/y	u(E(energy)) TJ/y	E(energy) %	u(E(energy)) %	U(E(energy)) %
GB	1949647.82	-4649.37	180.14	-0.238%	0.0092%	0.019
EA	146325.56	-1340.94	14.65	-0.916%	0.0100%	0.020
EM	209456.78	+873.10	18.90	+0.417%	0.0090%	0.018
NE	132824.24	+35.82	11.81	+0.027%	0.0089%	0.016
NO	122030.71	-859.01	11.22	-0.704%	0.0092%	0.018
NT	192524.32	+1067.21	17.01	+0.554%	0.0088%	0.018
NW	225447.73	-1158.34	21.25	-0.514%	0.0094%	0.019
SC	185894.52	-1322.03	16.21	-0.711%	0.0087%	0.017
SE	212684.32	-1432.11	20.98	-0.673%	0.0099%	0.020
SO	135247.54	-732.85	12.97	-0.542%	0.0096%	0.019
SW	99712.12	-310.26	9.48	-0.311%	0.0095%	0.019
WM	157773.44	+245.89	14.26	+0.156%	0.0090%	0.018
WN	23586.82	-148.20	2.18	-0.628%	0.0093%	0.019
WS	106139.73	+432.37	9.23	+0.407%	0.0087%	0.017

Note: expanded uncertainty in error in energy, U(E(energy)), is calculated using a coverage factor of k=2 and rounded to two significant figures.

Consumer billing at the outcode level of granularity

It is not practical to list error in annual outcode energy for each 2564 outcodes, so error is presented below for the two outcodes with the largest (most positive) and smallest (most negative) error in annual energy.

Error in annual outcode energy in 2011 varied from

-1.569% ±0.021% (for PE11)to+2.477% ±0.016% (for BD6).

Outcode PE11 contains 13124 MPRNs and outcode BD6 contains 10796 MPRNs. These correspond to 0.06% and 0.05% of total MPRNs, respectively.

Figure 2 shows the distribution oferrors in annual outcode energy for each outcode in terms of numbers of MPRNs within each outcode as a proportion of the total number of MPRNs.

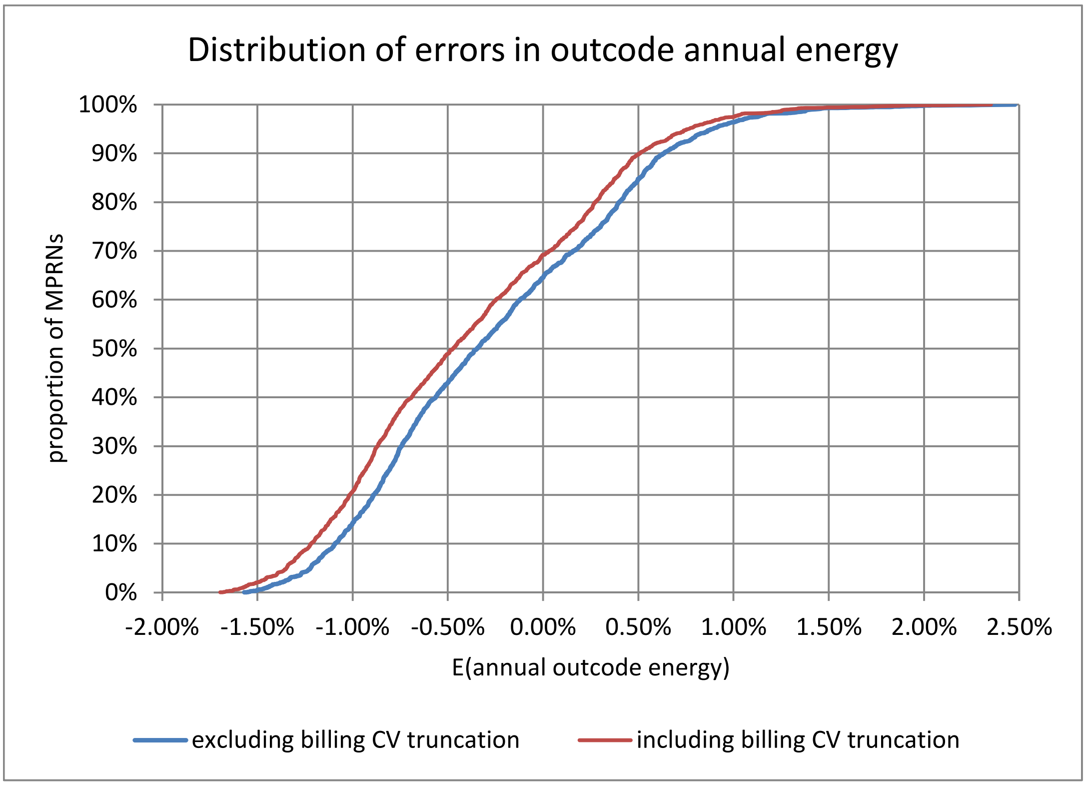

Figure 2: Cumulative distribution of errors in annual outcode energy

Two curves are shown. The blue curve shows the distribution of annual outcode energies arising solely from errors in the volume conversion factor. Consumers are billed using a charging period CV, which the Regulations require to be the arithmetic average of all daily charging area CVs for that charging period, truncated to one decimal place. In the long term this means that the consumer is under-billed by around 0.05 MJ/m^3, or about 0.126% (assuming an average CV of 39.5 MJ/m^3). The red curve shows the distribution of annual outcode energies arising from error in volume conversion factor and from billing CV truncation.

Notable points from the above distribution (excluding billing CV truncation):

- 80% of errors in outcode annual energy lie between -1.09% and +0.63%
- 90% of errors in outcode annual energy lie between -1.22% and +0.89%
- 95% of errors in outcode annual energy lie between -1.35% and +1.12%

Notable points from the above distribution (including billing CV truncation):

- 80% of errors in outcode annual energy lie between -1.22% and +0.51%
- 90% of errors in outcode annual energy lie between -1.35% and +0.76%
- 95% of errors in outcode annual energy lie between -1.48% and +1.00%

An estimate of the average cost of associated with such errors can be made by simply multiplying error by theaverage domestic gas bill. Figure 3 shows the distribution of cost equivalence of errors in annual outcode energy, assuming an annual energy bill of £750 per annum.

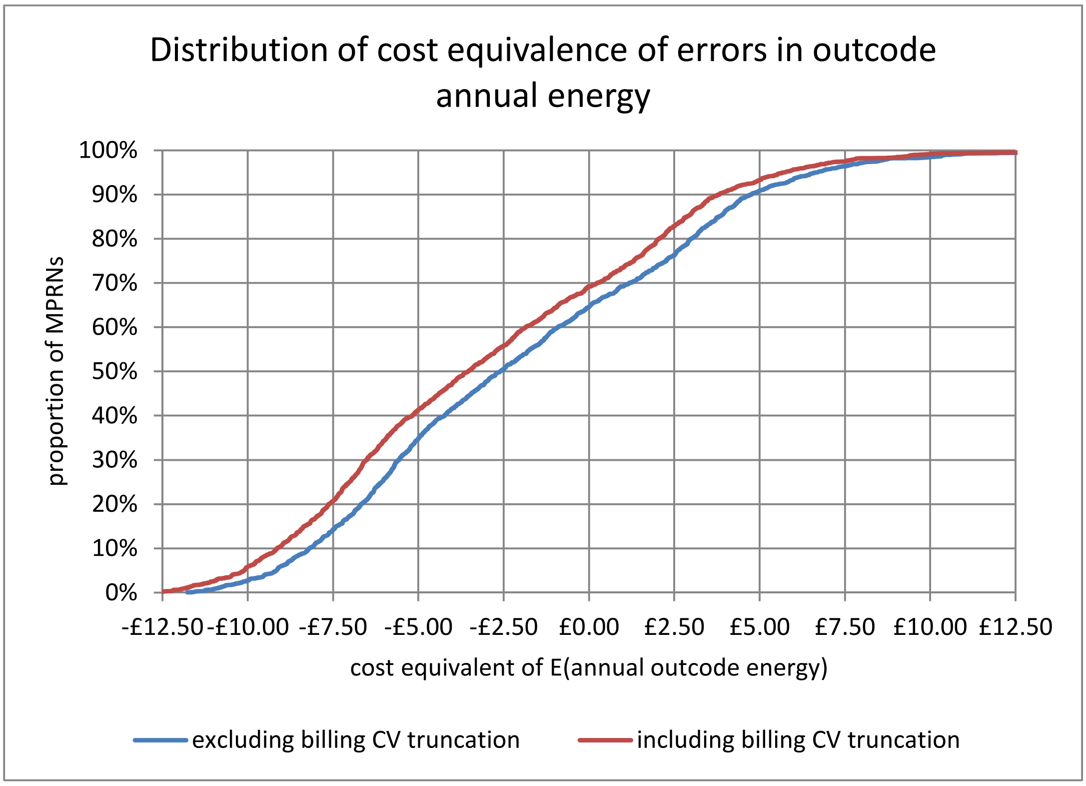

Figure 3: Cumulative distribution of costs associated with errors in annual outcode energy

Notable points from the above distribution (excluding billing CV truncation):

- 80% of cost of errors in outcode annual energy lie between -£8.19 and +£4.74
- 90% of cost of errors in outcode annual energy lie between -£9.16 and +£6.65
- 95% of cost of errors in outcode annual energy lie between -£10.12 and +£8.43

Notable points from the above distribution (including billing CV truncation):

- 80% of cost of errors in outcode annual energy lie between -£9.14 and +£3.80
- 90% of cost of errors in outcode annual energy lie between -£10.11 and +£5.71
- 95% of cost of errors in outcode annual energy lie between -£11.07 and +£7.48

Use of an alternative GB volume conversion factor

Use of a single fixed volume conversion factor will always result in under-billing and over-billing of consumers, since gas pressure and temperature vary across consumers, depending upon geographical, environmental and installation differences. The mean error in Annual GB energy for the existing factor was estimated to be -0.238% (i.e. a net under-billing of 0.238%). This error could be minimised by adjusting the value of the volume conversion factor. For instance, a value of 1.025085 would reduce the mean error to +0.000045%. Whilst changing the value of the VCF would correct the net under-billing, a relatively wide range in errors of outcode annual energy would still remain:

PE11 still has the smallest error in annual outcode energy at -1.334% ±0.021%

BD6 still has the largest error in annual outcode energy at +2.722% ±0.016%

So consumers in PE11 would be under-billed on average by around £10.00 p.a. (compared with £11.77 p.a.) and those in BD6 would be over-billed by around £20.42 (compared with £18.58 p.a.).

Use of LDZ-specific volume conversion factors

In principle, use of volume conversion factors specific to each LDZ offers scope for reducing the level of under and over-billing, since their smaller geographical areas offer potential for less geographical and environmental variation amongst consumers.

Using LDZ-specific volume conversion factors results in the distribution of errors in annual outcode energy shown in Figure 4 (excluding errors from billing CV truncation):

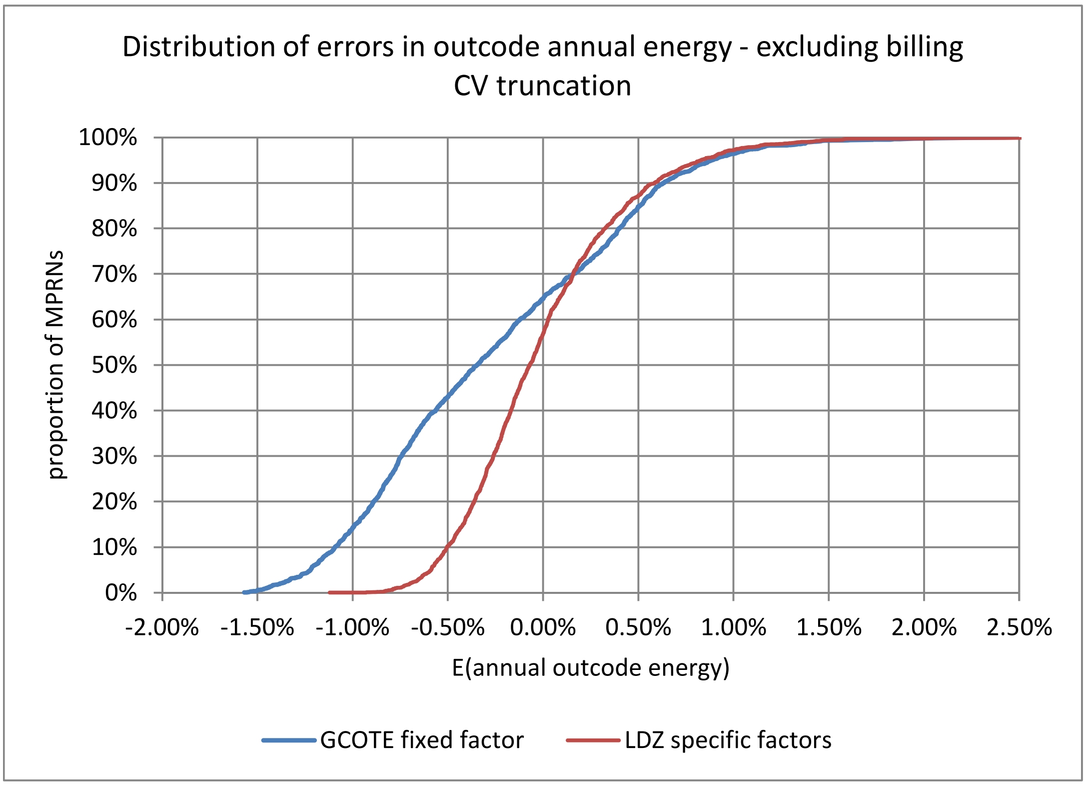

Figure 4Cumulative distribution of errors in outcode annual energy using LDZ-specific volume conversion factors compared with that seen using the existing factor in the Regulations.

The use of LDZ-specific volume conversion factors reduces the range of errors in outcode annual energy: -1.120% to +2.647% using LDZ-specific factors, compared with -1.569% to +2.477% using the existing factor in the Regulations. The cost equivalent to this range is -£8.40 to +£19.85 using location-specific factors, compared with -£11.77 to +£18.58 using the existing factor in the Regulations. Almost all of the reduction in range is seen as reduced under-billing; over-billing is slightly worsened at the extreme (although outcodes at the extremes are different). The error in annual GB energy is almost entirely reduced (-0.0017%, compared to -0.238%).

Use of location-specific volume conversion factors

One component of the VCF currently employed within the Regulations is the assumption about height of meter above sea level and in principle this could be separated out from the current fixed factor and pressure corrected for each MPRN from a knowledge of height at the meter location. In order to estimate the impact of a location-specific adjustment for height above sea level, the height for all outcodes was set to 67.5m – the height that (in combination with the altitude correction factor) is assumed in the factor employed in the Regulations. This effectively removes the errors associated with actual height, compared with the average height assumed in the Regulations.

Using such location-specific volume conversion factors results in the distribution of errors in annual outcode energy shown in Figure 5 (excluding errors from billing CV truncation):

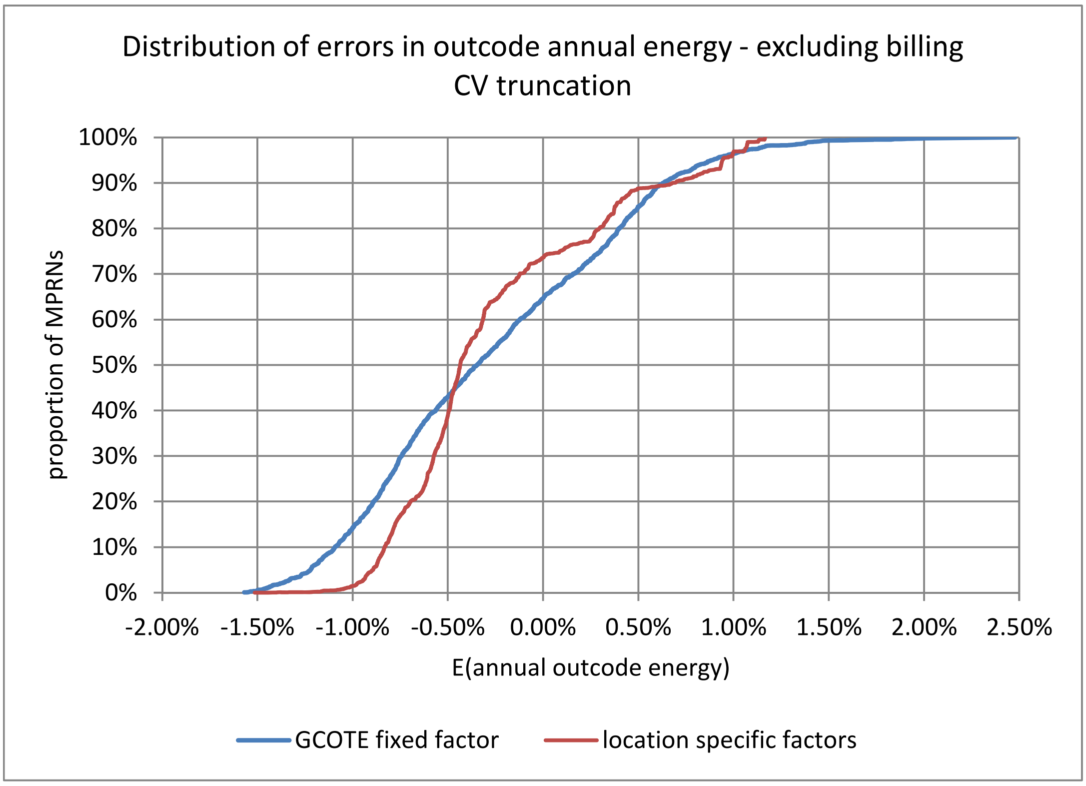

Figure 5Cumulative distribution of errors in outcode annual energy using location-specific volume conversion factors compared with that seen using the existing factor in the Regulations.

The use of location-specific volume conversion factors reduces the range of errors in outcode annual energy: -1.514% to +1.166% using location-specific factors, compared with -1.569% to +2.477% using the existing factor in the Regulations. The cost equivalent to this range is-£11.36 to +£8.74 using location-specific factors, compared with -£11.77 to +£18.58 using the existing factor in the Regulations.Again, outcodes at the extremes are different from those using the existing factor. The error in annual GB energy remains largely unchanged, however (-0.239%, compared to -0.238%).

Main Conclusions from Consumer Billing Study

1) For GB as a whole mean error in annual energy during 2011 is estimated to be

-0.238% ±0.019%

2) For GB as a whole, the mean error in daily energy during 2011 is estimated to be

+0.6% ±3.6%

The uncertainty of ±3.6% represents largely the variation in geographical and meteorological factors seen across GB. The reduction in mean error in daily energy compared with mean error in annual energy arises because individual daily errors tend to be negative during autumn/winter (when gas consumption is higher) and positive during spring summer (when gas consumption is lower). The reduction in uncertainty arises because the seasonal variation is removed.

3) Use of a single fixed factor necessarily results in under-billing and over-billing of groups of consumers. At the outcode level, under-/over-billing in 2011 is estimated to vary from

-1.569% ±0.021% (for PE11) to +2.477% ±0.016% (for BD6).

Assuming an average gas bill of £750 p.a., the extremes in this range are is equivalent to under-billing of £11.77 p.a. and over-billing of £18.58 p.a. For most consumers error in annual bill falls between these two extremes.

4) Use of an alternative single fixed volume conversion factor would have corrected the mean error, but at the expense of increased over-billing (and decreased under-billing) of some consumers.
5) Use of volume conversion factors specific to individual LDZs would have reduced the width of the distribution of errors in annual outcode energy, but largely by reducing the degree of under-billing. Over-billing would have remained largely unchanged.
6) Use of volume conversion factors incorporating mean height at each outcode would reduce the width of the distribution of errors in annual outcode energy.

Part 2 - Accuracy of Biomethane CVDDs CV study

General approach

An analytical model was developed that allows estimation of the uncertainty in the daily charging area CV.

The daily charging area CV that is used to calculate the average billing CV for the charging period is measured from determinations of CV made by the Gas Distribution Networks under direction of Ofgem. The Regulations require that daily charging area CV for a charging area is calculated from the net energy flow into the charging area (the "LDZ energy") divided by the net volume flowing into the charging area on that day (the "LDZ volume"). This can be expressed by the following equation:

$$F = \frac{\sum_{i=1}^{i=N}(V_i C_i)}{\sum_{i=1}^{i=N}(V_i)}$$

Application of the Guide to the expression of Uncertainty in Measurement (GUM[6]) leads to the following expression for the standard uncertainty in the FWACV:

$$u(F) = \sqrt{\sum_{i=1}^{i=N}\left[u^2(V_i)\cdot\left(\frac{C_i - F}{LDZV}\right)^2 + u^2(C_i)\cdot\left(\frac{V_i}{LDZV}\right)^2\right]}$$

Where:

F is the FWACV and *u(F)* its standard uncertainty;

V_i is the daily volume of the *i*th of *N* daily flows into (V_i positive) or out (V_i negative) of the charging area and $u(V_i)$ its standard uncertainty; and

C_i is the daily average CV of the *i*th of the *N* daily flows and $u(C_i)$ its standard uncertainty; and

LDZV is the daily volume of gas flowing into the charging area (i.e. the sum of allV_i).

The derivation of this equation is provided in Appendix D.

Note that the second and fourth terms in the above equation have important consequences for injection of biomethane flows into an LDZ:

- Enrichment of biomethane to a CV close to the FWACV results in a reduced contribution of the uncertainty in biomethane CV and uncertainty in biomethane volume to the uncertainty in FWACV. In fact if the CV is equal to the FWACV, (Ci – F) becomes zero and the accuracy of biomethane volume measurement has no impact on uncertainty in FWACV.
- The contribution of variance in biomethane CV to the variance in FWACV is directly proportional to the biomethane daily volume as a fraction of LDZ volume. The contribution of accuracy of CV measurement to the accuracy of FWACV is therefore less at low-volume sites. In principle therefore there is scope for reduction in accuracy in CVDDs for biomethane (or indeed low-volume inputs of any gas, conventional or unconventional) without material impact on accuracy of FWACV.

[6]Joint Committee for Guides in Metrology. JCGM 100 – Evaluation of measurement data – Guide to the expression of uncertainty in measurement

The above equations for *F* and *u(F)* were implemented into an excel spreadsheet in the form of user-defined functions and the F and u(F) determined for each LDZ for each day in 2011 assuming a standard uncertainty in daily volume at each NTS offtake of 1.5% (i.e. an expanded uncertainty of 3% converted to a standard uncertainty using a coverage factor of k=2) and standard uncertainty in daily average CV at each NTS offtake of 0.05 MJ/m^3 (i.e. an expanded uncertainty of 0.1 MJ/m^3 converted to a standard uncertainty using a coverage factor k=2).

Daily average CVs and daily volumes for each NTS offtake for each day in 2011 were acquired from the Shippers and Suppliers Information Service and provided by Ofgem.

To assess the impact of adding biomethane flows on the uncertainty in FWACV the model was re-run with different combinations of site biomethane daily volume and number of biomethane connections, biomethane CV (expressed as a difference from FWACV in the absence of biomethane flow), uncertainty in biomethane daily volume and uncertainty in biomethane CV.

Accuracy of charging area CV calculations

Table 3 below lists the minimum, maximum and mean FWACV, and the standard uncertainties in FWACV, for each LDZ over all days in 2011 under the following assumed base conditions:

- Standard uncertainty in daily volumes at each offtake was taken to be 1.5%. The Regulations require that accuracy of daily volumes shall be *"requisite to the calculation of FWACV"* and legacy NTS offtake metering systems have an "uncertainty" in flow rate of 2% over the range 30% - 100% of maximum flowrate and 3.5% over the range 10% - 30% of maximum flowrate. More recent NTS offtakes are typically designed for 1% "uncertainty". "Uncertainty" in this context is taken to be an expanded uncertainty and so for convenience, expanded uncertainty in daily offtake volume for all sites has been taken conservatively to be 3%, which corresponds to a standard uncertainty of 1.5% assuming a coverage factor of k = 2.
- Standard uncertainty in daily average CV was taken to be ±0.058 MJ/m^3, which corresponds to a maximum permissible error (MPE) of ±1.0 MJ/m^3 and is converted to a standard uncertainty of ±0.05 using a coverage factor of k = √3. The MPE criterion of ±0.1 MJ/m3 is, strictly speaking, applicable for individual measurements of CV and the daily average CV is typically the average of more than 300 measurements throughout the gas day, so the true uncertainty in daily average CV – assuming that the individual measurements are not correlated – would be more like ±0.058/√300 =0.003 MJ/m^3, but for the purposes of this study a more conservative value of ±0.058MJ/m^3has been assumed.

  Note: The assignment of accuracy of calorific value determination at NTS offtakes as an expanded uncertainty of 0.1 MJ/m^3 is based on custom and practice developed for performance evaluation of CVDDs according to ISO 10723 prior to and following the coming into force of the Regulations in 1996. Using the terminology in the recently revised ISO 10723, CVDDs currently approved by Ofgem generally comply with a Maximum Permissible Error (MPE) of ±0.1 MJ/m^3. Formally this can be expressed as:

  $$U\left(\bar{E}(CV)\right) < 0.1\ MJ/m^3$$

  Assuming that expanded uncertainty is based on a probability level of around 95%, this means that error would be expected to exceed 0.1 MJ/m3 in less than 5% of a series of CV determinations over a range of (usually specified) conditions.

  Similarly, relative error in daily volume would be expected to exceed 3% in less than 5% of daily volume measurements. In practice, high-pressure metering installations currently being *installed at new NTS offtakes daily volume measurement might be expected to comply with so-called "fiscal" standards and meet a requirement based on an MPE of ±1%.*

Expanded uncertainty of daily charging area CV determinations for each LDZ is conservatively estimated to be typically around 0.08 MJ/m^3 or around 0.2% (assuming a coverage factor of k=2).

Table 3: Minimum, mean and maximum values of daily FWACV and standard uncertainty in daily FWACV during 2011

	standard uncertainty in NTS offtake volumes			1.5%		
	standard uncertainty in daily average CV at NTS offtakes			0.058MJ/m^3 (MPE± 0.1 MJ/m^3)		
LDZ	FWACV, MJ/m^3			u FWACV, MJ/m^3		
	min	mean	max	min	mean	max
EA	38.67	39.34	39.98	0.022	0.030	0.037
EM	39.02	39.49	39.98	0.020	0.027	0.034
NE	39.06	39.99	40.52	0.022	0.029	0.036
NO	39.28	40.14	40.69	0.019	0.024	0.033
NT	38.94	39.34	39.90	0.025	0.032	0.040
NW	38.09	39.21	40.12	0.021	0.030	0.045
SC	38.88	39.76	40.68	0.022	0.026	0.031
SE	38.76	39.18	39.63	0.023	0.033	0.048
SO	38.90	39.26	39.90	0.023	0.030	0.044
SW	39.03	39.28	39.53	0.016	0.024	0.032
WM	39.00	39.36	39.84	0.018	0.032	0.048
WN	38.20	39.31	40.50	0.050	0.050	0.050
WS	39.00	39.31	39.55	0.030	0.031	0.035

Note that in the Consumer Billing Model (see Part 1) the standard uncertainty in FWACV for each outcode was taken to be the standard uncertainty for the relevant LDZ for that gas day.

Impact of injecting biomethane flows with lower accuracy of CV determination

From inspection of the equation for uncertainty in FWACV, the main variables that affect the impact of biomethane flows on the accuracy of charging area CV are:

- the daily volume for each biomethane site
- the number of biomethane injection points delivering that daily volume
- the difference between the CV of biomethane and the FWACV
- the accuracy of the biomethane CVDDs
- the accuracy of the biomethane daily volume measurements

The impact of biomethane will depend upon future growth of biomethane injection projects and hence how large a contribution biomethane makes to future gas consumption. For this study combinations of biomethane site daily volume and accuracy of biomethane CVDD were determined for each LDZ that resulted in a chosen value of change in accuracy of FWACV. Two levels of change in accuracy of FWACV were chosen:

a) An increase of standard uncertainty in FWACV of 0.05 MJ/m^3, which corresponds to an increase in expanded uncertainty of 0.1 MJ/m^3.
b) An increase of standard uncertainty in FWACV of 0.025 MJ/m^3, which corresponds to an increase in expanded uncertainty of 0.05 MJ/m^3.

Appendix E showsthe determined combinationsfor the above criteria when biomethane is introduced into each LDZ. For all cases, standard uncertainty in biomethane daily volume was conservatively taken to be 1.5%, CV of biomethane was taken to be FWACV less 0.5 MJ/m^3, and the number of biomethane injection points in each LDZ was taken to be either 5 or 10.

Assuming five biomethane injection points per LDZ, and a criterion of u(FWACV) changing by no more than 0.05 MJ/m^3 (i.e. expanded uncertainty changes by no more than 0.1 MJ/m^3) then relaxation of biomethane CVDD accuracy could be accommodated:

For biomethane site flows of up to 100,000 m^3/day an MPE for biomethane CVDD of ± 1.0 MJ/m^3 would be appropriate.

For biomethane site flows of up to 250,000 m^3/day an MPE for biomethane CVDD of ± 0.7 MJ/m^3 would be appropriate.

Note that the above thresholds are based on the most strongly impacted LDZ, which in all cases is WN. This is because of its small size; other larger LDZs are less strongly affected.

For the assumptions above the impact on uncertainty in annual error in energy is insignificant and this is discussed further in Appendix E.For the assumptions above the impact on CV capping is small and this is also discussed further in Appendix E.

One other consequence of reduced biomethane CVDD accuracy is the accuracy at which CV capping is applied. CV capping is discussed in Appendix A and it ensures that the lowest CV of gas entering a charging area on each gas day is no more than 1 MJ/m^3 lower than the daily charging area CV.

It should be noted that the above analysis is not specific to biomethane injection sites and could be applicable to any relatively small-scale injection site, injecting any conventional or non-conventional gas.

Main Conclusions from Accuracy of Billing CV Study

1) Expanded uncertainty of daily charging area CV is conservatively estimated to be currently around ±0.08 MJ/m^3, or 0.2%.
2) The contribution of biomethane CV determination accuracy on the future accuracy of billing CV depends on the size of the biomethane injection site; the number of biomethane injection sites and the CV of the biomethane (compared with the FWACV).
3) The following values of MPE for biomethane CVDDs are suggested:

   For site flows of up to 100,000 m^3/day an appropriate MPE for biomethane CVDD is ± 1.0 MJ/m^3.

   For site flows of up to 250,000 m^3/day an appropriate MPE for biomethane CVDD is ± 0.7 MJ/m^3.

The impact of use of these values on uncertainty in error in annual energy is expected to be negligible.The impact in terms of application of CV capping is expected to be small.

4) Although the above thresholds have been developed for biomethane, they are equally applicable to any low-volume injection site, injecting either conventional or non-conventional gases.

Appendix A –Gas consumer billing in GB

Energy billing of domestic gas consumers is based on the actual volume of gas consumed, converted to a volume at reference conditions of temperature and pressure. The resultant *quantity*[7] of gas is then converted to energy by multiplying it by a calorific value (CV) that is *representative* of that received by consumers in a given charging area. Generally, the billing CV applied by gas suppliers is the average of daily values determined by the Gas Transporter 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 the 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 "Declared CV", "lowest source CV" or "flow weighted average CV " approaches. Flow Weighted Average Calorific Value (FWACV) has been the method of choice by the then Transco, and now the four Gas Distribution Networks (GDNs)[8], since the amendment to the Regulations in 1997 which permitted its use.

The Regulations cap the value of the daily charging area CV to no more than 1 MJ/m^3 greater the lowest daily average CV for each gas supplied to the charging area on each gas day. Such "CV capping" ensures that consumers are billed on the basis of daily charging CVs that are no greater than 1 MJ/m^3 more than that actually received.

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 GDNs 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:

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[7] 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.

[8] The GDNs are National Grid, Scotia Gas Networks, Wales & West Utilities and Northern Gas Networks.

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 computing power, Monte Carlo (MC) methods have been used to determine error for a large (typically tens of thousands) set of hypothetical compositions. This probabilistic 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. Indeed the MC methods employed in the UK have now been incorporated in a revision of the ISO standard 107323, which covers the determination of the performance of process instruments for determination of composition of natural gas and associated properties.

The criterion of Maximum Permissible Error of ± 0.1 MJ/m^3 is historical and dictated by CVDD performance, rather than any notion of fairness to, or impact on, the domestic consumer for whom the 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 – MPR071[9] – set out a methodology for assessing and quantifying its impact.

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

Appendix B – Details of Consumer Billing Model

Model structure

Daily energy consumed at a given premises can be described by the following equation:

$$daily\ energy = V_{actual} \times VCF \times ECF$$

V_{actual} is the daily volume recorded by the meter at actual conditions of temperature and pressure.

VCF is the volume conversion factor, which converts the volume at actual temperature *T* and pressure *P* to the volume at UK reference conditions of 288.15 K (T_b) and 1013.25 mbar (P_b). VCF is given by:

$$VCF = \frac{P}{P_b} \times \frac{T_b}{T} \times \frac{Z_b}{Z}$$

Z_b and *Z* are the compression factors of the natural gas at UK reference conditions T_b andP_b, and actual metering conditions *T* and *P*, respectively.

The three terms on the RHS of the above equation are the pressure conversion factor (PCF), the Temperature conversion factor (TCV) and the compression factor conversion factor (ZCF).

The metering pressure *P* is controlled by a metering pressure regulator set to a gauge pressure of 21 mbar and so can be calculated as:

$$P = P_{meter} + P_{barom} + (A \times ACF)$$

Where P_{meter} is the gauge pressure at the meter = 21 mbar and *ACF* is the altitude conversion factor, which corrects the prevailing barometric pressure P_{barom}(given at mean sea level) to the pressure at altitude *A*.

The metering temperature T is estimated as the prevailing air temperature *Tair* plus a correction T_{corr}

$$T = T_{air} + T_{corr}$$

ECF is the energy conversion factor, which converts the daily volume of gas at reference conditions to the daily quantity of energy. Numerically the *ECF* is the charging area billing CV and on most gas days is computed for the charging area as the flow-weighted average CV (FWACV). The Regulations require that the billing CV cannot be more than 1MJ/m^3 greater than the lowest daily average CV of gases flowing into the charging area and in such circumstances the billing CV is computed as the lowest daily average CV plus 1 MJ/m^3.

The consumer billing model essentially implements the above equations at three levels of granularity:

- for GB as a whole, i.e. one single group of consumers
- for the current charging areas or LDZs, i.e. twelve groups of consumers
- for the GB outcode level, i.e. as 2564 groups[10] of consumers sharing the same outcode.

The billing model provides the best estimate of energy consumed within each outcode on any particular day. Also determined by the model is the amount of energy for which the group of

[10] Although there are more than 2564 outcodes, for some there are no gas consumers, so the actual number of groups of consumers is less.

consumers within each outcode would have been billed using the VCF prescribed in the Regulations. For the purposes of this study the error in the daily energy for that group is defined as billed energy minus the actual value (i.e. the best estimate referred to above):

E(daily energy) = daily energy (billed) – daily energy (actual)

The model calculates the actual and billed daily energy for a given volume of gas at metering conditions for each outcode on each day of a single year. The year chosen for this study was 2011; this was dictated by the ready availability of input data – principally daily average temperatures from the Met Office. The daily volume of gas for a given outcode at metering conditions was taken to be the LDZ volume at reference conditions multiplied by the proportion of Meter Point Reference Numbers (MPRNs) in the Outcode as a fraction of the number of MPRNs in the relevant LDZ and then back-corrected to the prevailing temperature and pressure for that day using the VCF calculated for that outcode.

The daily energy consumed across all outcodes was checked against the daily energy consumed across all LDZs in order to ensure consistency in the daily outcode energies. Note that apportioning daily consumption across outcodes carries an implicit assumption that seasonal patterns of consumption across each outcode are similar to that of the relevant LDZ.

The standard uncertainty in the error in daily energy was estimated by assigning standard uncertainties in each input to the model and combining each in accordance with methods compliant with the Guide to the Expression of Uncertainty in Measurement (GUM)[11]. Expanded uncertainty in error in daily energy was obtained by multiplication of the standard uncertainty by a coverage factor of k=2, which corresponds to a probability level of about 95%.

Input data sources (and key underlying assumptions)

The daily volume for each outcode at actual conditions of temperature and pressure was estimated to be the daily volume (at UK reference conditions of 15°C and 1013.25 mbar) for the relevant LDZ, multiplied by the number of MPRNs in that outcode as a proportion of the total number of MPRNs, and divided by the volume conversion factor in the Regulations (to convert the volume back to that at actual temperature and pressure). LDZ daily volumes for 2011 were provided by SGS (Ofgem's technical service provider).

> *This assumes that gas use for all outcodes across each LDZ is comparable – i.e. that there is a similar mix of domestic, commercial and industrial consumers in each outcode.*

Unconverted volumetric flowrate using a diaphragm meter may generally be assumed to give zero mean error with a standard uncertainty in mean error of around ±0.75% if compliant with EN1359 (excluding meters compliant with Annex B of EN 1359). Meters were assumed to have been selected to operate between 0.1Qmax and Qmax, and not be maintained and calibrated, so meter drift was assumed to be in accordance with the endurance/in-service requirements of EN1359 (Table2), so u(E(V) = 3/k = ±1.5%, assuming a value of coverage factor k=2.

Volume conversion factor was calculated from estimates of the actual average gas temperature, average gas pressure and average gas compression factor.

Average gas temperature on each day was estimated from ambient daily average air temperature for the relevant outcode. Air temperatures were obtained from the Met Office. Air temperature was

[11] JCGM 100 – Evaluation of measurement data – Guide to the expression of uncertainty in measurement (ISO/IEC Guide 98-3)

converted to gas temperature by addition of a correction that was estimated for each LDZ, based on work carried out in 1998 by BG Technology[12].

> *In practice gas-air temperature difference in each LDZ is not constant and varies according to a large number of factors, such as demand, meter location, meter aspect and this variation was included in the uncertainty estimate.*

Average gas pressure on each day was estimated from meter pressure mean barometric pressure at sea level and mean altitude for each outcode.

Gauge pressure at the meter was assumed to be 21 mbar. Assuming a meter pressure regulator of accuracy class RG10 the variation in meter inlet pressure was taken to be 10% of the gauge pressure or (0.1 x 21)/k = 1.05 mbar, assuming a value of coverage factor k=2.

> *This assumes that there was always sufficient gas pressure at the meter supply point.*

Mean barometric pressure was estimated for each outcode on each day of 2011 from the Northing of each outcode and quadratic interpolation of mean daily barometric pressure data at a variety of GB weather stations for each day of 2011. Barometric pressure data were obtained from Weather Underground.

Average altitude for each outcode was calculated from Ordinance Survey gridded data.

Compression factor was estimated from mean gas composition data for 2011 for GB as a whole. In practice, gas composition varies over time and within each LDZ. However at normal metering pressures the variation is very small and is included in the uncertainty estimate.

Energy conversion factor is taken to be the LDZ Flow Weighted Average CV, which was calculated for each LDZ on day of 2011 from daily volumes and energies provided by SGS.

> *This assumes that no capping of FWACV occurred.*

Annual outcode energies and errors in annual outcode energies were calculated by summing over all days of 2011 for each outcode.

Energies and errors in energies for each LDZ were calculated by summing over the relevant outcodes.Assignment of Outcodes to LDZ was provided by Exoserve.

Value of errors in annual energy is calculated as error x annual energy bill.

> *Annual energy bill was assumed to be £750 per annum.*

Numbers of MPRNs for each outcode were supplied by Xoserve.

[12] BG Technology. Report R 2278. Examination of environmental factors affecting gas metering accuracy. L.M.Wallis (1998)

Appendix C – Results of Consumer Billing Study

Consumer billing model

The model outputs for each outcode on each day of 201:

- the estimated daily outcode energy, the billed daily outcode energy (and hence the error in daily outcode energy)
- the estimated VCF for comparison with the VCF required in the Regulations (i.e. 1.02264).

The resultant distributions in energies, errors in energies and VCFs were then analysed at the desired level of granularity, i.e. GB, LDZ or outcode.

Annual energy, error in annual energy and uncertainty in error in annual energy were also analysed at each level of granularity from their daily values. This enables assessment of how under- and over-billing throughout the year for a particular group of consumers averaged out.

Results from consumer billing modelling

The maximum and minimum errors in daily energy for GB and each LDZ are shown in Table C1:

Table C1: Maximum and minimum error in daily energy for GB and each LDZ

LDZ	minimum E(energy) %	maximum E(energy) %
GB	-5.37%	+4.71%
EA	-5.71%	+4.38%
EM	-5.03%	+5.77%
NE	-5.39%	+5.33%
NO	-5.97%	+4.10%
NT	-4.12%	+5.98%
NW	-5.91%	+4.70%
SC	-5.92%	+4.51%
SE	-5.16%	+4.45%
SO	-5.51%	+4.25%
SW	-5.52%	+4.41%
WM	-5.18%	+5.65%
WN	-6.02%	+3.95%
WS	-5.42%	+4.84%

Error in daily GB energy varies throughout the year owing to variation in environmental factors (temperature, barometric pressure) and geographical factors (height above sea level) and the impact of these can be seen in Figure C1, which shows how error in daily energy, averaged across all outcodes, varies throughout 2011 and how this average error is partitioned between errors in PCF, TCF, ZCF and errors associated with truncation of the fixed factor employed in the Regulations[13]. The dominant sources of error are associated with the PCF and the TCF component of the VCF; non-ideal behaviour of natural gas and truncation of the VCF are less significant. The errors in PCF and that of TCF tend to have opposing signs and hence there is some compensation resulting in reduced overall error in daily average energy.

[13]Truncation of fixed factors in the Regulations occurs twice: the TCV used to calculate the VCF is truncated to 4dp prior to incorporation in the VCF and the final VCF is truncated to 5dp.

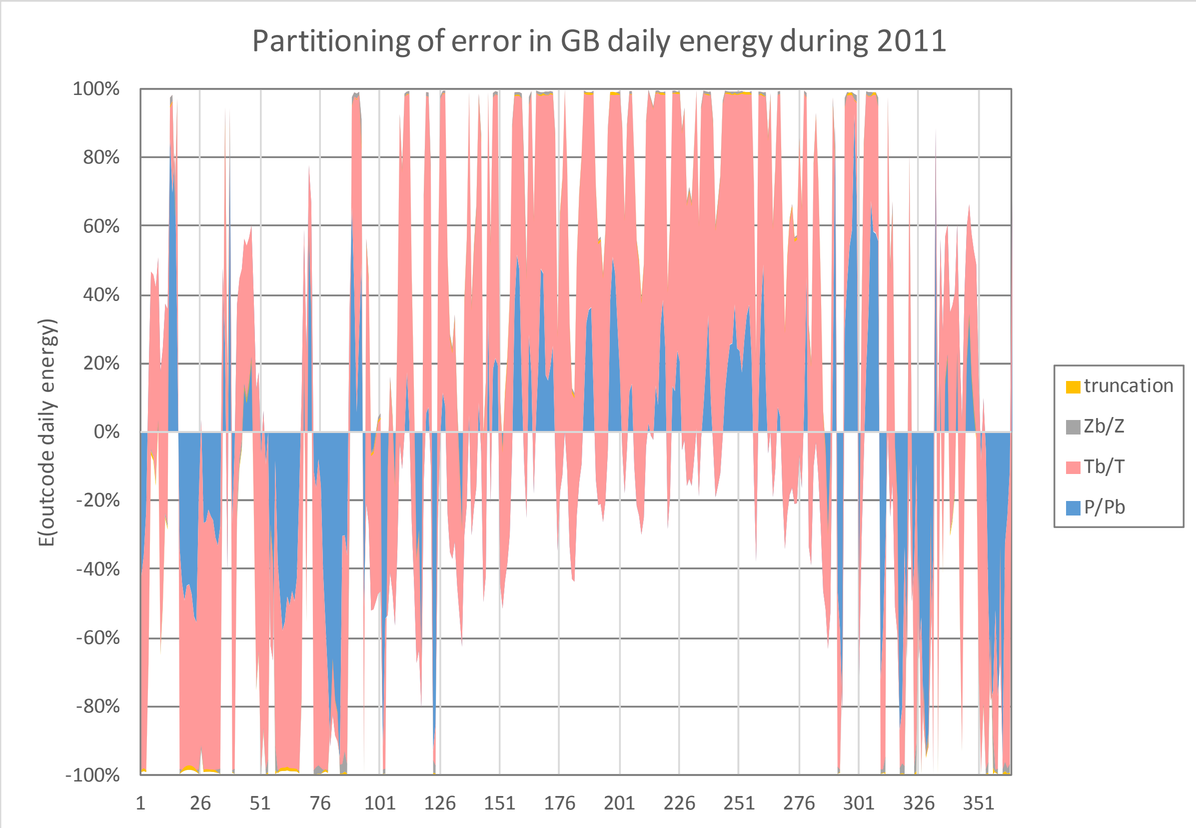

Figure C1: Partitioning of error in GB daily energy during 2011

The maximum and minimum errors in annual energy for GB and each LDZ are shown in Table C2:

Table C2: Annual energy, error in annual energy and uncertainty in annual energy for GB and each LDZ

Group	energy TJ/y	E(energy) TJ/y	u(E(energy)) TJ/y	E(energy) %	u(E(energy)) %	U(E(energy)) %
GB	1949647.82	-4649.37	180.14	-0.238%	0.0092%	0.019
EA	146325.56	-1340.94	14.65	-0.916%	0.0100%	0.020
EM	209456.78	+873.10	18.90	+0.417%	0.0090%	0.018
NE	132824.24	+35.82	11.81	+0.027%	0.0089%	0.016
NO	122030.71	-859.01	11.22	-0.704%	0.0092%	0.018
NT	192524.32	+1067.21	17.01	+0.554%	0.0088%	0.018
NW	225447.73	-1158.34	21.25	-0.514%	0.0094%	0.019
SC	185894.52	-1322.03	16.21	-0.711%	0.0087%	0.017
SE	212684.32	-1432.11	20.98	-0.673%	0.0099%	0.020
SO	135247.54	-732.85	12.97	-0.542%	0.0096%	0.019
SW	99712.12	-310.26	9.48	-0.311%	0.0095%	0.019
WM	157773.44	+245.89	14.26	+0.156%	0.0090%	0.018
WN	23586.82	-148.20	2.18	-0.628%	0.0093%	0.019
WS	106139.73	+432.37	9.23	+0.407%	0.0087%	0.017

Note: expanded uncertainty in error in energy, U(E(energy)), is calculated using a coverage factor of k=2 and rounded to two significant figures.

The maximum and minimum errors in daily energy for two outcodes (PE11 and BD6) are shown in Table C3:

Table C3: Maximum and minimum error in daily energy for outcodes PE11 and BD6

LDZ	minimum E(energy) %	maximum E(energy) %
PE11	-6.91%	+3.95%
BD6	-3.28%	+8.03%

These two outcodes showed the largest (most positive) and smallest (most negative) error in annual outcode billed energy.

Figure C2 illustrates the variation in error in daily outcode energy for PE11 and BD6 during 2011, together with the error in annual outcode billed energy.

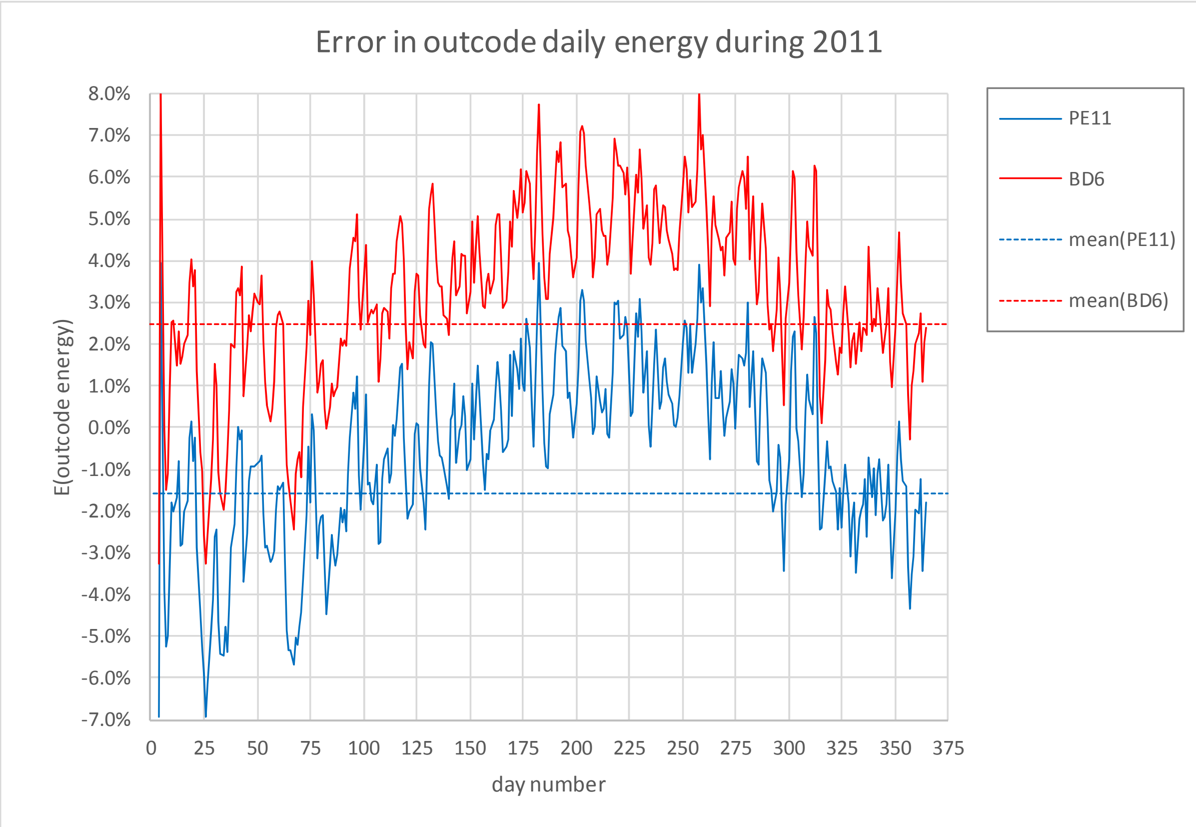

Figure C2: Error in outcode daily energy during 2011 for PE11 and BD6 outcodes

The maximum and minimum errors in annual energy for PE11 and BD6 are shown in Table C4:

Table C4: Annual energy, error in annual energy and uncertainty in annual energy for outcodes PE11 and BD6

Group	energy TJ/y	E(energy) TJ/y	u(E(energy)) TJ/y	E(energy) %	u(E(energy)) %	U(E(energy)) %

PE11	601.86	-9.44	0.06	-1.569%	0.0107%	0.021%
BD6	809.58	+20.05	0.07	+2.477%	0.0083%	0.017%

Note: expanded uncertainty in error in energy, U(E(energy)), is calculated using a coverage factor of k=2 and rounded to two significant figures.

Table C5 shows annual energy, error in annual energy and uncertainty in annual energy for GB using a single revised volume conversion factor, and for GB and each LDZ using LDZ-specific volume conversion factors. The LDZ-specific VCF was calculated as

$$VCF_{LDZ} = 1.02264 \times \frac{100}{(100 - E(LDZ\ annual\ energy))}$$

and rounded to seven decimal places. E(LDZ annual energy) is the error in annual energy for each LDZ, expressed as a percentage of annual LDZ energy, as reported in Table C2.

Use of LDZ-specific VCFs would correct for the estimated error in annual LDZ energy – absolute error was reduced to less than 0.005%.for all LDZs.

Table C5: Annual energy, error in annual energy and uncertainty in annual energy for GB using a single revised volume conversion factor, and for GB and each LDZ using LDZ-specific volume conversion factors

Group	VCF	energy TJ/y	E(energy) TJ/y	u(E(energy)) TJ/y	E(energy) %	u(E(energy)) %	U(E(energy)) %
GB	1.025085	1949647.82	+0.87	177.09	+0.0000%	0.0091%	0.018
	LDZ	1949647.82	-32.56	176.81	-0.0017%	0.0091%	0.018
EA	1.032136	146325.56	+5.35	13.55	+0.0037%	0.0093%	0.019
EM	1.018363	209456.78	-6.57	19.43	-0.0031%	0.0093%	0.019
NE	1.022333	132824.24	-4.07	11.83	-0.0031%	0.0089%	0.018
NO	1.029849	122030.71	-4.82	10.75	-0.0040%	0.0088%	0.018
NT	1.017046	192524.32	+8.24	17.73	+0.0043%	0.0092%	0.018
NW	1.027882	225447.73	-8.65	20.46	-0.0038%	0.0091%	0.018
SC	1.029953	185894.52	-2.14	15.50	-0.0011%	0.0083%	0.017
SE	1.029538	212684.32	-7.15	19.94	-0.0034%	0.0094%	0.019
SO	1.028192	135247.54	-2.56	12.41	-0.0019%	0.0092%	0.018
SW	1.025820	99712.12	-1.16	9.24	-0.0012%	0.0093%	0.019
WM	1.021006	157773.44	-6.60	14.45	-0.0042%	0.0092%	0.018
WN	1.029123	23586.82	+0.38	2.10	+0.0016%	0.0089%	0.018
WS	1.018464	106139.73	-2.82	9.42	-0.0027%	0.0089%	0.018

Note: expanded uncertainty in error in energy, U(E(energy)), is calculated using a coverage factor of k=2 and rounded to two significant figures.

Table C6 lists the minimum and maximum error in annual outcode billed energy using the LDZ-specific VCFs. Minimum error in annual outcode error varied from -1.12% to -0.53 and maximum error in annual outcode energy varied from +1.35% to +2.65%. The extremes in error in annual outcode energy are reduced, albeit somewhat modestly: the range in error in annual outcode energy across the LDZs varied from around 1.9% to 3.3%, compared with a range of around 4.0% using the existing and alternative VCFs.

Table C6: Maximum and minimum error in annual outcode energy within each LDZ using LDZ-specific volume conversion factors

LDZ	minimum E(energy) %	maximum E(energy) %
EA	-0.65%	+2.52%
EM	-0.85%	+2.03%
NE	-0.83%	+2.03%
NO	-0.75%	+2.58%
NT	-0.53%	+1.35%
NW	-0.82%	+1.46%
SC	-0.83%	+1.82%
SE	-0.64%	+1.30%
SO	-0.57%	+1.60%
SW	-0.69%	+2.65%
WM	-1.12%	+0.89%
WN	-0.93%	+1.39%
WS	-0.84%	+1.58%

One component of the VCF currently employed within the Regulations is the assumption about height of meter above sea level and in principle this could be separated out from the current fixed factor and pressure corrected for each MPRN from a knowledge of height at the meter location. In order to estimate the impact of a location-specific adjustment for height above sea level, the height for all outcodes was set to 67.5m – the height that (in combination with the altitude correction factor) is assumed in the factor employed in the Regulations. This effectively removes the errors associated with actual height, compared with the average height assumed in the Regulations.

Table C7 summarises annual LDZ energy, error in annual LDZ billed energy and uncertainty in annual LDZ billed energy for each LDZ that would be obtained.

Comparing results with those in Table C2, shows that the impact varies for each LDZ.

Table C7: Annual energy, error in annual energy and uncertainty in annual energy for GB and each LDZ, assuming altitude correction for meter location

Group	energy TJ/y	E(energy) TJ/y	u(E(energy)) TJ/y	E(energy) %	u(E(energy)) %	U(E(energy)) %
GB	1949647.82	-4667.23	179.47	-0.239%	0.0092%	0.019
EA	146325.56	-1153.01	14.65	-0.916%	0.0100%	0.020
EM	209456.78	+706.82	18.93	+0.337%	0.0090%	0.018
NE	132824.24	-156.96	11.85	-0.118%	0.0089%	0.016
NO	122030.71	-748.78	11.11	-0.614%	0.0091%	0.018
NT	192524.32	+1793.08	16.57	+0.931%	0.0086%	0.017
NW	225447.73	-1178.78	21.20	-0.523%	0.0094%	0.019
SC	185894.52	-1254.03	16.10	-0.675%	0.0087%	0.017
SE	212684.32	-1000.30	20.61	-0.470%	0.0097%	0.019
SO	135247.54	-526.11	12.78	-0.389%	0.0095%	0.019
SW	99712.12	-313.92	9.42	-0.315%	0.0094%	0.019
WM	157773.44	-787.49	15.01	-0.499%	0.0095%	0.019
WN	23586.82	-168.57	2.17	-0.715%	0.0092%	0.018
WS	106139.73	+120.83	9.24	+0.114%	0.0087%	0.017

Note: expanded uncertainty in error in energy, U(E(energy)), is calculated using a coverage factor of k=2 and rounded to two significant figures.

Appendix D - Analytical solution for uncertainty in LDZ billing cCV

Most consumers in a UK charging area are billed on the basis of daily charging area CVs that are calculated from then net energy flow into the charging area (the "LDZ energy") divided by the net volume flowing into the charging area on that day (the "LDZ volume"). This is equivalent to the weighted average of the daily calorific values of gas flows into and out of the charging area, where the weights are the daily volumes for each flow relative to the LDZ volume. For this reason the daily billing CV is often called the Flow Weighted Average CV (FWACV).

Assuming that all volume flows into and out of each LDZ are measured and the daily CV for each is determined the FWACV can be calculated as:

$$F = \frac{\sum_{i=1}^{i=N}(V_i C_i)}{\sum_{i=1}^{i=N}(V_i)}$$

Where:

F is the FWACV;

V_i is the daily volume of the *ith* of *N* daily flows into or out of the charging area; and

Ci is the daily average CV of the *ith* of the *N* daily flows.

Assuming that the daily volumes and daily average CVs are all uncorrelated, application of the GUM leads to:

$$u^2(F) = \sum_{i=1}^{i=N}\left[u^2(V_i)\left(\frac{\partial F}{\partial V_i}\right)^2 + u^2(C_i)\left(\frac{\partial F}{\partial C_i}\right)^2\right]$$

Where the partial derivatives $\left(\frac{\partial F}{\partial V_i}\right)$and $\left(\frac{\partial F}{\partial C_i}\right)$ are as follows:

$$\left(\frac{\partial F}{\partial V_i}\right) = \frac{C_i - F}{LDZV}$$

$$\left(\frac{\partial F}{\partial C_i}\right) = \frac{V_i}{LDZV}$$

Where *LDZV* is the LDZ volume.

The standard uncertainty in FWACV is therefore given by

$$u(F) = \sqrt{\sum_{i=1}^{i=N} \left[u^2(V_i) \cdot \left(\frac{C_i - F}{LDZV} \right)^2 + u^2(C_i) \cdot \left(\frac{V_i}{LDZV} \right)^2 \right]}$$

Appendix E – Results of impact of CVDD accuracy

The impact of flows of biomethane into each LDZ was assessed at different levels of the main variables that impact on uncertainty in FWACV:

- total biomethane flow, as a proportion of LDZ volume
- number of biomethane injection points per LDZ
- the difference between the daily average CV of biomethane and FWACV
- standard uncertainty in daily average CV of biomethane flows

Standard uncertainty in biomethane daily volume was conservatively taken to be 1.5%.

Table E1 shows the minimum, maximum and mean values of daily FWACV and its standard uncertainty during 2011:

Table E1: Minimum, mean and maximum values of daily FWACV and standard uncertainty in daily FWACV during 2011

	standard uncertainty in NTS offtake volumes			1.5%		
	standard uncertainty in daily average CV at NTS offtakes			$0.058 MJ/m^3$ (MPE± $0.1 MJ/m^3$)		
LDZ	FWACV, MJ/m^3			u FWACV, MJ/m^3		
	min	mean	max	min	mean	max
EA	38.67	39.34	39.98	0.022	0.030	0.037
EM	39.02	39.49	39.98	0.020	0.027	0.034
NE	39.06	39.99	40.52	0.022	0.029	0.036
NO	39.28	40.14	40.69	0.019	0.024	0.033
NT	38.94	39.34	39.90	0.025	0.032	0.040
NW	38.09	39.21	40.12	0.021	0.030	0.045
SC	38.88	39.76	40.68	0.022	0.026	0.031
SE	38.76	39.18	39.63	0.023	0.033	0.048
SO	38.90	39.26	39.90	0.023	0.030	0.044
SW	39.03	39.28	39.53	0.016	0.024	0.032
WM	39.00	39.36	39.84	0.018	0.032	0.048
WN	38.20	39.31	40.50	0.050	0.050	0.050
WS	39.00	39.31	39.55	0.030	0.031	0.035

Tables E2 and E3 show combinations of accuracy of CVDDand daily volume of biomethane injection site that result in amaximum[14]increase in standard uncertainty in FWACV of $0.05 MJ/m^3$. The

[14] Increase in standard uncertainty in FWACV was evaluated for each LDZ for each day in 2011 and combinations refer to the largest increase seen.

combinations in Table E2 assume five biomethane injection sites per LDZ; those in Table E4 assume ten biomethane sites per LDZ.

Table E2: combinations of accuracy of CVDD and daily volume of biomethane injection site that result in a maximum increase in standard uncertainty in FWACV of 0.05 MJ/m^3 (five biomethane sites per LDZ).

number of biomethane sites	5					
BNCV-FWACV, MJ/m^3	-0.5					
target change in u(FWACV), MJ/m^3	0.050					
biomethane daily volume, million m^3	0.250	0.200	0.150	0.100	0.050	0.010
	change in u(FWACV), MJ/m^3					
biomethane daily volume, million m^3	0.250	0.200	0.150	0.100	0.050	0.010
EA	0.770	0.908	1.140	1.601	2.986	13.994
EM	0.972	1.163	1.485	2.124	4.049	19.331
NE	0.680	0.798	0.997	1.390	2.572	11.972
NO	0.662	0.781	0.982	1.381	2.582	12.291
NT	0.916	1.091	1.386	1.971	3.733	17.725
NW	1.066	1.267	1.612	2.293	4.347	20.615
SC	0.884	1.056	1.344	1.916	3.639	17.574
SE	1.022	1.211	1.544	2.201	4.184	19.909
SO	0.720	0.843	1.051	1.462	2.699	12.520
SW	0.533	0.618	0.761	1.046	1.901	8.814
WM	0.738	0.866	1.082	1.511	2.801	13.044
WN	0.374	0.401	0.452	0.553	0.852	3.179
WS	0.543	0.629	0.773	1.058	1.913	8.831

Table E3: combinations of accuracy of CVDD and daily volume of biomethane injection site that result in a maximum increase in standard uncertainty in FWACV of 0.05 MJ/m^3 (ten biomethane sites per LDZ).

number of biomethane sites	10					
BNCV-FWACV, MJ/m^3	-0.5					
target change in u(FWACV), MJ/m^3	0.050					
biomethane daily volume, million m^3	0.250	0.200	0.150	0.100	0.050	0.010
	change in u(FWACV), MJ/m^3					
biomethane daily volume, million m^3	0.250	0.200	0.150	0.100	0.050	0.010
EA	0.692	0.791	0.957	1.283	2.262	10.110
EM	0.828	0.964	1.193	1.645	3.004	13.924
NE	0.624	0.708	0.849	1.129	1.964	8.654
NO	0.594	0.680	0.822	1.105	1.953	8.750
NT	0.793	0.918	1.128	1.542	2.786	12.783
NW	0.918	1.065	1.309	1.792	3.241	14.897
SC	0.761	0.883	1.087	1.493	2.709	12.480
SE	0.870	1.011	1.247	1.713	3.113	14.365
SO	0.666	0.752	0.900	1.179	2.067	9.061
SW	0.504	0.570	0.671	0.875	1.490	6.308

WM	0.673	0.765	0.919	1.224	2.135	9.434
WN	0.434	0.457	0.494	0.568	0.782	2.432
WS	0.522	0.579	0.686	0.891	1.507	6.324

Tables E4 and E5 show combinations of accuracy of CVDD and daily volume of biomethane injection site that result in a maximum increase in standard uncertainty in FWACV of 0.025 MJ/m^3. The combinations in Table E4 assume five biomethane injection sites per LDZ; those in Table E5 assume ten biomethane sites per LDZ.

Table E4: combinations of accuracy of CVDD and daily volume of biomethane injection site that result in a maximum increase in standard uncertainty in FWACV of 0.025 MJ/m^3 (five biomethane sites per LDZ).

number of biomethane sites	5					
BNCV-FWACV, MJ/m^3	-0.5					
target change in u(FWACV), MJ/m^3	0.025					
biomethane daily volume, million m^3	0.250	0.200	0.150	0.100	0.050	0.010
	change in u(FWACV), MJ/m^3					
biomethane daily volume, million m^3	0.250	0.200	0.150	0.100	0.050	0.010
EA	0.522	0.611	0.761	1.055	1.939	9.072
EM	0.641	0.763	0.968	1.370	2.587	12.425
NE	0.459	0.535	0.662	0.912	1.662	7.708
NO	0.428	0.503	0.629	0.876	1.620	7.621
NT	0.612	0.724	0.913	1.284	2.405	11.465
NW	0.732	0.870	1.093	1.530	2.859	13.612
SC	0.579	0.688	0.870	1.228	2.312	11.062
SE	0.685	0.811	1.026	1.446	2.716	12.987
SO	0.497	0.579	0.713	0.976	1.770	8.165
SW	0.348	0.404	0.500	0.677	1.212	5.514
WM	0.505	0.589	0.729	1.004	1.829	8.487
WN	0.284	0.303	0.336	0.409	0.611	2.120
WS	0.367	0.422	0.514	0.695	1.235	5.577

Table E5: combinations of accuracy of CVDD and daily volume of biomethane injection site that result in a maximum increase in standard uncertainty in FWACV of 0.025 MJ/m^3 (ten biomethane sites per LDZ).

number of biomethane sites	10					
BNCV-FWACV, MJ/m^3	-0.5					
target change in u(FWACV), MJ/m^3	0.025					
biomethane daily volume, million m^3	0.250	0.200	0.150	0.100	0.050	0.010
	change in u(FWACV), MJ/m^3					
biomethane daily volume, million m^3	0.250	0.200	0.150	0.100	0.050	0.010
EA	0.483	0.536	0.654	0.857	1.465	6.498
EM	0.561	0.646	0.792	1.078	1.937	8.843
NE	0.426	0.473	0.581	0.761	1.302	5.513
NO	0.392	0.446	0.535	0.701	1.238	5.448
NT	0.545	0.624	0.759	1.024	1.815	8.168
NW	0.627	0.730	0.900	1.226	2.160	9.692
SC	0.511	0.587	0.717	0.972	1.736	7.879
SE	0.599	0.692	0.848	1.147	2.043	9.244
SO	0.458	0.508	0.619	0.811	1.386	5.698
SW	0.331	0.367	0.437	0.572	0.979	4.022
WM	0.474	0.526	0.635	0.832	1.423	6.072
WN	0.333	0.348	0.375	0.428	0.577	1.703
WS	0.361	0.400	0.467	0.599	0.995	4.088

Uncertainty in FWACV contributes very little to the overall uncertainty in error in consumer billing and to illustrate this the uncertainties in daily FWACV used for the Accuracy of Consumer Billing study were replaced with the larger values derived for the conditions in Table E2 with biomethane injection daily volume of 250,000 m^3 (i.e. the first column of results in Table E2). Using these data:

a) expanded uncertainty in GB error in annual energy increased from 0.0018576% to 0.018581%
b) expanded uncertainty in PE11 error in annual energy increased from 0.02146% to 0.02147%
c) expanded uncertainty in BD6 error in annual energy increased from 0.01653% to 0.01654%

The impact of relaxation of accuracy in CVDD for biomethane sites is therefore negligible at the conditions examined in this study and examination of Table E2 suggests appropriate values of standard uncertainty in CV of ±0.553 MJ/m^3 and ±0.374 MJ/m^3at threshold daily volumes of 100,000 m^3/d and 250,000 m^3/d, respectively (i.e. the values seen for WN LDZ). Values of MPE for CVDDs at biomethane injection points of ±1.0 MJ/m^3 and ±0.7 MJ/m^3 at threshold daily volumes of 100,000 m^3/d and 250,000 m^3/d, respectively, are therefore recommended.

CV capping (discussed in Appendix A) ensures that the lowest CV of gas entering a charging area (the "Lowest Source CV" or LSCV) on each gas day is no more than 1 MJ/m^3 lower than the daily charging area CV. Capping therefore starts when

$$(FWACV - LSCV) = 1\ MJ/m^3$$

The uncertainty of the capping point under the existing arrangements is governed by the uncertainties in FWACV and LSCV. Assuming that the daily LSCV is computed as the average of around 300 individual CV measurements the standard uncertainty in LSCV,u(LSCV), is estimated as

$$u(LSCV) = \frac{u(CV)}{\sqrt{300}} = \frac{0.05}{\sqrt{300}} = 0.003\, MJ/m^3$$

Assuming an average value of u(FWACV) as ±0.03 MJ/m^3 (see Table 3) the standard uncertainty of the capping point becomes:

$$u(FWACV - LSCV) = \sqrt{0.03^2 + 0.003^2} = 0.0301\ \ MJ/m^3$$

Using a revised value for u(FWACV) of ±0.08 MJ/$m^3$and relaxed u(CV) for biomethane of ±1.0 MJ/m^3 the standard uncertainty of the capping point with reduced accuracy biomethane CVDDs becomes:

$$u(FWACV - LSCV) = \sqrt{0.08^2 + \left(\frac{0.5}{\sqrt{300}}\right)^2} = \sqrt{0.08^2 + (0.0289)^2} = 0.085\, MJ/m^3$$

The expanded uncertainty in capping point is expected to increase from ±0.6 MJ/m^3 to 0.17 MJ/m^3. This is relatively small, i.e. at a determined capping point of 1.0 MJ/m^3, the value of true capping point is expected to be between 0.83 and ±1.17 MJ/m^3.