Carbon trading in the European Union: ‘Calculation’ vs ‘Measurement’

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European Union Emissions Trading System (EU ETS)

- Largest multi-country, multi-sector GHG emissions trading system in the world, commencing 2005: **CO_2**; 2013: **CO_2**; **N_2O**; **PFCs**
- EU has 20% emissions reduction target from 1990 levels (by 2020)
- Market-based mechanism - allocating and trading greenhouse gas emissions allowances (one allowance = one tonne CO_2 equivalent)
- Phase III of the EU ETS began on 1 Jan 2013 → centralised EU-wide cap based on the total number of allowances issued to installations that reduces each year until 2020
- A proportion of the total number of allowances is issued free of charge to installations and the remainder is auctioned (Phase III – no free allocations for power sector)
- EU ETS covers electricity generation and the main energy-intensive industries: refineries, iron & steel, cement & lime, paper, food & drink, glass, ceramics, engineering, the manufacture of vehicles and aviation

EU ETS: Combustion Activities

- ‘Combustion’ means any oxidation of fuel, regardless of the way in which the heat, electrical or mechanical energy is used, and any other directly associated activities, including waste gas scrubbing
- Combustion includes all types of boilers, burners, turbines, heaters, furnaces, incinerators, calciners, kilns, ovens, fryers, dryers, engines, fuel cells, chemical looping units, flares, thermal/catalytic post-combustion units
- Stand-by generation or boiler capacity is included unless this physically cannot run at the same time as the main units (capacity based)
- Installations with a total aggregated (net) rated thermal input exceeding 20 MW (68.24 MMBtu/h) excluding units < 3 MW and biomass units
- If the threshold of 20 MW is exceeded there is no 'de minimis rule' – all combustion sources are included, regardless of size, including biomass units but biomass is zero-rated
- An installation that only fires biomass is excluded from EU ETS

EU ETS: General requirements on installations

- Requirement for a permit - must include a monitoring plan in accordance with the EU Monitoring and Reporting Regulation (MRR)
- Requirement to monitor the annual reportable emissions arising from the regulated activity (in $CO_{2(e)}$)
- Requirement to submit a verified report of emissions by 31 March in following year (must be in accordance with the Monitoring and Reporting Regulation and the Verification Regulation)
- Requirement to surrender allowances by 30 April in following year (equal to the annual reportable emissions) via the Operator's Union Registry account
- Requirements to notify changes, vary/transfer/surrender permits

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EU ETS: Calculation approach I

- CO_2 = Activity data * Emission Factor * Oxidation factor
- CO_2 = Fuel Burn [TJ] * CO_2 [tonne CO_2/TJ] * Oxidation factor
- CO_2 = Fuel Burn [Nm^3] * CO_2 [tonne CO_2/Nm^3] * Oxidation factor

Emission	**Category A**	**Category B**	**Category C**
ktonnes $CO_{2(e)}$ /annum	≤ 50	50 - 500	> 500

Source stream	**de minimis**	**minor**	**major**
the higher of	< 1 kt/a or < 2% with 20 kt/a cap	< 5 kt/a or < 10% with 100 kt/a cap	all other sources

Normal conditions: 0°C, 101.325 kPa (32°F ,14.696 psi, 1 atm)
1 metric tonne = 1.102311 US ton = 0.984207 UK ton)

EU ETS: Calculation approach II

- Uncertainty defined by Tier requirements
- Highest Tier = Lowest Uncertainty = Category B & C Requirement
  (for major & minor unless technically unfeasible or unreasonable cost)
- Category A must meet Tier 2 for Activity data and Tier 1 for OF
- No Tier methods allowed for ‘de minimis’ sources

Uncertainty	Tier 1	Tier 2	Tier 3	Tier 4
Activity data	± 7.5%	± 5.0%	± 2.5%	± 1.5%
Emission factor	Fixed factor	Fixed factor/ Proxy	± 0.5%	-
Oxidation factor	Fixed factor (1.0)	Fixed factor (various)	± 0.5%	-

- Overall uncertainty requirement U ~ ±1.6%

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EU ETS: Calculation approach III

- Fall back methodology subject to

  - technically infeasibility or unreasonable costs

  - full uncertainty analysis

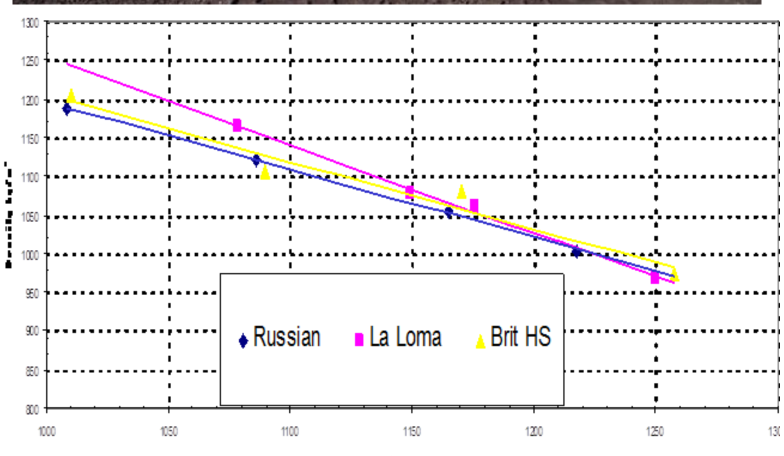
  - uncertainty within following tolerances

  (demonstrated to the satisfaction of the Competent Authority)

Uncertainty	**Category A**	**Category B**	**Category C**
Fall back approach	± 7.5%	± 5.0%	± 2.5%

EU ETS: Implementation at UK coal fired power stations (Activity data)

- Static weighbridges (rail and road) for fuel deliveries ± 0.5%
- Coal Stock Field Density Measurement (together with volume and fuel analysis surveys) with uncertainties of ± 1% on measurement



Stock change generally small compared with consumption (reconciled with heat accountancy)
Stock uncertainty < 2.5%
but Δ stock generally small

EU ETS: Implementation at UK coal fired power stations (carbon analysis and oxidation factor)

Carbon content (~ 65% ar)

- Sampling bias and precision to ISO 13909: 2001
- Analysis to ISO 609 (C); ISO 11722 (M)
- Combined uncertainty single sample: ± 0.9%
- Multiple samples taken of different coal types to give tonnage weighted uncertainty better than ± 0.5%

Oxidation factor (~0.98)

- Fixed factor allowed or
- Monthly composite samples fly ash and bottom ash for C analysis
- Weighted according to production tonnages
- Uncertainty in oxidation factor < ± 0.2%

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EU ETS: Implementation at UK gas fired power stations

- High quality fiscal metering for natural gas consumption
- OIML R 140 (Measuring systems for gaseous fuels) 2007
- Consistent with UK Petroleum Custody Transfer Guidelines

	Class		
Quantity	A	B	C
Converted volume	±0.9%	±1.5%	±2.0%
Measuring volume at metering conditions	±0.7%	±1.2%	±1.5%
Converting into volume at base conditions	±0.5%	±1.0%	±1.5%

- Dedicated Gas Chromatographs for fuel composition (carbon content) with calibration by accredited laboratory to ISO 10723 for analysis and ISO 6976 for property calculation → ± 0.2%

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EU ETS: Calculation approach over-view

Preferred in Europe because:

- Based on fuel consumption and fuel quality
- Arrangements already in place for fiscal metering and energy content
- Sampling frequency increased to meet uncertainty requirements, e.g., on-line GC analysis of natural gas
- Very low uncertainties are achievable at the installation level

But

- Flue gas measurement is allowed…

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EU ETS: Measurement approach I

- Tier 4 CEMs approach required if Calculation Tier 4 (otherwise Tier 3)

Table 1

Tiers for CEMS (maximum permissible uncertainty for each tier)

	Tier 1	Tier 2	Tier 3	Tier 4
CO_2 emission sources	± 10 %	± 7,5 %	± 5 %	± 2,5 %
N_2O emission sources	± 10 %	± 7,5 %	± 5 %	N.A.

Table 2

Minimum requirements for measurement-based methodologies

Greenhouse gas	Minimum tier level required		
	Category A	Category B	Category C
CO_2	2	2	3
N_2O	2	2	3

EU ETS: Measurement approach I

- Reporting based on hourly average concentration (CO_2 + CO) g/Nm^3 and hourly emitted volume

$$GHG_{\text{tot ann}}[t] = \sum_{i=1}^{\text{operating hours p.a.}} GHGconc_{\text{hourly } i} * \text{flue gas flow}_i * 10^{-6}[t/g]$$

- Flow can be measured or calculated
- Biomass CO_2 must be subtracted (calculation)
- Valid hour: at least 80% data capture
- Data loss: > 5 consecutive days → competent authority → improvement
- Data substitution: Concentration from $C^*_{subst} = \overline{C} + 2\sigma_{C\_}$

  Flow from mass or energy balance
- Corroboration: against calculated emissions

EU ETS: Measurement approach II

- The operator shall consider all relevant aspects of the continuous measurement system, including the location of the equipment, calibration, measurement, quality assurance and quality control.
- Methods based on EN 14181 (QA), EN 15259 (sample representativeness and location) … hierarchy of standards
- Laboratories shall be accredited to ISO 17025 for the relevant analytical methods or calibration activities
- Note that EN 1481 contains statistics largely based on Emission Limit Value (ELV) which is not defined for GHGs therefore….
- ISO 14385-1 Stationary source emissions - Green house gases - Part 1: Calibration of automated measuring systems
- ISO 14385-2 Stationary source emissions - Green house gases - Part 2: Ongoing quality control of automated measuring systems

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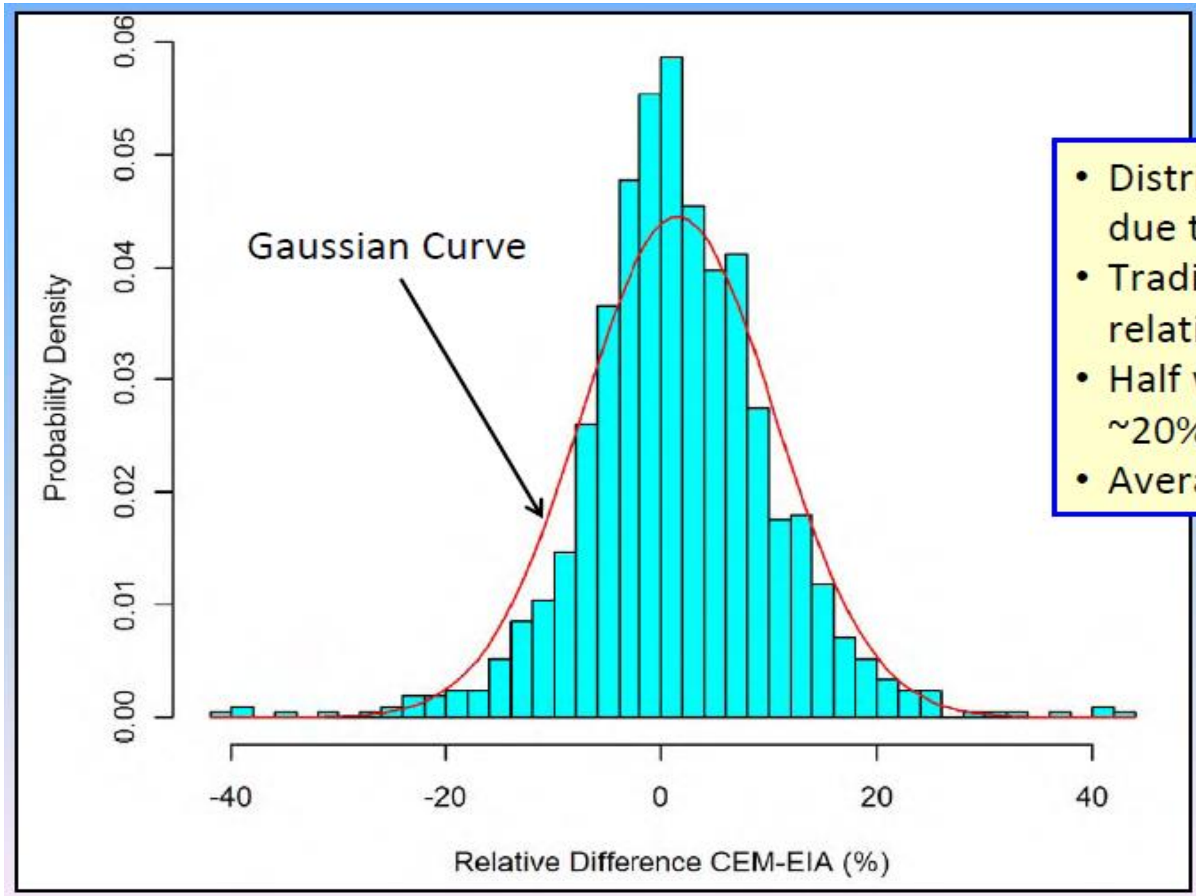
How do ‘Calculation’ and ‘Measurement’ compare?



- Distribution is non-Gaussian due to heavy distribution tails
- Traditional uncertainty relationships do not hold
- Half width of the distribution ~20%
- Average difference is 1.5%

R. Paul Borthwick, James Whetstone, Jiann Yang and Antonio Possolo

NIST, Gaithersburg MD

EPRI CEM USER Group June 2011

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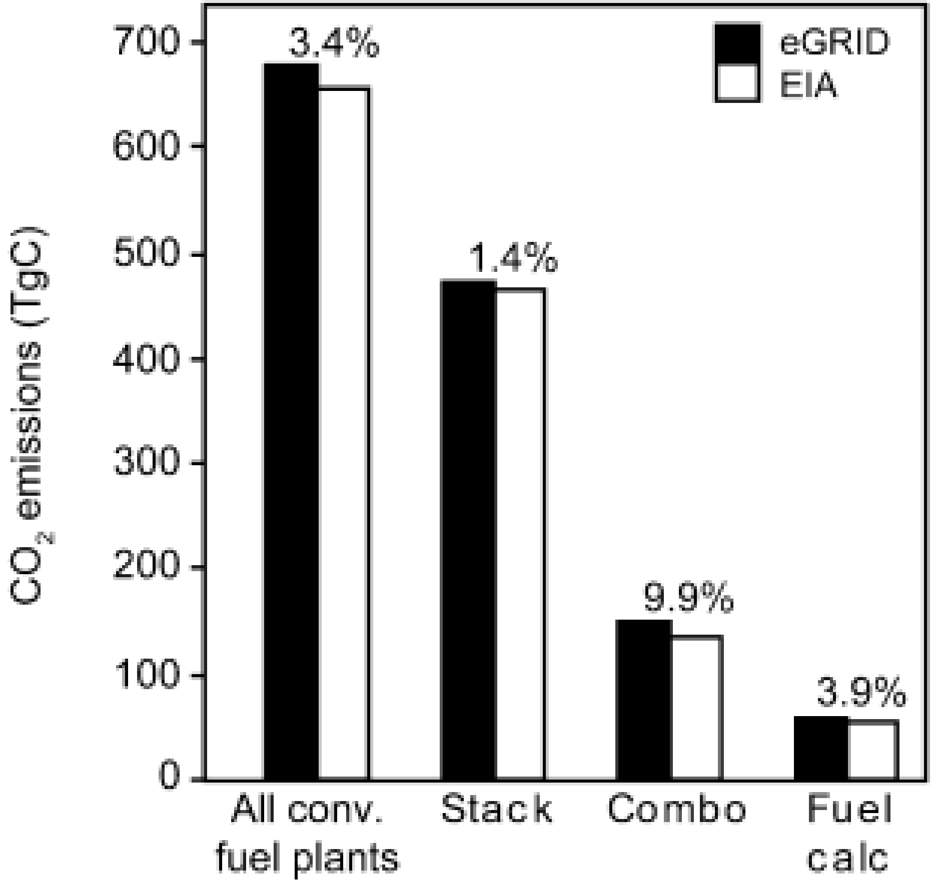


Comparison of Two U.S. Power-Plant Carbon Dioxide Emissions Data Sets

KATHERINE V. ACKERMAN* AND ERIC T. SUNDQUIST

U.S. Geological Survey, 384 Woods Hole Road, Woods Hole, Massachusetts 02543

Environ. Sci. Technol. **2008,** *42,* 5688–5693

Case Study: Lignite fired power plant in Germany

- Motivation: Operator evaluation of an alternative measurement based approach for determining CO_2 emissions from a large lignite fired power plant for EU ETS reporting
- Online checking of a continuous CO_2 emission measurement system by thermodynamic process simulation
- Offline checking by heat balance (electricity output and efficiency) and mass balance (fuel consumption and carbon content) →
- Improved quality control of Continuous Emissions Monitoring (CEM) system

INFORMATION SOURCES:

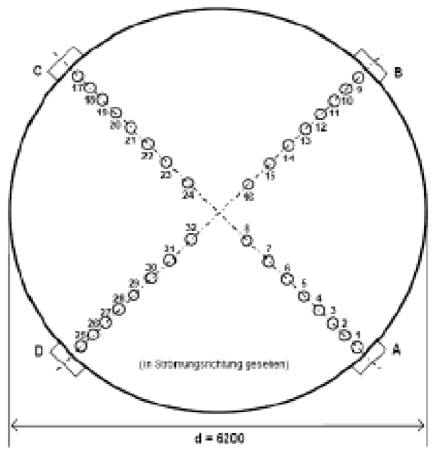
SCHILLING U, KNIESCHKE A & BIANCHIN R. “CO_2 monitoring im Kraftwerk Boxberg Werk III unter Verwendung eines direkt messenden kontinuierlichen“. VDI Berichte, Nr 2178, 2012.

KRAUSE M. (Vattenfall PowerConsult GmbH) Online Plausibilitätskontrolle eines kontinuierlichen CO_2-Emissionsmesssystems mittels thermodynamischer Prozesssimulation, EBSILON - User Conference,

Nov 2012

Primary measurements and boundary conditions

- Measurement system with individual instruments for Raw Gas flow rate, CO_2 concentration, temperature and pressure
- Flow rate: multipath ultrasonic transit time measurement with Pitot calibration and 3D laser scanner measurement of duct cross-section

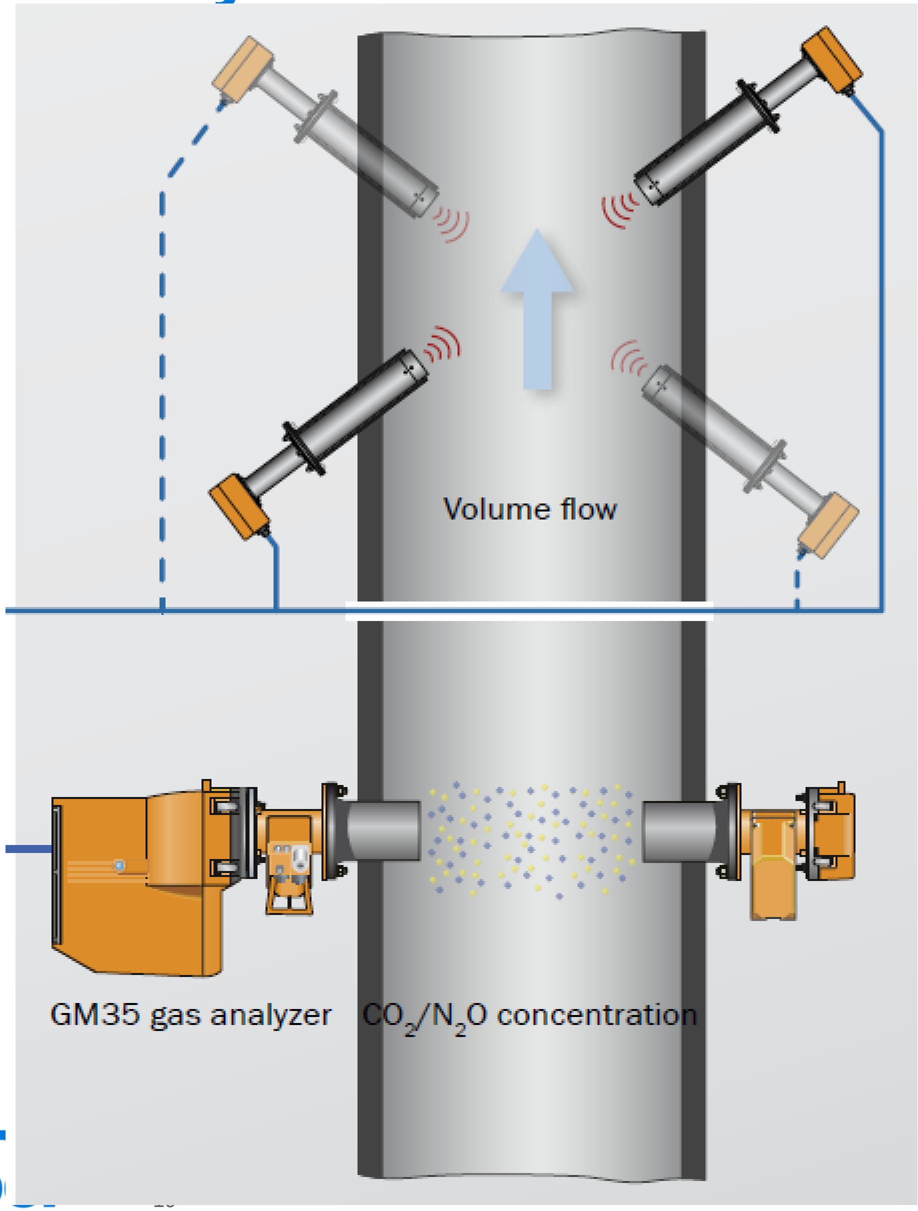


Number of traverse points increased from 20 to 32

- CO_2 concentration: in-situ measurement (GFC/IF correlation) with EN14181 QAL2
- Temperature: multiple thermocouples
- Pressure: absolute pressure transmitter

Source: Vattenfall Europe Generation AG

Primary measurements and boundary conditions



Source: SICK-Maihak

Enhanced Quality Assurance

- On-line thermodynamic determination of heat input combined with an emission factor (based on a model fuel composition), noting that the CO_2 specific emission factor (tCO_2/TJ) is essentially invariant for a specific fuel type. (Emitted CO_2 is proportional to the thermal input of the power plant).
- Off-line Unit performance testing according to EN 12952-15, DIN 1941 and VDI 3986 using calibrated instruments → off-line validated efficiency calculations → thermal input → CO_2 mass emission
- Off-line fuel mass balance approach based on fuel consumption (delivered fuel and stock changes) and fuel carbon content

  → CO_2 mass emission

Source: Vattenfall Europe Generation AG

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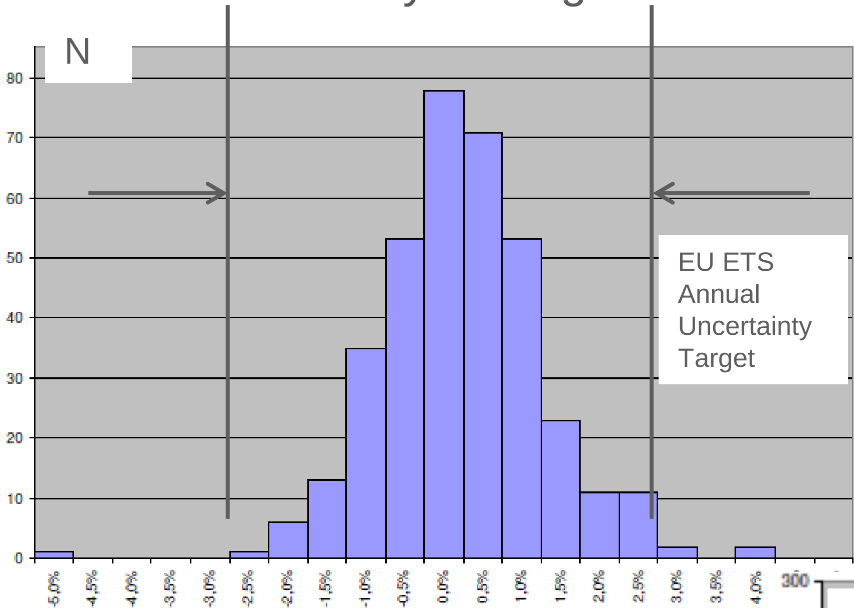
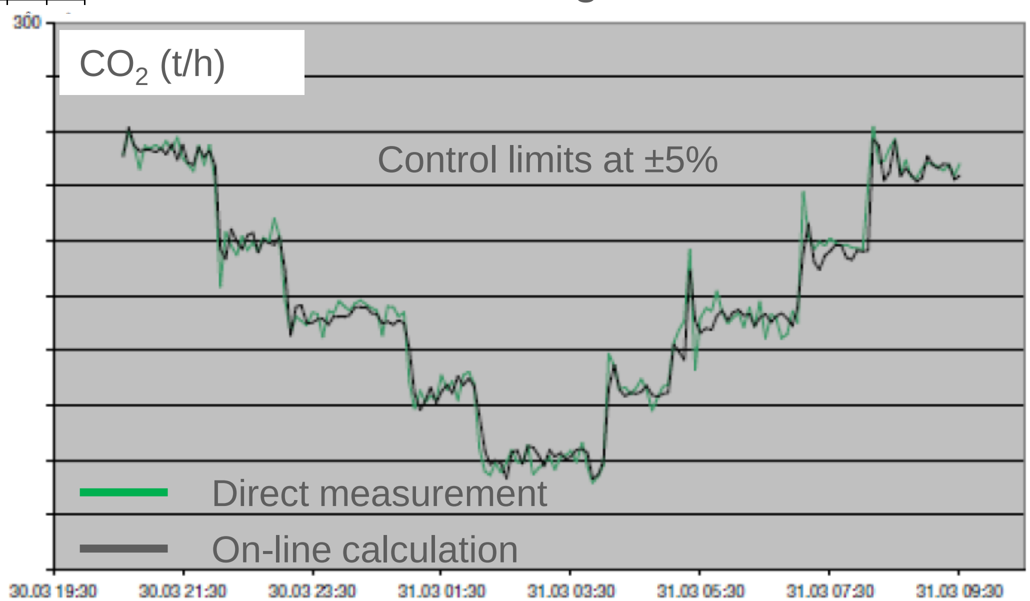
On-line checking for enhanced Quality Assurance

Deviations in daily averages

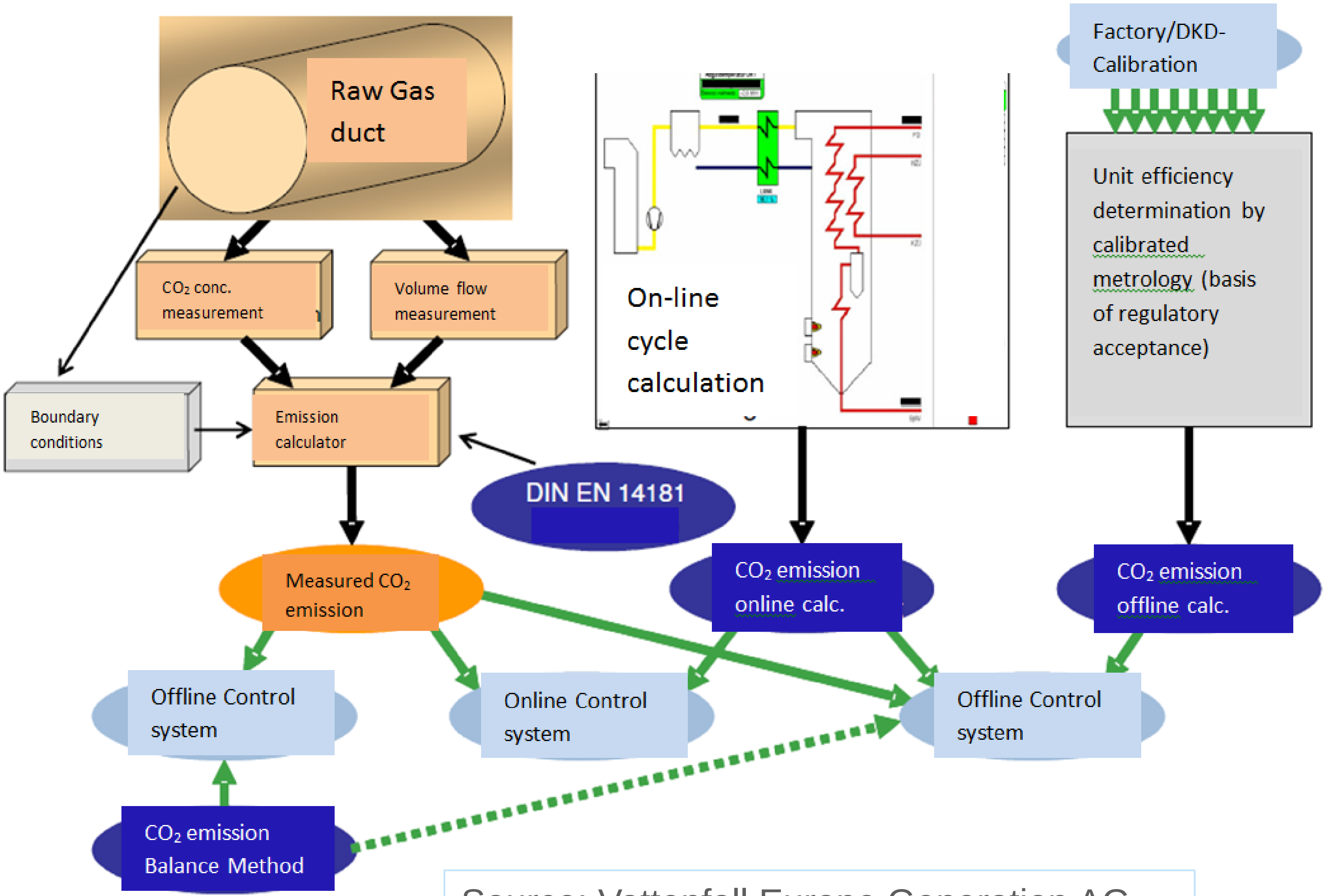


Instantaneous readings



Source:
Vattenfall Europe Generation AG

Schematic Over-view



Source: Vattenfall Europe Generation AG

Case Study Conclusions

- CO_2 mass emission based on flue gas measurement is equivalent to mass emissions calculated from mass and heat balances …
- Provided that all of the measurements are based on traceable calibration and care is taken to minimise uncertainty ...
- EU ETS uncertainty requirement of ± 2.5% can be achieved although…
- Standards for measuring flue gas CO_2 concentration require further development
- Quality Assurance can be enhanced by means of CO_2 calculation from:

    On-line thermodynamic determination of heat input

    Off-line Unit performance testing

    Off-line fuel mass balance approach

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Potential sources of uncertainty improvement

Flow rate measurement

- Need ±2.25% for flow with ±1.0% on CO_2 to achieve ±2.5% overall
- 3D / 2D Pitots or tracer methods with low uncertainty and traceable calibration

CO_2 concentration

- Instruments with low certification ranges (5% CO_2 for gas turbines)
- Ultra-low uncertainty calibration gases (for CEM and SRM) < ±0.2%
- Accounting for non-ideal gas behaviour of CO_2 span gas (0.5%)
- Accounting for inherent CO_2 in the combustion air
    - i) Coal fired plant ~0.3% over-reading at 6% O_2 dry
    - ii) Combined cycle gas turbine ~1.0% over-reading at 13% O_2 dry

Concluding remarks

- Monitoring & Reporting requirements under the EU ETS have developed and matured since 2005 with a progressively greater emphasis placed on uncertainty assessment
- Power industry generally prefers calculation from fuel consumption and fuel quality measurements at an installation level (fiscal underpinning) - but significantly greater fuel sampling is required in some cases (e.g., natural gas on-line chromatographs)
- Flue gas measurement is allowed but achieving the required uncertainty of ± 2.5% is difficult, even with advanced flue gas flow measurement, and requires further developments in:
- Standards for measuring flue gas CO_2 concentration; instrument certification; span gas quality and corrections for small biases
- QA can be enhanced using on-line analysis of thermal performance, reconciled with fuel consumption off-line.

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