

Allocation of GHG Emissions from a Combined Heat and Power (CHP) Plant

Guide to calculation worksheets (September 2006) v1.0

A WRI/WBCSD GHG Protocol Initiative calculation tool

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I. Overview

Purpose and domain of this tool

This tool intends to facilitate the allocation of GHG emissions attributable to the purchase or sale of energy from a combined heat and power (CHP) plant. **This document is to be used in conjunction with calculation worksheets – “Allocation of GHG Emissions from a Combined Heat and Power (CHP) Plant”**, which can be downloaded from the GHG Protocol Initiative website, www.ghgprotocol.org.

Depending on circumstances, this tool may also be used in conjunction with up to five additional documents and tools, which can also all be downloaded from the GHG Protocol Initiative website. These documents and tools include:

- “The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard (Revised Edition)”;
- Calculation worksheets – “Direct emissions from stationary combustion” (revised);
- Guide to calculation worksheets – “Direct emissions from stationary combustion” (revised);
- Calculation worksheets – “Indirect CO₂ emissions from the consumption of purchased electricity, heat or steam”; and
- Guide to calculation worksheets – “Indirect CO₂ emissions from the consumption of purchased electricity, heat or steam”.

This is a cross-sector tool, which should be applied by all companies whose operations involve the purchase or sale of energy from a CHP plant.

Process description

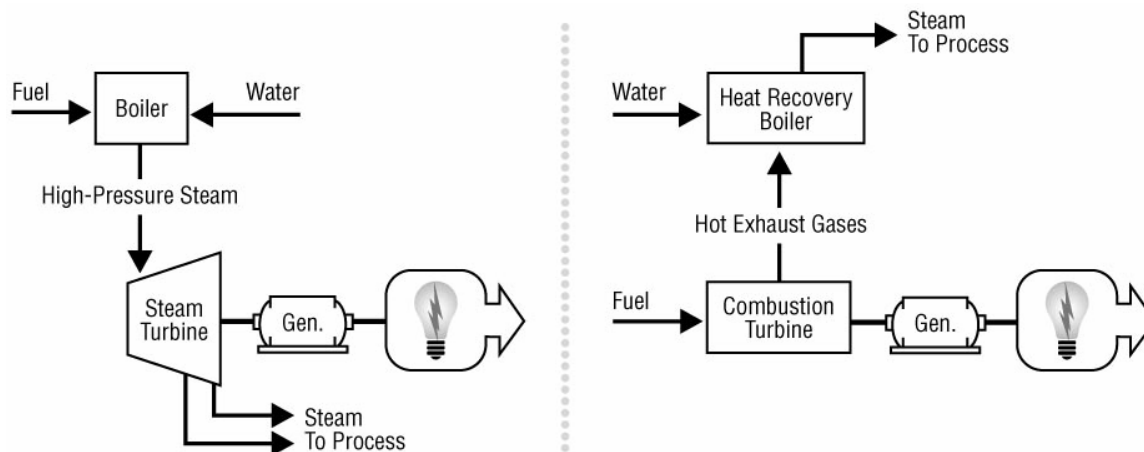
In a CHP system, which is also commonly referred to as “co-generation”, multiple forms of energy (most often electricity and steam) are generated simultaneously in an integrated system, from the same input fuel supply. GHG emissions from a CHP plant occur from the combustion of fossil fuels (input fuel) in the CHP plant to generate the multiple energy streams. These GHG emissions include carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O).

There are two common configurations for CHP systems, shown in Figure 1. The steam boiler/turbine CHP approach on the left has been the most widely used CHP system to date. In this approach, a boiler makes high-pressure steam that is fed to a turbine to produce electricity. However, the turbine is designed so that there is low-pressure steam left over to feed an industrial process. Thus, one fuel input to the boiler supplies electric and thermal energy by extracting uncondensed steam from the turbine driving the electric generator. Typically, two thirds of the energy in a conventional power plant is lost when low-pressure steam is condensed in the cooling tower. This type of CHP system typically generates about 5 times as much thermal energy as electric energy. Steam boiler/turbine CHP systems are widely used in the paper, chemical and refining industries, especially when there is waste or by-product fuel that can be used to fuel the boiler.

In the other approach on the right, a combustion turbine or reciprocating engine is used to drive an electrical generator, and thermal energy is recovered from the exhaust stream to make steam or supply other thermal uses. The application of these systems has been more recent as the prime mover technologies have developed. These types of CHP systems can use very large (hundreds of

MW) gas turbines or very small (tens of kW) microturbine, engine, or fuel cell systems. In these systems, the thermal energy is typically 1 to 2 times the electric energy¹.

Figure 1. Typical CHP Configurations



Applicability of the tool

If a company is purchasing or selling all of the electricity and steam from a CHP plant, or purchasing or selling the various output streams in the same proportions as they are generated, then an average emission factor will be sufficient for calculating the GHG emissions from the total electricity and steam purchased or sold from the CHP plant. An average emission factor for the CHP plant can be obtained by dividing the total direct emissions of the CHP plant by the total output generated. Total direct emissions of the CHP plant can be determined by using the revised GHG Protocol calculation tool for Direct Emissions from Stationary Combustion, available on the GHG Protocol website, www.ghgprotocol.org. To obtain the total output generated from the CHP plant, convert the electricity and steam outputs to the same units and add them together.

However, in cases where only a portion of the electricity and steam outputs from a CHP plant are purchased or sold, it is necessary to allocate total emissions to the each output stream. This is done by determining separate emission factors for the electricity and steam outputs and multiplying those emission factors by the output purchased or sold from its respective energy stream.

The purpose of this tool is to facilitate this allocation of GHG emissions to a CHP plant's separate energy streams by determining the separate GHG emission factors associated with each stream. To do this, it is first necessary to determine the total direct emissions emitted by the CHP plant. Note that this tool *does not* facilitate this calculation. Total direct emissions of the CHP plant can be determined by using the revised GHG Protocol calculation tool for Direct Emissions from Stationary Combustion, available on the GHG Protocol website, www.ghgprotocol.org.

Although CO₂ is the primary GHG emitted during the combustion of fossil fuels, CH₄, and N₂O emissions also occur during the combustion process. The approaches described in this tool can be

¹ Reference: "Analysis of Output-Based Allocation of Emission Trading Allowances", U.S. Combined Heat and Power Association, submitted by: Energy and Environmental Analysis, Inc., June 2003

applied to the allocation of CO₂, CH₄, and N₂O emissions from the purchase or sale of electricity or steam from a CHP plant, although the calculations should be performed separately for each gas. However, it should be noted that the methods used to determine total direct CO₂ emissions from a plant may differ from the methods used to determine total direct CH₄ or N₂O emissions from a plant. The method for calculating the emissions of all three gases can be found in the revised GHG Protocol calculation tool for “Direct Emissions from Stationary Combustion”, available on the GHG Protocol website, www.ghgprotocol.org.

Accounting for emissions associated with energy purchases and sales from a CHP plant in a GHG inventory

Once the emission shares from a CHP plant are allocated to each energy stream, the indirect emissions associated with the purchase or sale of electricity, heat or steam from a CHP facility should be accounted for in a GHG inventory the same way as indirect emissions associated with the purchase or sale of electricity, heat or steam from a non-CHP plant:

- Emissions associated with electricity, heat or steam purchased for consumption should be categorized as scope 2 indirect emissions;
- Emissions associated with purchased electricity, heat or steam for resale to end-users should be categorized as scope 3 indirect emissions. According to GHG Protocol standards, it is optional, but strongly encouraged, to account for and report these emissions;
- Emissions associated with the sale of own-generated electricity, heat or steam to another entity are *not* deducted/netted from scope 1 direct emissions, and may be reported in optional information.

For more information on accounting for emissions from electricity, heat or steam purchases and sales, see the GHG Protocol Corporate Standard (revised edition) and the calculation tool for Indirect CO₂ Emissions from the Consumption of Purchased Electricity, Heat or Steam, both available on the GHG Protocol website.

II. CHP emission allocation methods

As noted above, it will be necessary to assign the total emissions to the different generated energy streams (normally steam and electricity) if a company is not purchasing or selling all of the energy from a CHP plant or is not purchasing or selling the energy streams in the same proportions as they are generated.

The three most common methods to allocate emissions from a CHP plant are:

- ***Efficiency method:*** GHG emissions are allocated based on the energy inputs used to produce the separate steam and electricity products. (See Sections III, IV, and V). The efficiency method is the preferred method of this guidance document and the method on which the calculation worksheets are based.
- ***Energy content method:*** GHG emissions are allocated based on the energy content of the output steam and electricity products. (See Appendix I)
- ***Work potential method:*** GHG emissions are allocated based on the energy content of the steam and electricity products. (See Appendix II)

GHG emissions of CHP plants could also be allocated based on:

- The economic value of the steam and electricity products
- Allocating 100% of GHG emissions to electricity production (steam production is emissions free)
- Allocating 100% of GHG emissions to steam production (electricity production is emissions free)
- Allocating savings to electricity production (electricity emissions = total emissions – emissions from conventional steam production; steam emissions = emissions of conventional steam production)
- Allocating savings to steam production (steam emissions = total emissions – emissions from conventional electricity production; electricity emissions = emissions of conventional electricity production)
- Allocating emissions according to a contractual agreement or other understanding between the affected parties.

Selecting a CHP emissions allocation approach

While this guidance document and automated calculation worksheets focus on the efficiency method, following the energy content, work potential, or one of the other CHP emission allocation methods may be acceptable as long as the methods used are clearly stated, along with any and all assumptions inherent to the approach adopted. When selecting an approach to allocate emissions from a CHP plant, the following considerations may be useful.²

Efficiency Method

- Allocates GHG emissions according to the amount of fuel energy used to produce each final energy stream.
- Assumes that conversion of fuel energy to steam energy is more efficient than converting fuel to electricity. Thus, focuses on the initial fuel-to-steam conversion process.
- Actual efficiencies of heat and of power production will not be fully characterized, necessitating the use of assumed values.

Energy Content Method

- Allocates GHG emissions according to the useful energy contained in each CHP output stream.
- Need information regarding the intended use of the heat energy.
- Best suited where heat can be characterized as useful energy, e.g., for process or district heating.
- May not be appropriate where heat used for mechanical work because it may overstate the amount of useful energy in the heat, resulting in a low emissions factor associated with the heat stream.

² California Climate Action Registry (CCAR), *General Reporting Protocol, Version 2.1*. Part III, Chapter 8 – Allocating Emissions from Co-Generation. June 2006. CCAR guidelines based in-part on the guidance provided in the previous version of the GHG Protocol calculation tool “Direct Emissions from Stationary Combustion” (October 2004 version).

Work Potential Method

- Allocates emissions based on the useful energy represented by electric power and heat, and defines useful energy on the ability of heat to perform work.
- Appropriate where heat is to be used for producing mechanical work (where much of the heat energy will not be characterized as useful energy).
- May not be appropriate for systems that sell hot water because hot water cannot be used, as steam can, to perform mechanical work.

Another key consideration no matter which allocation method is considered is that both the producer (i.e., seller) and all consumers (i.e., purchasers) of the electricity or steam should use the same method. If different methods are used it could lead to double counting of emissions. To insure all parties use the same method, emissions could also be allocated based on a contractual agreement. However, if there is no contract in place it is recommended that all purchasers of steam or electricity use the same method as the producer of the steam or electricity.

In order to insure a consistent approach to CHP allocation, the efficiency method is recommended where no contract is in place.

The following sections outline the efficiency method of allocating emissions of a CHP plant, and provide:

- Step-by-step guidance on following the efficiency method;
- Instructions on using the automated worksheet for the efficiency method; and
- Example calculations using the efficiency method.

Appendices I and II of this document provide additional information and step-by-step guidance on following the work potential and energy content methods respectively.

III. Guidance on following the efficiency method

For this method, emissions are allocated based on the separate efficiencies of steam and electricity production. To determine the share of GHG emissions attributable to steam and electricity production, the following steps are needed. Note that if estimating emission shares for multiple GHGs (e.g., CO₂, CH₄, and N₂O), calculations for each gas should be performed separately.

Step 1: Determine the total direct emissions and the total steam and electricity outputs for the CHP system. The CHP system from which steam or electricity is either purchased or sold could have multiple fuel inputs and multiple steam or electricity outputs. For this allocation approach, the fuel input flows should be converted to emissions based on the guidance in the revised GHG Protocol calculation tool for “Direct Emissions from Stationary Combustion”, available on the GHG Protocol website, www.ghgprotocol.org. The different output flows should be combined into two separate values, one for steam output and one for electricity output. Furthermore, these output flows should be in the same units of energy (e.g., all expressed as GJ or BTU). Steam tables provide energy content (enthalpy) values for steam at different temperature and pressure conditions. Enthalpy values multiplied by the quantity of steam give energy output values.

Step 2: Estimate the efficiencies of steam and electricity production. This method is based on the assumption that conversion of fuel energy to steam energy is more efficient than converting fuel to electricity. The efficiencies are used to determine the amount of fuel input, and therefore emissions, associated with steam vs. electricity production. The use of source specific efficiency factors is recommended. However, if source specific factors are unavailable, default values can be used, which are provided in the worksheet.

Step 3: Determine the fraction of total emissions to allocate to steam and electricity production. The following formulas are used for this step.

$$E_H = \frac{H/e_H}{H/e_H + P/e_P} * E_T \quad \text{and} \quad E_P = E_T - E_H$$

where:

- E_H = emissions allocated to steam production
- H = steam output (energy)
- e_H = assumed efficiency of steam production
- P = delivered electricity generation (energy)
- e_P = assumed efficiency of electricity generation
- E_T = total direct emissions of the CHP system
- E_P = emissions allocated to electricity production

Note: The use of default efficiency values may, in some cases, violate the energy balance constraints of some CHP systems. This can be checked by comparing the calculated assumed energy input with the actual energy input of the CHP plant. Assumed energy input is calculated based on the heat and power output and the assumed efficiencies as shown in the following equation.

$$\text{Assumed Energy Input} = \frac{H}{e_H} + \frac{P}{e_P}$$

It is not a significant issue if energy balance is violated, since total emissions would still be allocated between the energy outputs. However, the user should be aware of the energy balance and if the constraints are not satisfied e_H and e_P can be modified until constraints are met.

Step 4: Calculate emission rates for steam and electricity production. Divide the total emissions from steam production (Step 3) by the total amount of steam produced to get an emission rate (e.g., mass CO₂/amount of steam). Divide the total emissions from electricity production (Step 3) by the total amount of electricity produced to get an emission rate (e.g., mass CO₂/amount of electricity).

Step 5: Estimate emissions from purchases or sales. To estimate emissions, multiply the amount of steam or electricity either purchased or sold by the appropriate emission rate (Step 4). Units used for the amount of steam or electricity purchased or sold should be the same as used to calculate the emission rates (e.g., GJ).

Note: Shares of emissions allocated to steam production (E_H) should be assigned to different heat products based on their energy content.

IV. Using the calculation worksheets for the efficiency method

Step 1

- A. Enter the total direct emissions from CHP plant in column A.
- B. Enter the steam output from the CHP plant in GJ, BTU or kWh (or other suitable energy unit) in column B.
- C. Enter the electricity output from the CHP plant in column C. Make sure to use the same energy unit as for the steam output.

Step 2

- D. Enter assumed efficiency of typical steam production in column D.
- E. Enter assumed efficiency of typical electricity production in column E.

Step 3

- F. The emissions share attributable to steam production is calculated automatically in column F.
- G. The emissions share attributable to electricity production is calculated automatically in column G.

Step 4

- H. The emissions rate for steam production is calculated automatically in column H.
- I. The emissions rate for electricity production is calculated automatically in column I.

Assign shares of E_{HI} to different heat products based on their energy content.

For step 2 listed above, use of source specific efficiency factors is recommended. If source specific factors are unavailable, the worksheets offer default efficiency factors.

V. Example calculations to illustrate application of the efficiency method

As an example, consider a hypothetical CHP system that fires a total of 5,000 GJ (LHV) of distillate fuel oil to produce the four energy outputs shown in Table 1. The total emissions from this CHP system will be computed and allocated among the four output streams using the efficiency method, the energy content method, and the work potential method. The values for specific enthalpy and specific entropy for the three steam streams, and for the reference condition (the choice of which is arbitrary, but for this example was chosen as liquid water at 100°C and 1 atmosphere pressure = 101.325 bar), which are used in the energy content and work potential methods, were drawn from standard steam tables which can be found in most thermodynamic textbooks.

Table 1. Hypothetical CHP System Energy Outputs for Example Calculations

	Total Energy	Steam Temp.	Steam Press.	Specific Enthalpy	Specific Entropy
	(GJ)	(°C)	(bar)	(kJ/kg)	(kJ/kg·K)
Reference	N/A	100	101.325	419.1	1.3069
Electricity	245	N/A	N/A	N/A	N/A

Steam 1	1,355	400	40	3,215.7	6.7733
Steam 2	1,100	300	20	3,025.0	6.7696
Steam 3	750	200	10	2,826.8	6.6922
Total	3,450				

As outlined above, the efficiency method requires use of efficiency factors for the production of electricity and steam (either actual or assumed values if actual values are not available). The simplest approach to applying the efficiency method is to assign a single efficiency factor to all electricity output and a single efficiency factor to all heat (steam and hot water) output. In this example, the recommended default values for the US will be used (35% for electricity production, 80% for heat production).

Step 1: Determine the total direct emissions and the total steam and electricity output for the CHP system. Total emissions are computed from total fuel use and emission rates as described in the revised GHG Protocol calculation tool for “Direct Emissions from Stationary Combustion”.

$$E_H = 5000 \text{ GJ(LHV)} \times 74.1 \text{ kg CO}_2 / \text{GJ(LHV)} = 370,500 \text{ kg CO}_2$$

$$H = 1355 + 1100 + 750 = 3205 \text{ GJ}$$

$$P = 245 \text{ GJ}$$

Step 2: Estimate the efficiencies of steam and electricity production. The recommended default values for the US will be used: 35% for electricity production, 80% for heat production.

It may be helpful to ensure that use of these default efficiency values do not violate the constraints imposed on the system by the energy balance.

$$\frac{3205 \text{ GJ steam}}{0.8 \text{ GJ steam/GJ fuel}} + \frac{245 \text{ GJ power}}{0.35 \text{ GJ power/GJ fuel}} = 4706 \text{ GJ fuel}$$

The energy balance constraint has not been violated because 4,706 GJ is less than the fuel consumption of the CHP system (5,000 GJ).

Step 3: Determine the fraction of total emissions to allocate to steam and electricity production. The following formulas are used for this step.

$$E_H = \frac{H/e_H}{H/e_H + P/e_P} * E_T \quad \text{and} \quad E_P = E_T - E_H$$

where:

- E_H = emissions allocated to steam production
- H = steam output (energy)
- e_H = assumed efficiency of steam production
- P = delivered electricity generation (energy)

- e_p = assumed efficiency of electricity generation
 E_T = total direct emissions of the CHP system
 E_p = emissions allocated to electricity production

$$E_H = \frac{\left(\frac{3205}{0.8}\right)}{\left(\frac{3205}{0.8}\right) + \left(\frac{245}{0.35}\right)} * 370,500 = 315,392 \text{ kg } CO_2$$

$$E_p = 370,500 - 315,392 = 55,108 \text{ kg } CO_2$$

Step 4: Calculate emission rates for steam and electricity production.

For steam: $\frac{315,392 \text{ kg } CO_2}{3205 \text{ GJ}} = 98.40 \text{ kg } CO_2 / \text{GJ}$

For electricity: $\frac{55,108 \text{ kg } CO_2}{245 \text{ GJ}} = 224.9 \text{ kg } CO_2 / \text{GJ}$

Table 2. Allocated Emissions and Emission Rate Results Using the Efficiency Method

	Allocated Emissions (tonne CO ₂)	Emission Rates (kg CO ₂ /GJ)
Electricity	55.1	225
Steam 1	133	98.4
Steam 2	108	98.4
Steam 3	73.8	98.4
Total	369.9	n/a

VI. Quality control

To identify calculation errors and omissions, it is recommended to follow general guidelines provided in Chapter 7 (Managing Inventory Quality) of GHG Protocol Corporate Standard (revised edition) for implementing a quality assurance process for all emission estimates. In addition, guidelines and tool on quantification of uncertainty is available at the GHG Protocol website www.ghgprotocol.org

VII. Reporting and documentation

Reporting requirements are provided in Chapter 9 (Reporting GHG Emissions) of the GHG Protocol Corporate Standard (revised edition).

In order to ensure that estimates are verifiable, the following documentation should be maintained. (See Table 3) This information should be collected for auditing and certification purposes, but is not required to be reported.

Table 3. Documentation that should be maintained

Data	Documentation Source
Fuel consumption data	Purchase receipts, delivery receipts, contract purchase or firm purchase records, stock inventory documentation, metered fuel documentation
Heat contents, emission factors, and efficiency values used other than defaults provided	Purchase receipts; delivery receipts; contract purchase or firm purchase records; IPCC, IEA, national or industry reports, test reports
Prices used to convert currency of fuel purchased to amount or energy content of fuel consumed	Purchase receipts; delivery receipts; contract purchase or firm purchase records; IPCC, IEA, national or industry reports
All assumptions made in estimating fuel consumption, heat contents, and emission factors	All applicable sources

Appendix I: Guidance on following the work potential method

For this method, GHG emissions are allocated based on the work potential of the different energy streams generated. This method is based on the assumption that the useful energy in steam corresponds to the maximum amount of work that could be done by the steam in an open (flow), steady state, and thermodynamically reversible process (the thermodynamic term for this is “availability” or “energy”). In the case where steam is used for process heat, the useful energy in steam corresponds to the heat content of the steam, or its enthalpy. Therefore, in cases where steam is used for process heating, the work potential method underestimates the amount of useful energy in the steam and should not be used. To determine the share of GHG emissions attributable to steam and electricity production, the following steps are used³. Note that if estimating emission shares for multiple GHGs (e.g., CO₂, CH₄, and N₂O), calculations for each gas should be performed separately.

Step 1: Obtain the total emissions produced for the generation of electricity and steam based on the total fuel consumption. Obtain or estimate this value for the CHP plant. This can be calculated based on the fuel mix of the CHP plant, and the guidance in the revised GHG Protocol calculation tool for “Direct Emissions from Stationary Combustion”, available on the GHG Protocol website, www.ghgprotocol.org.

Step 2: Calculate the work potential for each energy stream. For electricity, the work potential is equal to energy output. Steam may be supplied at different temperatures and pressure conditions and hence can have a different work potential to enthalpy ratio. For steam, the work potential is calculated from the specific enthalpy (or heat content) and specific entropy (a theoretical measure of energy that cannot be transformed into mechanical work) of the stream according to the formula shown below (example units are shown).

$$W_i = F_i \times [(h_i - T_{ref} \times S_i) - (h_{ref} - T_{ref} \times S_{ref})]$$

where:

W_i	=	work potential of stream i (kJ)
F_i	=	mass of steam (kg)
T_{ref}	=	reference temperature (°K)
h_i	=	specific enthalpy of steam flow i (kJ/kg)
h_{ref}	=	specific enthalpy at reference conditions (kJ/kg)
S_i	=	specific entropy of steam flow i (kJ/kg-°K)
S_{ref}	=	specific entropy at reference conditions (kJ/kg-°K)

The values of enthalpy and entropy (h_i , h_{ref} , s_i , and s_{ref}) can be found in standard steam tables that provide these values at different temperatures and pressures. Selection of reference conditions (pertaining to T_{ref} and S_{ref}) are arbitrary, and could correspond to the return condensate temperature or make up water temperature and pressure.

Step 3: Calculate the total work potential. Sum the work potential of all streams.

³ The basis for this calculation method was provided by BP, Environmental Performance Group Reporting Guidelines.

Step 4: Determine the fraction of total emissions to allocate to each energy stream. Divide the work potentials of each stream (Step 2) by the total work potential (Step 3).

Step 5: Allocate the total emissions of the CHP facility to the individual streams in proportion to their work potential. For each energy stream, multiply the fraction of emissions attributable to each stream (Step 4) by the total emissions (Step 1).

Step 6: Calculate emission rates for steam and electricity production. Divide the total emissions from each stream (Step 5) by the total amount of steam or electricity for that stream to get an emission rate (e.g., mass CO₂/amount of steam or electricity).

Step 7: Estimate emissions from purchases or sales. To estimate emissions, multiply the amount of steam or electricity either purchased or sold by the appropriate emission rate (Step 6). Units used for the amount of steam or electricity purchased or sold should be the same as used to calculate the emission rates (e.g., GJ).

Appendix II: Guidance on following the energy content method

The energy content method allocates emissions based on the amount of energy in each energy output. The energy content of electrical power is simply the amount of electricity produced by the system. The energy content of steam (or hot water) is equivalent to the energy content of the output stream minus any energy in the returned condensate. Losses due to inefficient use of either the electricity or steam outputs are not considered. This allocation method is particularly well suited for situations in which steam is used for process heat. To determine the share of GHG emissions attributable to steam and electricity production, the following steps are used⁴. Note that if estimating emission shares for multiple GHGs (e.g., CO₂, CH₄, and N₂O), calculations for each gas should be performed separately.

Step 1: Obtain the total emissions produced for the generation of electricity and steam based on the total fuel consumption. Obtain or estimate this value for the CHP plant. This can be calculated based on the fuel mix of the CHP plant, and the guidance in the revised GHG Protocol calculation tool for “Direct Emissions from Stationary Combustion”, available on the GHG Protocol website, www.ghgprotocol.org.

Step 2: Calculate the energy content for each energy stream. For electricity, the energy content is equal to energy output. For steam, only the fraction of the total energy in steam (or hot water) that can be used for process heating is considered. Furthermore, it is assumed that the steam is used for indirect heating, with condensates returned to the CHP system. Alternatively, if the condensates are not returned or if a hot water output stream is considered in the allocation, reference conditions other than those shown below may be used (e.g., the temperature and pressure of boiler feed water). Therefore, the energy content of steam can be calculated using the formula shown below (example units are shown).

$$\text{Energy} = F_i \times (h_i - h_{ref})$$

Where:

F_i	=	the mass of steam in tonnes (1,000 kg)
h_i	=	the specific enthalpy of steam flow i, in kJ/kg
h_{ref}	=	the specific enthalpy at reference conditions (corresponding to returned condensates, assume at 100°C and 1 atm pressure)

The values of enthalpy (h_i , h_{ref}) can be found in standard steam tables which provide these values at different temperatures and pressures.

Step 3: Calculate the total energy content. Sum the energy content of all streams.

Step 4: Determine the fraction of total emissions to allocate to each energy stream. Divide the energy content of each stream (Step 2) by the total energy content (Step 3).

⁴ The basis for this calculation method was drawn from Annex E of the report *Calculation Tools for Estimating Greenhouse Gas Emissions from Pulp and Paper Mills*, published by NCASI in November 2002.

Step 5: Allocate the total emissions of the CHP facility to the individual streams in proportion to their energy content. For each energy stream, multiply the fraction of emissions attributable to each stream (Step 4) by the total emissions (Step 1).

Step 6: Calculate emission rates for steam and electricity production. Divide the total emissions from each stream (Step 5) by the total amount of steam or electricity for that stream to get an emission rate (e.g., mass CO₂/amount of steam or electricity).

Step 7: Estimate emissions from purchases or sales. To estimate emissions, multiply the amount of steam or electricity either purchased or sold by the appropriate emission rate (Step 6). Units used for the amount of steam or electricity purchased or sold should be the same as used to calculate the emission rates (e.g., GJ).

Appendix III. References

The following references also include those from the first edition of the GHG Protocol calculation tool and guidance document “CO₂ emissions from stationary combustion”. These revised guidelines on the allocation of GHG emissions from a CHP plant have been based in part on relevant aspects of that tool.

BP (2000), Environmental Performance – Group Reporting Guidelines – Version 2.2, Mike McMahon and Louise Johnson

CCAR (2006), General Reporting Protocol, Version 2.1, Part III, Chapter 8 – Allocating Emissions from Co-Generation, June 2006

EIA (2001), Voluntary Reporting of Greenhouse Gases, Form EIA-1605, US Department of Energy

EIA (2000), Annual Energy Review, US Department of Energy

Holderbank (2000), Holderbank CO₂ Emissions Inventory, Bruno Vanderborcht and Urs Brodmann

IEA (2000), CO₂ Emissions from Fuel Combustion

IPCC (1996a), Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Greenhouse Gas Inventory Reporting Instructions

IPCC (1996b), Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Greenhouse Gas Inventory Workbook

IPCC (1996c), Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Greenhouse Gas Inventory Reference Manual

NCASI (2002), Calculation Tools for Estimating Greenhouse Gas Emissions from Pulp and Paper Mills, National Council for Air and Stream Improvement, Inc.

UK DETR (1999), *Environmental Reporting - Guidelines for Company Reporting on Greenhouse Gas Emissions*, Department of the Environment, Transport and the Regions: London

UNEP (1998), Creating a Standard for a Corporate CO₂ Indicator, Charles Thomas and Tessa Tennant

UNEP (2000), The GHG Indicator, UNEP Guidelines for Calculating GHG Emissions from Businesses and Non-Commercial Organizations, 2000

US CHP Association (2003), Analysis of Output-Based Allocation of Emission Trading Allowances, submitted by: Energy and Environmental Analysis, Inc., June 2003

US EPA (2004), Climate Leaders Greenhouse Gas Inventory Protocol, Core Module Guidance, Indirect Emissions from Purchases/Sales of Electricity and Steam, October 2004

Appendix IV. Acknowledgements

These guidelines have been developed by the WRI/WBCSD GHG Protocol Initiative team, based in part on relevant aspects of the first edition of the “CO₂ Emissions from Stationary Combustion” calculation tool and guidance document.

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Please visit the GHG Protocol Initiative website at www.ghgprotocol.org for other GHG calculation tools.