Assessment of CO_2 emissions of electricity and heat used at industrial plants

Mirjam Harmelink
Harmelink consulting
Troosterlaan 36
3571 NN Utrecht
The Netherlands
Mirjam@harmelinkconsulting.nl

Lex Bosselaar
Netherlands Enterprise Agency (RVO.nl) formally NL Agency
Croeselaan 15
3521 BJ Utrecht
The Netherlands
Lex.Bosselaar@rvo.nl

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Abstract
Clear and unambiguous calculation rules for attributing CO_2 emissions to heat and electricity are currently lacking. We found that emission factors used by the Dutch industry to determine CO_2 emissions from electricity consumption, production or savings range from 0.4 to 0.7 kg of CO_2 per kWh. However, clear arguments for the choice of a specific emission factor are often lacking, basic information on how the factors were determined is missing and factors aren't regularly updated. One of the reasons for these varying emission factors is the different methods applied for attributing CO_2 emissions to heat and electricity produced by CHP installations. Also on the European level there is lack of clarity on how to value delivery and use of utilities like heat and electricity. As a consequence claimed CO_2 emissions reductions for different options – like cross border delivery of heat, end-use energy efficiency measures and use of renewable energy sources – in the industry cannot be properly assessed and "fair" comparison cannot be made.

This paper starts with providing an overview on various methods to attribute CO_2 emissions to heat and electricity produced with CHP installations, and concludes that the choice for a particular method can make a huge difference in how CHP heat scores compared to other CO_2 emission reduction options. Next the paper gives a comprehensive overview on different methods applied to determine CO_2 emissions per kWh electricity produced, consumed or saved, and includes a description of two methods that have been developed for monitoring purposes in the Netherlands. Finally the paper discusses the guidelines and default values developed within the framework of the "Uniform Metrics for the industry" for the allocation of CO_2 to imported and exported heat.

Introduction: need for assessment methods
When monitoring the climate impact of (renewable) energy, energy efficiency and climate policies it is often necessary to attribute CO_2 emissions to electricity and heat. In contrast to CO_2 emissions for fossil fuels (like coal, natural gas and oil), where IPCCC values on the carbon contents are a commonly accepted starting point for calculating CO_2 emissions, there are no default value for the CO_2 contents of electricity, and for heat produced with CHP (cogeneration) installations. An assessment of CO_2 emission factors and methods applied within the framework of various monitoring activities in the Netherlands revealed that factors used by the Dutch industry to determine CO_2 emissions related to electricity consumption, production or savings range from 0.4 to 0.7 kg CO_2/kWh. However, clear arguments for the choice of a specific emission factor are often lacking, basic information on how the factors were determined is missing and factors aren't regularly updated (Harmelink et al, 2012a). One of the reasons for this broad range of applied emission factors is due to the fact that there is no agreed method on how to treat CHP installations. In other words there is no agreed method on how to allocate fossil fuel inputs and CO_2 emissions to the produced heat and electricity. In countries (like the Netherlands), where CHP installations have a substantial part in the electricity supply, the choice for one or the other method can have a significant impact on the calculated CO_2 intensity of electricity.

The lack of clarity on the amount CO_2 emissions that needs to be allocated to electricity and heat, affects the result of assessments in which a comparison is made between different options for energy savings and renewable energy for specific industrial locations. A recent consultation of market parties revealed that very different approaches are applied for attributing CO_2 emissions to heat and as consequence claimed CO_2 emission reductions for various projects cannot be properly assessed and compared (Harmelink et al, 2012b). Also on the European level there is lack of clarity on how to value delivery of utilities like electricity and CHP heat. As a consequence claimed CO_2 emissions across sectors and countries cannot be properly assessed and compared. For example in the calculation of the energy performance of buildings, the efficiency of the electricity supply and the CO_2 emissions are often politically decided and not based on standardized calculations.

Our interest with this paper is to contribute to the further development of transparent and well-founded methods for attributing CO_2 emission to electricity and heat to ensure a "fair" comparison of energy savings and renewable energy options for specific industrial locations and between industries. The *first section* of this paper starts with an overview of methods applied to allocate CO_2 emissions to electricity and heat produced by CHP installations, illustrated with calculations for a set of common CHP configurations. In the *second section* various approaches and methods are discussed to attribute CO_2 emissions to electricity consumption, production and savings, distinguishing between "average" and "marginal" approaches. This section includes guidance on which methods preferably should be used for which type of monitoring activity and a description of two methods that were developed for monitoring purposes in the Netherlands. The *third section* describes guidelines that were developed within the framework of the project "Uniform metrics for the industry". The objective of this project was to improve comparison of different options to reduce CO_2 emissions at industries. This paper specifically describes the metrics that were developed for the attribution of CO_2 emission to heat produced by CHP installations.

Allocating CO_2 emissions to electricity and heat produced by CHP installations

In case of *separate* production of electricity and heat, CO_2 emission can simply be allocated to these products by multiplying (fossil) fuel input with IPCC default values for CO_2 emissions of the various fuels (IPCC, 2006). For installations *simultaneously* producing heat and electricity there is no commonly accepted method to attribute fuel input and CO_2 emissions to the produced heat and electricity. This attribution is necessary in cases where:

- Produced heat and electricity are consumed by different customers, and where a comparison needs to be made with; other means of supplying heat, implementation of end-use energy efficiency measures or the use of renewables.
- CO_2 emissions per kWh of produced electricity need to be calculated for a specific country or region. In case CHP installations supply in a substantial part of the electricity demand for a country or region, CO_2 emissions of these installations need to be allocated to the heat and electricity in order to establish a fair presentation of the development in the CO_2 emissions of the electricity production system.

Table 1 provides an overview of various methods that can be applied to allocate fuel input and CO_2 emissions to heat and electricity produced by CHP installations. The methods include allocation based on:

- *Energy content of heat and electricity*. In this method fuel input or CO_2 emissions are allocated to the produced heat and electricity based on the energy content of the produced products. The advantage of this method is that it is very simple and transparent. The disadvantage is that the energy content of the products does not correspond to the quality of the usefulness or the energy carriers. Eurostat/IEA (IEA/Eurostat, 2004) in their energy surveys recommends this method when it comes to attributing fuel to heat produced by CHP plants in cased where the heat is not sold but used by the producer.
- *Primary energy content of heat and electricity*. In this method fuel input or CO_2 emissions are allocated to the produced heat and electricity based on the primary energy content of the produced products. This means that conversion losses occurring during electricity production are taking into account when valuing the production of heat and electricity with CHP. The advantage of this method is that it is relatively simple and takes into account the differences in the primary use of the product. The disadvantage of this method is that a choice needs to be made on the assumed reference-efficiency of the electricity system in order to be able to calculate the primary factor (primary factor = 1/average efficiency of the electricity system). This method is used in the monitoring of the EED Directive (EC, 2012) and it is the proposed method in the European Therra project (Therra, 2009).
- *Exergy content of heat and electricity*. In this method fuel use or CO_2 emissions are allocated to the produced heat and electricity based the exergy content of the products. The exergy content of a product is a measure for the maximum useful work that can be performed by the product and thus an indicator for the quality of the product. The ratio between the energy and exergy content is referred to as the quality factor[1]. The advantage of this method is that it takes into account the quality of the produced products and in this ways distinguished in the impact between delivery of steam, high-temperature water and low-temperature water. The disadvantage of this method is that the temperature level of the produced heat isn't always known or that one installations produces heat at different temperature levels. This approach is recommended within the "Uniform Metrics for the industry" (Harmelink et al, 2012b) and applied in CO_2 assessment tool GHG emission reductions of biomass (AgNL, 2011).

1. Quality factor (Q_f) = Exergy content / Energy contents = $1\text{-}T_0/T_1$.
T_0 = reference temperature (usually annual average outdoor temperature).
$T_1 = T_0$ plus the temperature level of the thermal energy flow.
E.g. the quality factor for hot water at a temperature level of 70 °C and a reference temperature of 12 °C is 1-285/343 = 0.17. The quality factor for electricity is equal to 1.

- *All savings allocated to heat or electricity*. In many cases, CHP is either studied from the perspective of electricity or heat production. In such cases, achieved savings can either be fully allocated to the electricity or the heat production. The disadvantage of this method is that a choice must be made on the reference value for heat and electricity, and this choice can have a large influence on the resulting allocation of fuel consumption and CO_2 emissions to the two products. Allocating all savings to electricity is used in the current system of electricity labelling in the Netherlands (CE, 2012) and for the allocation of free emission right to heat under the EU-ETS (EC, 2011).
- *Other criteria.* The allocation of fuel input or CO_2 emissions to heat and electricity can also be based on other choices e.g. the economic value of the products or the wish that saving should be "fairly" distributed among the involved parties. The latter approach is currently applied for a large range of monitoring activities in the Netherland (see next section "Allocating CO_2 emissions to electricity consumption, savings and production" for more details) (ECN, 2001; AgNL, 2010). While establishing these methods discussions arose on the distribution of the achieved saving resulting in the compromise of a 50 %-50 % sharing of savings between heat and electricity. The disadvantage of this approach is that; the definition of "fair" distribution can give rise to much discussion, the method is difficult to apply for individual installations/project and it is only applicable for a small range of efficiencies (for low electricity or heat production results are meaningless).

Figure 1 and Figure 2 illustrate for a set of common CHP installations applied in the Netherland the amount of CO_2 emissions allocated to the produced electricity and heat when applying the methods listed in Table 1. The thermal and electrical efficiencies for the various installations apply to the situations when the CHP are heat driven.

The figures show that allocated CO_2 emissions can differ significantly depending on: i) the type of method used, ii) thermal and electrical efficiencies of the CHP, iii) the temperature level of the heat (expressed through the quality factor Q_f), and iv) the assumed reference efficiencies. The figures show that with increasing electrical efficiencies (E_{eff}) differences between the methods are less prominent but that for smaller installations the choice for a particular method has great influence on the way heat supply by the these CHP installations scores compared to other options. This means for these installations the choice for a particular methods needs to be well substantiated and/or a sensitively analysis should be carried out to show the impact of the various methods on the results of the assessment.

Allocating CO_2 emissions to electricity consumption, savings and production

This section discusses various approaching for attributing CO_2 emissions to electricity consumption, production and savings. The methods can be divided into two broad categories: 1) average approaches, and 2) marginal approaches.

AVERAGE APPROACHES

For average approaches in principle all electricity production resources of a country or a region are included in the calculations for the CO_2 emission per kWh. The indicator therefore represent the actual CO_2 emissions per unit of produced or consumed electricity and is used to e.g. determine the CO_2 footprint associated with electricity consumptions of a country, region or a specific industrial production company.

Table 1. Overview of available methods to allocate fuel input and CO_2 emissions to electricity and heat produced by CHP installations. Source: Harmelink (2010) based on (Blok, 2006).

Allocation Method:	Advantage	Disadvantage	Applied in/by:
1. Energy content of heat and electricity	Simple and transparent	Does not account for quality of products	IEA/Eurostat
2. Exergy content of heat and electricity	Accounts for quality of products	Quality factor often unknown, relatively high share of fuel is allocated to electricity	Uniform metric for the industry CO_2 assessment tool GHG emission reductions of biomass
3. All savings allocated to electricity	Simple	Heat production is relatively poorly valued, choice must be made for reference heat efficiency	Electricity labelling EU-ETS
4. All savings allocated to heat	Simple	Electricity production is relatively poorly valued, choice must be made for reference electricity production efficiency	Energy Performance Calculation new building
5. Primary energy content of heat and electricity	Simple and transparent and relatively insensitive for choice of reference situation	Choice must be made on reference efficiency for electricity production	Monitoring of the Energy Efficiency Directive Therra
6. 50 %-50 % sharing of saving between heat and electricity	"Fair sharing" of savings among heat and electricity	Definition of "Fair sharing" is open for discussion	Protocol Energy savings Protocol Monitoring Renewable Energy

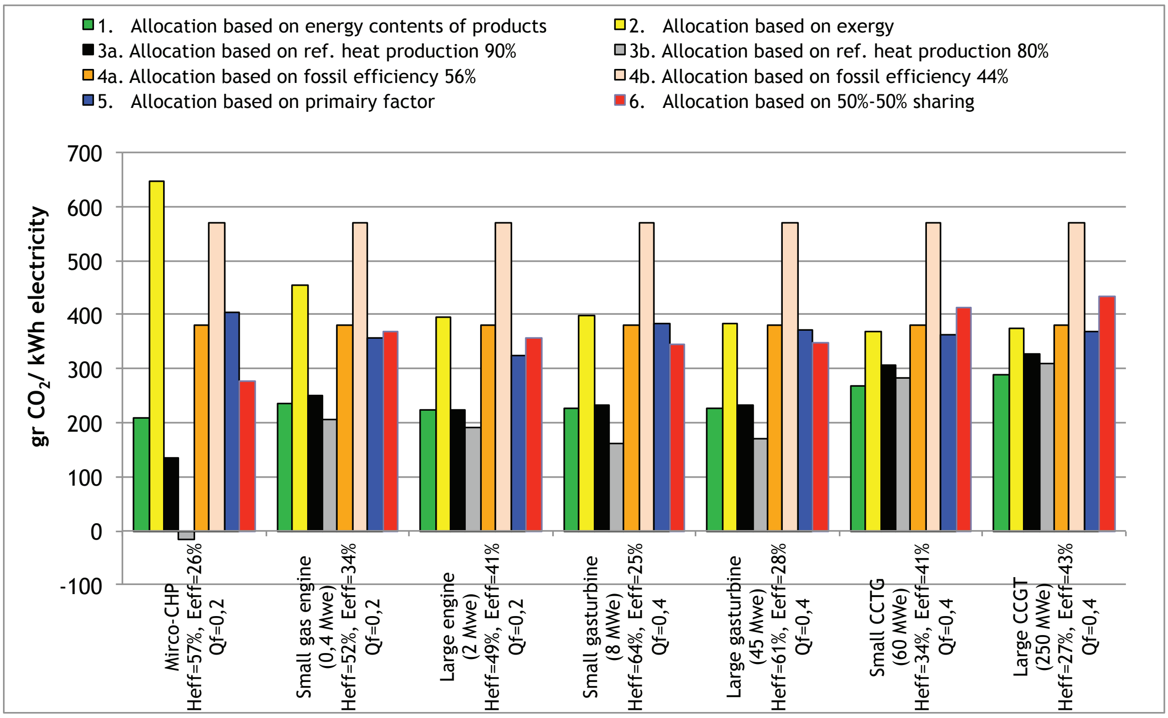

Figure 1. Kg CO_2 emissions per kWh of electricity produced applying different allocation methods and references for a common set of natural gas fired cogeneration plants. H_{eff} = thermal efficiency of the CHP installation, E_{eff} = electrical efficiency of the CHP installation, Q_f = quality factor of the supplied, CCGT = Combined Cycle Gas Turbine. Note: for method 4 CO_2 emissions per kWh are the same across all installations because all savings are allocated to the heat and for allocation of CO_2 emissions to the electricity the same reference efficiency is used across all installations. Source: Harmelink (2010).

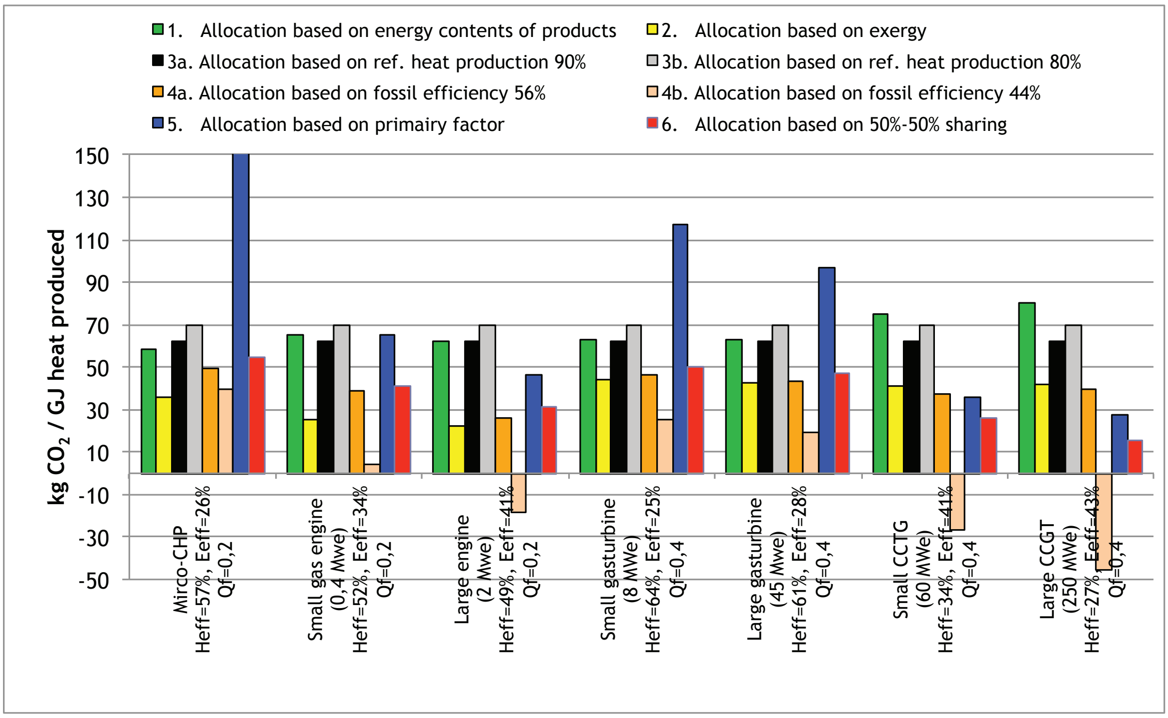

Figure 2. Kg CO_2 emissions per GJ of heat produced applying different allocation methods and references used for different types of natural gas fired cogeneration plants. H_{eff} = thermal efficiency of the CHP installation, E_{eff} = electrical efficiency of the CHP installation, Q_f = quality factor of the supplied, CCGT = Combined Cycle Gas Turbine. Note: for method 3 CO_2 emissions per GJ are the same across all installations because all savings are allocated to the electricity and for allocation of CO_2 emissions to the produced heat the same reference efficiency is used across all installations. Source: Harmelink (2010).

MARGINAL APPROACHES

Marginal approaches are being used within the framework of monitoring and evaluation activities to analyse the impact of *changes* in the *operation of existing electricity production capacity* and *the need for new capacity* due to changes in: i) electricity consumption, ii) electricity production with renewable energy sources and iii) feed-in of locally produced electricity into the grid. This implies that for marginal approaches an analysis is made which production facilities accommodate these changes. Once it is defined which part of the existing or new production capacity will accommodate these changes, the indicators can be calculated. The calculated factors represent the achieved CO_2 emission *reductions* per kWh that do not need to be produced. In the application of marginal methods the discussion is focussed on the issue which electricity production facility (which technique) or mixture of techniques needs to be defined as the marginal option. Impact on existing capacity is being analysed by defining the so-called operating margin, and impact on needs for new investments is being analysed by defining the build margin.

- "Operating margin" includes existing power plants, which can increase or decrease their electricity output quickly (short ramp up and down time) depending on the demand for electricity. In the Netherlands usually natural gas-fired power plants accommodate short-term fluctuations in demand and are therefore usually defined as the operating margin.
- "Build Margin" includes electricity production capacity, which need not be built or for which the capacity may be reduced because the demand for electricity decreases or production of electricity from renewable energy sources increased.

Figure 3 provides an overview of most commonly used methods for calculating emission factors for both operating margin and build margin approaches. Which production facilities are included in the definition of the operating and build margin depends upon a variety of factors: i) the purpose of the analysis, ii) the geographical and time scale of the analysis, iii) predictability and controllability electricity production from renewable energy sources and other local production (including CHP). After the operational and build margin is defined a specific method or model is chosen.

METHODS DEVELOPED FOR THE NETHERLANDS

An assessment of CO_2 emission factors and methods applied in the Netherlands showed substantial differences in the calculated CO_2 intensities per kWh applied in the Netherlands due to different choices made in the development of the method. Dutch parties responsible for monitoring activities therefore took the initiative to provide: i) more guidance on which method to use in which situation, ii) to develop an average and marginal method that are clearly described, and iii) to calculate emissions for both approaches (Harmelink et al, 2012a).

"Integral method"

The developed average method – called the "Integral Method" – includes the following choices and assumptions:

- *Type of electricity production facilities included in the calculations.* All electricity production facilities within the Dutch borders are taken into account to calculate the CO_2 intensity of electricity, including installations using renewable sources and CHP installations. The fact that the electricity production mix gets less carbon intensive due to more renewable energy production is in this way reflected in the calculation

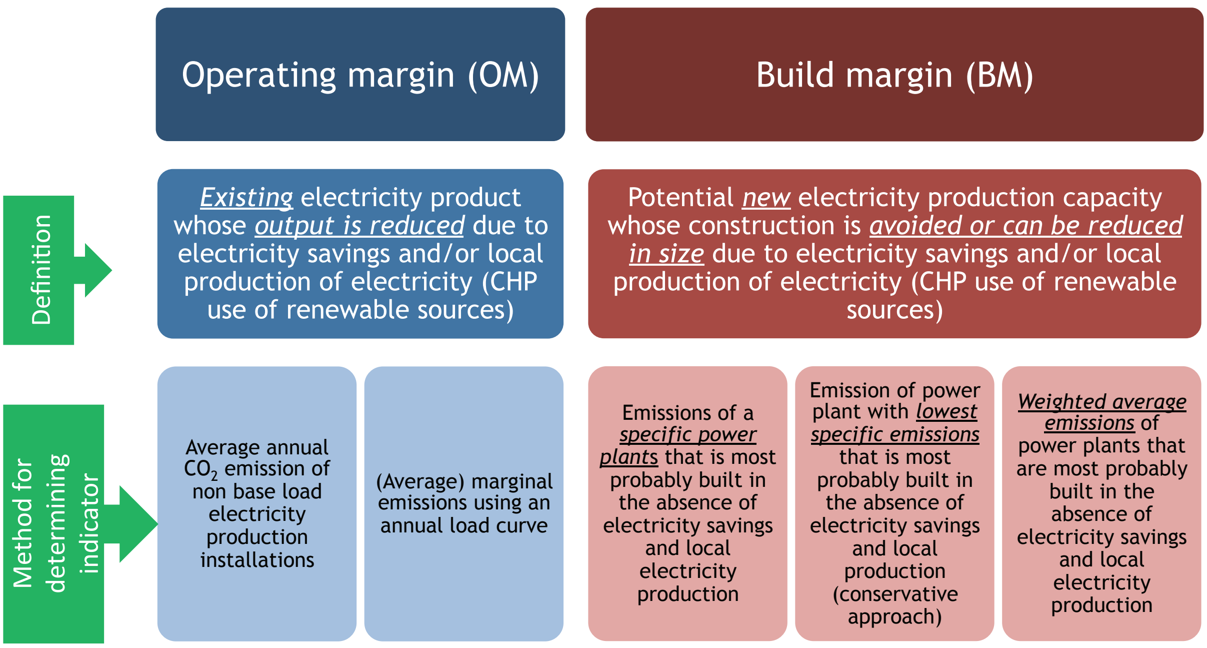

Figure 3. Overview of applied marginal approaches (WRI, 2007).

of the indicator. For electricity produced with biomass it is assumed that on the European level sustainability criteria will be developed for solid biomass similar to the criteria for liquid biomass, and that in case biomass meets these criteria CO_2 emissions are 'zero' (EC, 2009) (EC, 2010a).

- *Treatment of CHP installation.* The "Integral Method" distinguishes between:
  - *Heat driven CHP installations* that have the primary objective to fulfil heat demand and where electricity in more a less a by-product. The "Integral Method" follows the approach developed within the framework of the "Protocol for energy savings" in which energy savings by CHP (compared to a reference efficiency of 90 % for heat production and an efficiency of the central Dutch power production park for electricity) are 50 % allocated to heat and 50 % to electricity (ECN, 2001) (Method #6 in Table 1).
  - *Electricity driven CHP installations* that have the primary objective to fulfil electricity demand but besides produce a relatively small amount of heat. As a result of heat production the electrical efficiency of these production plants is lower than for "electricity-only" installations. Fuel is allocated to the produced heat using an auxiliary factor of 4, i.e. each GJ of heat is allocated ¼ GJ of fuel. Next savings (compared to a reference efficiency of 90 % for heat production and an efficiency of the central Dutch power production park for electricity) are 50 % allocated to heat and 50 % to electricity (ECN, 2001).
- *Treatment of installations that besides the production of heat and electricity also have another function* (e.g. waste incineration plants) *or where CO_2 emissions mainly belong to other production processes*. For waste incineration plants the main activity is burning waste besides they produce electricity and heat. There is no accepted method for the allocation of CO_2 emission to these 3 functions (see for discussion on this topic Harmelink *et al*, 2009). This is also the case when using blast furnace, coke oven and chemical waste gases for electricity production. In these cases CO_2 emissions leaving the chimney at the electricity production plant for a large part should be allocated to the steal or the chemical production process. The "Integral method" assumes that CO_2 emission per kWh electricity produced by waste incineration plants and plants using blast furnace, coke oven or chemical waste gases, is equal to CO_2 emissions of the Dutch power mix (including renewables but excluding waste incineration plants, and installations using blast furnace and coke over gas).
- *Treatment of import and export of electricity*. Import of electricity in principle affects CO_2 emissions of electricity consumed in the Netherlands. It is however very difficult to trace CO_2 emissions of imported electricity. The situation is similar for export of electricity, as it is difficult to determine the CO_2 emission factor that should be attributed to electricity being exported. The "Integral Method" therefore takes into account the electricity, and related CO_2 emissions, which is being produced within the Dutch borders and not the electricity that is consumed.
- *Setting project boundaries*. The "Integral Method" sets the project boundaries around the production installations and the transport infrastructure. This implies that CO_2 emissions related to extraction, refining and transport of raw materials and electricity production equipment are not included in the calculations. This is in line with the approach currently applied by the Dutch statistical bureau and Eurostat (IEA, Eurostat, 2004). Analysis furthermore shows that for current electricity production systems > 95 % of CO_2 emissions occur during the production of electricity (IPCC, 2012).
- *Net versus gross electricity production.* The CO_2 emissions per kWh are in the end calculated including net electricity generation for the Netherland. This means that total electricity production is corrected for auxiliary electricity use at the power plants and transmission and distribution losses.
- *Only direct and indirect emissions in scope 1 and no full life-cycle approach.* The methodology takes into account only the CO_2-emissions caused by the generation of electricity. The production of coal, oil or biomass is not taken into account. In terms of life-cycle analysis, this means that only scope 1 and 2 emissions are included. Scope 3 emissions are excluded. A full life-cycle analysis is possible, but not in line with the current methodology by IEA and Eurostat.

"Reference Park method"

The simplified marginal method – called the "Reference park" method – that was developed for the Netherlands (ECN, 2011a). This method is called "Reference park", because the main energy producing park is assumed to be the marginal producer. The rest of the park includes renewable energy that has priority on the grid and a lot of heat driven CHP. This method includes the following choices and assumptions:

- *Definition of the marginal option*. The marginal production mix is defined as all fossil fuelled and nuclear electricity production installations in the Netherlands wholly or for the major part producing electricity, which is fed into the high voltage grid. This means that it is assumed that changes in demand for electricity as a result of electricity savings, production with renewables and local electricity production is accommodated by reducing output of these production installations.
- *Electricity production facilities included in the calculations.* The marginal production mix includes: i) centralized production installations that only produce electricity, and ii) centralized production installations that next to electricity produce a relatively small amount of heat (electricity driven CHP installations) (up to 20 % of the fuel input). This implies that all centralized production units that produce more heat and decentralized CHP installations are not included in the marginal production mix. Arguments to exclude these installations from the definition of the marginal option are that that these installations are usually "heat driven" (i.e. they have to meet a certain heat demand) and are therefore not flexible to accommodate short-term changes in electricity demand.

Table 2. Indicators for the 'Integral Method' and the "Reference Park Method" (CBS, 2013a).

	Integral method			Reference Park Method		
	CO_2-emission factor	Primary fossil energy use (LHV)	Efficiency on primary fossil (LHV)	CO_2-emission factor	Primary fossil energy use (LHV)	Efficiency on primary fossil (LHV)
	kg/kWh	MJprim/kWh	%	kg/kWh	MJprim/kWh	%
2000	0.55	8.3	43.5	0.64	9.0	40.0
2001	0.56	8.5	42.6	0.65	9.1	39.4
2002	0.55	8.4	43.0	0.65	9.1	39.4
2003	0.55	8.4	43.0	0.64	9.1	39.6
2004	0.53	8.1	44.2	0.62	9.0	40.2
2005	0.51	7.9	45.5	0.62	8.9	40.3
2006	0.50	7.7	47.0	0.61	8.7	41.2
2007	0.50	7.7	46.8	0.60	8.7	41.5
2008	0.49	7.6	47.5	0.61	8.8	40.8
2009	0.48	7.4	48.6	0.59	8.6	41.6
2010	0.46	7.2	49.8	0.57	8.4	42.7
2011	0.44	7.0	51.7	0.56	8.2	43.6

- *Allocation of fuel to electricity driven CHP installations.* The "Reference Park method" follows the same approach as the "Integral Method" for these installations.

Results for the Netherlands

Table 2 provides an overview of the resulting indicators for the "Integral method" and the "Reference Park Method". Next to the CO_2 emissions factor the table also shows the primary fossil energy use per kWh (based on the lower heating value[2] of the fuels) and the efficiency on primary fossil (equal to net electricity generation divided by total fossil fuel input that can be attributed to electricity production). Table 2 shows that the CO_2 emission factor decreased by 20 % for the Integral method and with 13 % for the Reference park method over the period 2000–2011.

Allocating CO_2 emissions to imported and exported heat at industrial locations

Stimulating the use and exchange of heat is one of the ways for the Dutch government to reduce emissions of CO_2 and realise energy savings. A consultation among market parties by NL Agency revealed that very different approaches are applied for attributing CO_2 emissions to imported and exported heat at industrial locations. This has consequences for the way in which investments in cross-border heat-exchange 'score' in terms of CO_2 reductions compared to investments in other energy savings and renewable energy options. NL Agency therefore took the initiative to develop a set of clear guidelines and calculations rules for attributing CO_2 to imported and exported heat, which were developed within the framework of the project "Uniform Metrics for the industry" (Harmelink et al, 2012b). The "Uniform Metrics" distinguishes the following situations:

2. The quantity known as lower heating value (LHV) (net calorific value (NCV) or lower calorific value (LCV)) is determined by subtracting the heat of vaporization of the water vapor from the higher heating value.

A: HEAT DRIVEN CHP INSTALLATIONS

Heat driven CHP installations have the primary objective to fulfil heat demand and electricity in more a less a by-product. We distinguish between:

- An industrial producer who has full operational authority over the CHP and uses the produced heat for its own production processes. The produced electricity is used either for own production processes or fed into the grid. In this situation the industrial producer can claims full savings and CO_2 reductions achieved with the CHP installations. In this case there is not need for allocation of CO_2 emissions.
- An industrial producer who purchases heat from a CHP plant, which is operated and owned by a third party. In this case the industrial manufacturer can only claim the energy savings can CO_2 reductions related to the consumed heat produced by the CHP installation. For these situations the "Uniform Metrics" recommends to allocate fossil fuel input and CO_2 emissions to the produced heat based on the exergy content of the products. Arguments to select this method were that this method makes it possible to distinguish between the quality of high-pressure steam, low-pressure steam and hot water.

B: ELECTRICITY DRIVEN CHP INSTALLATIONS

Electricity driven CHP installations have the primary objective to fulfil electricity demand but besides produce a relatively small amount of heat. Operators driving these installations knowingly choose to either produce less or no electricity with the aim to produce more heat when this results in a positive case for the systems as a whole. Industries can purchase this heat, which replaces locally produced heat or steam (with e.g. a boiler or a CHP unit), to drive their production processes. Because the customer only purchases the heat a choice needs to be made on how much CO_2 emissions should be allocated to the heat and the electricity produced with these installations. The "Uniform metrics" recommend for electricity driven CHP installations to allocate all savings to the consumed heat using the power loss factor. Arguments for this approach are that the primary objective of the plant is electricity generation. The operator normally calculates the loss in electricity production caused by the heat production. The "Uniform Metrics" follows this well-established principle, which means that all the savings are contributed to the heat production. As the heat production is small, the impact of this choice on the emissions attributed to the electricity production is very small.

Power losses with heat production

Electricity driven CHP installations produce less electricity when delivering heat, this can be expressed into a so-called power loss factor (GJ_e loss/GJ_{heat} produced). The size of these power losses will depend on the temperature level of the heat and the type of installation. At large power stations electricity is produced by first burning fossil fuels to produce steam, in the next step the thermal energy of the steam is converted into kinetic energy by allowing the steam to expand along a turbine and letting the turbine drive a generator producing electricity. The produced steam enters the turbine typically at temperature levels between 450 °C and 500 °C. Large power stations can still produce electricity at very low pressures (large vacuum in the condenser). With cooling water at a temperature of typically 7–14 °C electricity can be produced from the steam up to an exhaust temperature of about 20 °C. For smaller plants (e.g. waste incineration installations) the vacuum and thus the lowest temperature at which electricity can be produced in the turbine is higher (typically 40 °C–50 °C). For even smaller plants, like e.g. gas engines, the temperatures up to which electricity is produced are even higher, as the flue gasses (in this case the 'working' medium) leaves the electricity-generating process already at a temperature of about 400 °C. The "Uniform metrics" recommends using actual power loss data for a particular plant in case these are available. If these data are not available, or in case of exploratory scenario calculations, it is recommended to use the following guidelines and default data:

- For heat delivered at temperature level > 200 °C it is assumed that the steam will be directly tapped from the steam boiler and the steam will not expand across the turbine in order to produce, implying that and that no electricity is being produced. This means that power losses are equal to the electrical efficiency of the particular installation (see Table 3 for an overview of recommended default values for various techniques).
- For heat at a temperature level < 200 °C it is assumed that power losses are depending on the temperature level at which the heat is delivered with the user and the exhaust temperature at the turbine.

Figure 4 provides an overview of power losses in case of heat delivery for temperature levels at the user between 80 °C and 200 °C as a function of exhaust temperatures of the turbine of 50 °C and 20 °C. The lines in this graph were calculated taking the ideal Carnot efficiency[3] for different temperature levels and correcting these efficiencies for losses that occur in practice. By multiplying the Carnot efficiency by a factor of 0.65, the efficiencies come close to values for power losses known from field measurements (e.g. SenterNovem, 2007).

Allocating fossil fuel use and CO_2 emission to power losses

Assuming that total demand for electricity for a specific country or region will not decrease the loss in power production needs to be compensated by an increase in production by other installations. As we have seen in the section "Allocating CO_2 emissions to electricity consumption, savings and production" of this paper, analysing *changes* in electricity production systems requires the application of a marginal approach for determining the fossil fuel use and CO_2 emission per GJ_e (or kWh). As it is in most cases hard to determine which specific installation will provide the additional electricity the "Uniform Metrics" recommends to assume that power losses are offset by additional production elsewhere in the Dutch power production park and indicators for the "Reference Park method" are used to calculate CO_2 emissions that need to be allocated to the heat. When allocating CO_2 emissions and fossil fuel use to heat produced by waste incineration plants it is taken into account that 54 % of the waste that goes into the incineration is biogenic in 2012 (CBS, 2013b). This biogenic input is considered as renewable under the European Renewable Energy Directive and therefore included in the calculations with zero CO_2 emission.

C: WASTE HEAT RECOVERY

In the "Uniform Metrics" waste heat is defined as heat that at the current location cannot be utilized and in the current situation would disappear in the environment through the chimney or the cooling water. This means that the heat at this point in time has no economic value for the operator. In case of waste heat recovery this heat is put to economic use in industries, households, office buildings, greenhouses, etc. to replace heat production with e.g. boilers. Waste heat does not lead to efficiency losses in the system from which the heat is recovered. However, additional energy is needed for pumping and compressing of the heat. The amount of energy needed can vary widely in practice. The default value recommended in the guidelines is to allocate 0.09 GJ primary energy per GJ of waste heat recovered (ECN, 2011b). CO_2 emission reductions and fossil fuel saving due to the utilization of waste heat recovery are calculated by assuming that in absence of waste heat use this heat is produced with a natural gas-fired boiler with an efficiency of 90 %. The guidelines do not prescribe how the parties involved in import and export of waste should share the CO_2 reductions. The only condition that the guidelines state is that double counting is avoided.

Conclusions and discussion

This paper shows that a variety of methods can be applied to attribute CO_2 emission to cross-border delivery of heat and electricity. The choice for a specific method has consequences for the claimed amount of CO_2 emissions reductions for investments in cross-border delivery of heat and electricity. As a consequence different options that can be applied in the industry to reduce CO_2 emissions – next to exchange of heat, investments in end-use energy efficiency measures and using of

3. Carnot efficiency (%) = 1 - (Exhaust temperature + 273) / (Temperature with user + 273).

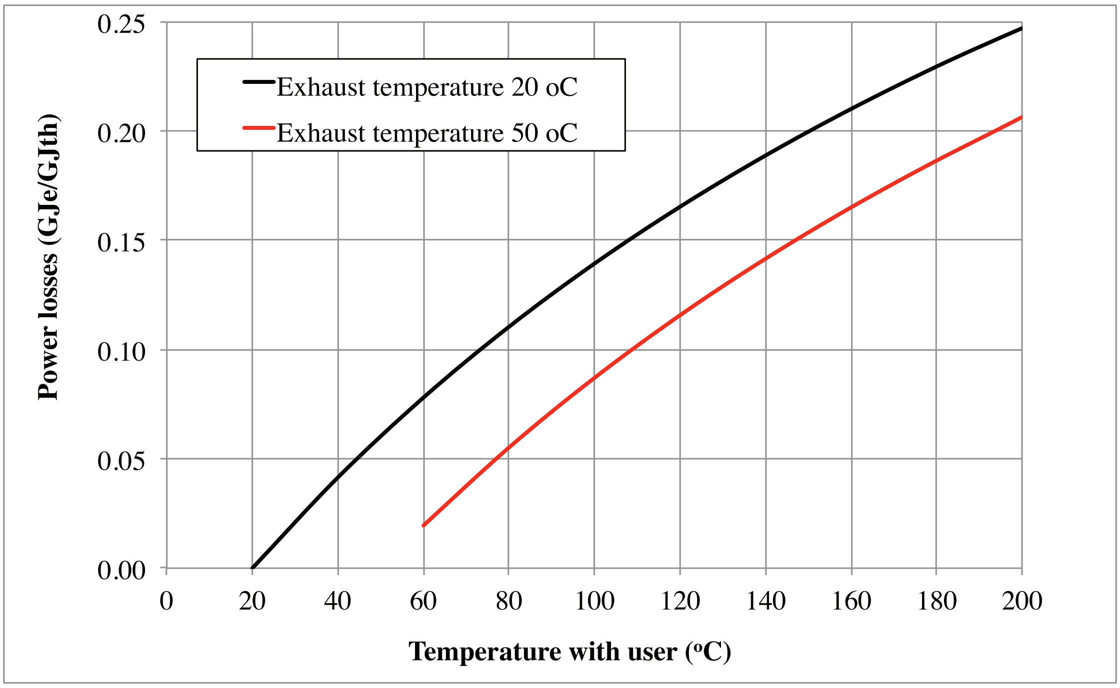

Figure 4. Power losses in case of heat delivery for temperature levels at the user between 80 °C and 200 °C. The red line indicates the power losses with an exhaust in the turbine of 50 °C and the black line with an exhaust temperature of 20 °C.

Table 3. Recommended default values for power losses at different temperature levels and for different technologies.

GJ electricity/GJ heat	T > 200 °C	T < 200 °C
Waste Incineration Plant	0.20–0.25	Power losses = 0.65 × Carnot efficiency
Coal fired power plant	0.40	
Natural gas fired power plant	0.60	

Table 4. Calculated default CO_2 emission factors and fossil fuel allocated to various sources for tap heat for 3 different temperature levels (excluding emissions related to energy use of pumping and losses of heat during transport and distribution).

	kg CO_2/GJ heat			Fossil fuel GJ/GJ Heat		
	> 200 °C	120 °C	60 °C	> 200 °C	120 °C	60 °C
Waste Incineration plant	15.9	9.2	1.5	0.23	0.51	0.08
Coal fired power station	62.2	18.0	3.0	0.91	0.26	0.04
Natural gas fired power station	93.3	18.0	3.0	1.37	0.26	0.04

renewable energy sources – are currently not properly assessed and a "fair" comparison cannot be made.

In this paper we have shown how for the Netherlands we reached agreement on methods and default numbers that are currently broadly applied by parties responsible for monitoring in the Netherlands. These methods in principle can be easily applied to calculate emission factors for other countries as well, as they usually do not require additional data gathering. Input data are a set of default (conversion) factors and statistical information that is annually gathered by most national statistical bureau. The IEA recently published a report on CO_2 emissions factors for electricity production using electricity statistics submitted to them (IEA, 2013).

With this paper we like to make a first step to start a discussion on harmonisation of methods around Europe and address issues like: growing share of renewables and how this affects calculated impact of energy savings and how to value electricity from CHP units. In our view the following European policy fields could benefit from this discussion:

- Within the framework of the Energy Efficiency Directive (EC, 2012b) savings on electricity in kWh can be converted to saving in primary energy terms applying a default coefficient of 2.5. However, Member States are allowed to apply a different coefficient provided they can justify it but no guidance is available at this point in time.

- Within the framework of the Renewable Energy Directive (EC, 2009) every two years Member States have to submit a progress report to the Commission, which needs to include an estimate of the net greenhouse gas emission savings due to the use of energy from renewable sources. However, no specific guidance is provided on CO_2 emission factors to be applied to calculate CO_2 reductions from renewable energy production and not all countries are transparent on the factor they applied.
- Within the framework of the Energy Performance (EC, 2010b) of building directive the energy performance certificate for buildings should also provide information about the actual impact of heating and cooling on the primary energy consumption and on the carbon dioxide emissions.

References

AgNL (2010). Protocol Monitoring Renewable Energy. Update 2010 (Protocol Monitoring Hernieuwbare Energie. Update 2010. AgentschapNL, Utrecht, December 2010.

AgNL (2011) Methodology CO_2-tool for electricity, gas and heat from biomass. Agentschap NL, Utrecht, May 2011.

Blok (2006) Introduction to energy analysis. Techne Press, Amsterdam 2006. (Section 8.4 Allocation in multi-output processes).

CBS (2013a) Efficiencies and CO_2 emissions of electricity production in the Netherlands, update 2011 (Rendementen en CO_2-emissie van elektriciteitproductie in Nederland, update 2011. CBS, Den Haag.

CBS (2013b) Hernieuwbare energie in Nederland 2012. Centraal Bureau voor de Statistiek.

CE (2012) Achtergrondgegevens Stroometikettering 2011. CE, Delft.

EC (2009) Directive 2009/28/EC of the European Parliament and the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

EC (2010a) Report from the commission to the Council and the European Parliament on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling. European Commission, 2010.

EC (2010b) Directive 2010/31/EC of the European Parliament and the Council of 19 May 2010 on the energy performance of buildings.

EC (2011) Commission Decision of 27 April 2011 determining transitional Union-wide rules for harmonised free allocation of emission allowances pursuant to Article 10a of Directive 2003/87/EC of the European Parliament and of the Council.

EC (2012) Directive 2012/27/EU of the European Parliament and the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC.

ECN (2001) Protocol Monitoring Energy Savings (Protocol Monitoring energiebesparing) ECN, CPB, RIVM, Novem, December 2001.

ECN (2011a) Calculation of the reference efficiency of electricity production (Berekening referentierendement voor de opwekking van elektriciteit) ECN-N-11-016.

ECN (2011b) Waste heat recovery: potentials, savings and alternatives (Restwarmtebenutting. Potentiëlen, besparingen, alternatieven). ECN-E-11-058, November 2011.

Harmelink (2010) Discussion Memo: CHP: comparing (1) definitions, (2) references to calculate energy savings and CO_2 reductions, and (3) allocation methods (Discussienotitie "Warmtekrachtkoppeling (WKK)" Een vergelijking van gehanteerde (1) definities voor WKK, (2) referenties bij het berekenen van energiebesparing en CO_2-prestaties, en (3) allocatiemethoden) Harmelink consulting iov Agentschap NL, mei 2010.

Harmelink M, D Phylipsen (2012b) Uniform Metrics for the industry (Uniforme maatlat voor de industrie). SQ Consult, Utrecht, 2012.

Harmelink M, L Bosselaar (2009) Valuation of tap heat from power stations and waste incinerations plants (Waardering van warmte uit aftapinstallaties en afvalverbrandingsinstallaties). Harmelink consulting, Agentschap NL, November 2009.

Harmelink M, L Bosselaar, J Gerdes, R Segers, M Verdonk (2012a) Calculation of CO_2 emission, primary fossil energy use and efficiency of electricity in the Netherlands (Berekening van de CO_2-emissies, het primair fossiel energiegebruik en het rendement van elektriciteit in Nederland). Agentschap NL, CBS, ECN, PBL.

Harmsen R, W Graus (2013) How much CO_2-emissions do we reduce by saving electricity? A focus on methods. Energy Policy, 2013, vol. 60, issue C, pages 803–812.

IEA/Eurostat (2004) Energy Statistics Manual IEA, OECD, Eurostat, Paris.

IEA (2013) CO_2 emission from fossil fuel production. IEA Statistics 2013.

IPCC (2006) IPCC Guidelines version 2006.

IPCC (2012) Renewable Energy Sources and Climate Change Mitigation Special Report of the Intergovernmental Panel on Climate Change. 2012.

SenterNovem (2007) Heat Delivery Systems in the Netherlands (Warmteleveringssystemen voor Nederland. Hoofdrapport) Juli 2007 (concept). Blz 49.

Therra (2009) THERRA Project WP3 – Proposal for the definition and calculation principle for renewable heat. Therra, June 2009.

WRI (2007) Guidelines for Quantifying GHG Reductions from Grid-Connected Electricity projects. WRI/WBCSD, August 2007.