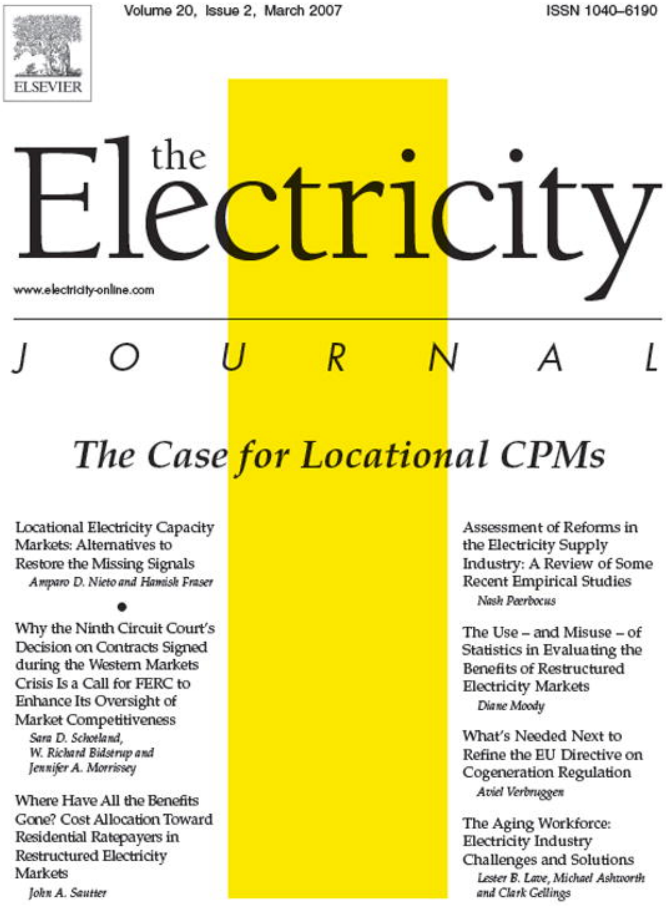
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What's Needed Next to Refine the EU Directive on Cogeneration Regulation

Efforts to develop a more precise definition and measurement of cogenerated electricity than those contained in the European Union's 2004 Directive have made real progress, but additional improvements are needed to yield a better-founded, more transparent methodology. The author offers suggestions on how to complete this important job.

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I. Introduction

In 1997, the EU Commission starts the regulation process to support and promote cogeneration (or, to use the term most commonly used in Europe, combined heat and power, or CHP) with a position paper.[1] After two draft versions were discussed,[2] the final Directive[3] was published in February 2004, but still fell short of providing a harmonized and consistent approach to CHP, the ultimate goal of such directives.

Although it may seem odd at first sight, the bottleneck holding up an effective regulation has been the definition (and measurement) of what truly is CHP activity. The manager's maxim ''You cannot manage what you cannot measure'' is equally valid for regulators, who ''cannot well regulate what they do not define precisely.''

The variable generally accepted as the best indicator of CHP activity is the quantity of cogenerated electricity E_{CHP}. The problem is defining this variable and measuring it when cogeneration takes place *joined to* condensing power generation. Once this has been solved, further steps in qualifying cogeneration activities are feasible. Without solving the problem, qualifying based on the wrong magnitudes is perverse for the future development of CHP.[4]

In this article, I first discuss how the problem is addressed by the EU (using "EU" as short-hand for the three institutes that prepare, discuss, and finally adopt Directives: the Commission, the Parliament, and the Council of Ministers). Then I present the methodology proposed by CEN (short for the CEN/CEGELEC Workshop Agreement CWA 45547). Finally, I identify the weak point in the CEN proposals and show how my methodology remedies the weakness while improving transparency and regulatory incentives and answering the remaining questions of the EU Directive itself.

The symbols used in this article are listed in **Table 1**, along with their equivalents in other sources.

Table 1: CHP Nomenclature

Q	Heat flow (Wh)[a].
Q_{CHP}	$=Q_{useful}$, heat recovered in thermal power generation for an end use.
Q_{Cond}	$=Q_{waste}$, heat dissipated related to condensing thermal power generation.
Q_{plant}	Heat set free at the thermal power generation process, i.e., $Q_{CHP} + Q_{Cond}$.
E	Electricity flow (Wh)[a].
E_{CHP}	Electricity output from cogeneration activity of the CHP plant.
E_{Cond}	Electricity output from condensing activity of the CHP plant.
E_{plant}	Electricity output of the CHP plant, i.e., $E_{CHP} + E_{Cond}$.
F	Fuel flow (Wh)[a].
F_{CHP}	Fuel devoted to combined or back-pressure power generation in a CHP plant.
F_{Cond}	Fuel spent on the condensing activity in a CHP plant.
F_{plant}	Fuel consumed by the CHP plant, i.e., $F_{CHP} + F_{Cond}$.
S	*Bliss point* of the production possibility set of a CHP process, where at maximum output of useful heat the cogenerated power output is also maximized. Complex CHP processes can exhibit multiple bliss points, while they also can be virtual (=outside the actually attainable production possibilities).
σ	*Design* power-to-heat ratio of a CHP process. Mostly σ is the constant power-to-heat ratio at the single bliss point S of the CHP process, but more variable situations can be accommodated by writing σ as a function (see analysis).
η	Overall energy conversion efficiency of the CHP plant $(E_{plant} + Q_{CHP})/F_{plant}$.
η_{CHP}	Energy efficiency of CHP activity or $(E_{CHP} + Q_{CHP})/F_{CHP}$.
η_{Cond}	Efficiency of the pure condensing activity of the CHP plant (E_{Cond}/F_{plant}) when $Q_{CHP} = 0$.
β	Power loss factor by a heat extraction at a steam turbine (directly linked to σ through η_{Cond} and η_{CHP}).

[a] With capacities in W (Watt) and energy in Wh, units can represent both capacities and (momentary or average) hourly energy flows.

II. The EU Directive 2004/8/EC on Identifying and Quantifying CHP Activity

CHP activity of a given thermal power plant within a given period of time is characterized by three energy flows: the amount of recovered useful heat Q_{CHP}, the amount of cogenerated electricity E_{CHP} and the amount of fuel consumption related to the cogeneration activity as such F_{CHP}. The first quantity Q_{CHP} is directly measurable when agreement is reached on where and how to meter the recovered heat flows, as, e.g., the CEN proposal presents with care. The quantities of cogenerated electricity E_{CHP} and of the related fuel consumption F_{CHP} are not directly observable in case cogeneration and condensing activities are joined (mixed) activities (mostly the case in large-scale CHP plants).

There is consensus that basing the qualification of CHP on the sole variable of recovered, useful, or cogenerated heat Q_{CHP} is not satisfactory, because it lacks incentives to improve and maximize the *quality* of the CHP activity expressed by the power-to-heat ratio. Therefore one also wants to know E_{CHP}, the amount of cogenerated power.

Defining and measuring E_{CHP} is not a problem when the CHP plant is limited to only cogeneration activity (e.g., a back-pressure

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steam turbine) and *cannot* operate in condensing or in mixed modes. But when joint condensing and cogeneration activities take place, one needs a method to split the cogeneration activity from the condensing activity. This issue is addressed in Annex II of the EU CHP Directive.

Annex II is titled ''Calculation of Electricity from Cogeneration'' (EU-OJ, at page L52/58). It opens with ''Values used for calculation of electricity from cogeneration shall be determined on the basis of the expected or actual operation of the unit under normal conditions of use. For micro-cogeneration units the calculation may be based on certified values.'' Then it splits the approach into two cases. First, when the overall thermal efficiency η of the operations exceeds 75 percent for steam back-pressure turbines, gas turbines with heat recovery, internal combustion engines, micro-turbines, stirling engines, and fuel cells, all power generated is accepted to be cogenerated. Analogously, an 80 percent η efficiency threshold applies for CCGTs with heat recovery and for steam-condensing extraction turbines.

Second, when overall efficiency η falls short of the stated thresholds of 75 percent/80 percent, cogenerated electricity E_{CHP} should be calculated according to the formula $E_{CHP} = CQ_{CHP}$, with C the power-to-heat ratio.[5] Article 3(k) of the Directive (at L52/53) states '''power-to-heat ratio' shall mean the ratio between electricity from cogeneration and useful heat when operating in *full cogeneration mode* using *operational* data of the specific unit.'' This definition improves the versions of the first 2002 draft by emphasizing the *full* cogeneration mode for the measurement of C. However, the use of operational data for assessing C requires more detail about how to proceed for a variety of technologies and circumstances,

The EU Directive is very incomplete in its treatment, even though good identification and measurement is a prerequisite for good regulation.

e.g., when a steam power turbine is designed to function partially (e.g., 25 percent) as a cogeneration turbine. One would expect to get the necessary detail in Annex II, but it is only stated that C is the ''*actual* power-to-heat ratio.'' And when the latter is ''not known, the following default values may be used, notably for statistical purposes, . . ., provided that the calculated cogeneration electricity is less or equal to total electricity production of the unit [sic].'' Then follows a table with C values: 0.95 for a combined-cycle gas turbine (CCGT) with heat recovery; 0.45 for a steam back pressure and steam condensing extraction turbine; 0.55 for a gas turbine with heat recovery, and 0.75 for an internal combustion engine.

Here I limit the discussion on how the EU treats the subject of quantifying CHP activity to two points.

First, the EU Directive is very incomplete in its treatment of the subject, even though good identification and measurement is a prerequisite for good regulation. Starting from the right basic principle that ''the amount of electricity from cogeneration power is the product of the power-to-heat ratio and the amount of useful heat from cogeneration,'' the Directive falls short in defining the principle clearly enough and in offering solutions for the extensions of the principle to practical CHP processes, e.g., steam turbines with more than one useful heat extraction point and, e.g., CCGT plants with cogeneration. By lacking the right method, Annex II offers average default values by technology group, but this is ''*notably for statistical purposes*.'' One may question the practical value of very approximate statistical data, but more problematic is the lack of reliable data on the particular CHP activity of particular plants the EU wants to qualify as such. The wrong answer to the difficulties in quantifying cogeneration activity is to negate the question, and proceed without answer. This is what the EU does when, in Annex III, it forgets Annex II and qualifies cogeneration performance on the basis of mixed

Table 2: Range of Characteristics of CHP Plants

Technology	Capacity (MWe)	Power-to-Heat Ratio[a]	Electrical Efficiency (Percent)	Overall Efficiency (Percent)
Steam turbine	0.5–500	0.2–0.8	17–35	60–80
Gas turbine	0.25–50+	0.6–0.9	25–42	65–87
CCGT	3–300+	0.9–1.25	35–55	73–90
Ignition engines	0.15–20+	0.6–1.0	25–45	65–92

Sources: EDUCOGEN, 2001, complemented by manufacturers and field data.
[a] Values are very dependent on technical designs and for steam turbines on the temperature of the extracted heat. For CCGT they also depend on the adopted convention to include – yes or no – the gas turbine output in the cogeneration activity.

values, with perverse effects for the development of CHP.[6]

Added to the non-identification and non-quantification of E_{CHP}, the EU skips the problem of identifying and quantifying CHP fuel consumption F_{CHP}. The latter variable is also necessary to assess the efficiency η_{CHP} of the cogeneration activity of a thermal power plant.

Second, simplifying the calculation of E_{CHP} by splitting the CHP activities into two groups, as Annex II does, increases the workability of the task. Although it is true that thermal power generation surpassing overall efficiencies of 75 percent and 80 percent will be composed predominantly of cogeneration activity, threshold values, and average default values are arbitrary and should be avoided in a regulation that wants to promote ''high-efficiency CHP.'' **Table 2** shows the characteristics of CHP technologies currently available today, which vary within wide ranges. It follows that regulation on the basis of average values does not promote best practices.

Presumably because of the many caveats, the Directive is not firm in imposing its method on the Member States. Article 12 allows for ''alternative calculations'' with, e.g., §1 stating: ''Until the end of 2010 and subject to prior approval by the Commission, Member States may use other methods than the one provided for in Annex II(b) to subtract possible electricity production not produced in a cogeneration process from the reported figures.'' Although the EU is wise not to impose an emergent method, the identification issue remains open and this will not increase the harmonization that is stated as being the ''general objective of the Directive'' (''whereas n° 15,'' EU-OJ, at L52/51, where reference is made to the upcoming CEN proposals).

In the period during which the Directive was drafted, the interest group Euroheat & Power was very active in developing alternative methods[7] for the quantification problem. Their proposals were adopted by the Commission of the European Parliament in its November 2002 amendment[8] on the 2002 draft Directive, but did not make it through to the final Directive. The method was opaque and the results tended to overestimate CHP activity. Euroheat & Power participated in the CEN effort to come up with a methodology with broader acceptance.

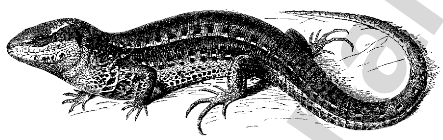
III. The CEN Propositions for Quantifying CHP Activity

Even before the EU CHP Directive was published, interested stakeholders gathered at the CEN/CEGELEC offices in Brussels to agree on a methodology to identify and quantify CHP activities more accurately than the text of the Directive offers. The consensus is published as a manual[9] and is available on the Internet. The approach is extensive; a flow-chart (CEN, at 18) summarizes it well and specific questions are addressed in separate sections (e.g., CEN section 9, at 38–40, for more complex steam turbine processes with more than one steam pass-out).

CEN admits the high importance of the CHP quantification issue, noting that ''The determination of CHP products (heat and power outputs) is important not only for the CHP Directive but also for the EU Emission Trading Scheme, State Aid guidelines for environmental improvement and the energy taxation Directive'' (CEN, at 6). CEN's objective ''is to present a set of transparent and accurate formulae and definitions for determination of CHP (cogeneration) energy products and the referring energy inputs. The CEN/CENELEC Workshop Agreement shall simply formulate the procedure for quantifying CHP output and inputs (...). It does not include quality rankings such as assessments of fuel savings or environmental impact'' (CEN, at 6). The clarity in objectives contributes significantly to the value of the work. The approach matches the analysis[10] that I submitted through Worldwide Fund for Nature (WWF) and some members of the European Parliament (in particular Claude Thurmes) during the discussions on the drafts of the Directive. In this section I show what the main remaining differences[11] are, and in the next section I discuss where the CEN quantification can be improved.

First, CEN accepts the Annex II method of dividing CHP plant outputs into two groups, according to whether the overall efficiency is above or below the fixed 75 percent/80 percent thresholds, with the ''above ones'' fully accepted as cogeneration. Table 2 shows that this approximate method is no best practice (section IV offers a straightforward alternative).

Second, for the ''below ones,'' CEN addresses the issue of separating CHP and non-CHP activity from the *mixed* activity and searches to quantify both E_{CHP} and F_{CHP} values, next to the directly measurable value Q_{CHP} during a particular period. CEN hereby distinguishes



cogeneration processes *with* power output loss by the extraction of useful heat at the thermal power process from the ones *without* power output loss when heat is recovered. CEN focuses on extraction-condensing steam turbines[12] where mixed activity and power loss are prominent, with the added complexity that useful heat extraction may occur at several pressures (temperatures). I will continue on this most important and most complex CHP case (CEN, section 9, at 38–40).

CEN proceeds through following steps:

1. Determination of the power loss coefficient(s) β (see CEN section 9.1). There is described an extensive method to measure the β values of specific mixed power generation and useful heat extraction activities.[13]

2. Determination of the efficiency of non-CHP power generation η_{Cond}. The latter value equals E_{Cond}/F_{plant} when $Q_{CHP} = 0$ (see Table 1). CEN makes here some detour by calculating the numerator as E_{Cond} by $E_{plant} + \{E_{Cond} - E_{plant}\}$, the expression in brackets being the power lost by heat extraction.

3. Determination of the power-to-heat ratio $\sigma = (\eta_{cond} - \beta\eta_{CHP})/(\eta_{CHP} - \eta_{cond})$.

4. Determination of $E_{CHP} = \sigma Q_{CHP}$

More steps follow, but steps 3 and 4 contain a ''circular reference.'' Obviously E_{CHP} is calculated in step 4. However, the formula of step 3 includes η_{CHP} what requires knowledge on E_{CHP} (next to Q_{CHP} and F_{CHP} as Table 1 shows). CEN escapes from its circular reference by applying ''the CHP overall efficiency (η_{CHP}) according to Annex II of the CHP Directive'' (CEN, at 38), or more clearly stated: CEN adopts a fixed value of 75 percent/80 percent for η_{CHP}. Table 2 shows that fixing such constant parameters does not cover the reality of CHP technologies and applications. It is also a shortcoming in meeting the stated objective of delivering ''transparent and accurate formulae.'' In Section IV, I show that a consistent regulation has no need for arbitrarily fixed parameters.

The further steps of the CEN solution are:

5. Determination of non-CHP power output:
$E_{Cond} = E_{plant} - E_{CHP}$.

6. Determination of fuel energy for non-CHP power output:
$F_{Cond} = E_{Cond}/\eta_{Cond}$.

7. Determination of fuel energy for CHP power output:
$F_{CHP} = F_{plant} - F_{Cond}$, or
$F_{CHP} = (E_{CHP} + Q_{CHP})/\eta_{CHP}$,
where η_{CHP} is again the fixed parameter 75 percent/80 percent.

IV. Closing the CHP Quantification Gap

Some of the CHP literature[14] starts at the first law of thermodynamics with the equation:

fuel input
= power output
+ (recoverable) heat output
+ (non-recoverable) losses.

This universal law is valid for any thermal power plant, but requires more elaboration when cogeneration takes place. Using the notation of Table 1, one writes:

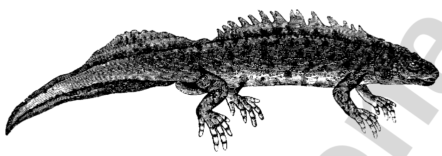
$$F_{plant} = E_{plant} + Q_{plant} + \text{non-recoverable losses},$$

or:

$$F_{CHP} + F_{Cond} = E_{CHP} + E_{Cond} + Q_{CHP} + Q_{Cond} + \text{non-recoverable losses}$$

The equations help in stating the final steps the quantification discussion should take.

First, it is obvious that when $Q_{Cond} = 0$, it follows $E_{Cond} = 0$ and $F_{Cond} = 0$, and further $E_{CHP} = E_{plant}$ and $F_{CHP} = F_{plant}$. Therefore, rather than using fixed efficiency thresholds, one better accepts all electricity as E_{CHP} when the plant is not equipped with heat rejection (condensing) facilities, because there may be peculiar conditions that make overall efficiency fall short of the efficiency thresholds, e.g., when



the plant is combusting waste fuels. The distinguishing property among ''pure'' and ''mixed'' CHP plants is whether they own – yes or no – ''heat rejection facilities.'' If ''no,'' the thermal power plant is a ''pure'' CHP activity and there is no CHP definition, identification, and quantification problem because all useful heat, all power, and all fuel relate to cogeneration. So the 75 percent/80 percent thresholds are of no use.

Second, the very issue of identification arises when the CHP activity is embedded in a plant owning heat rejection facilities. In case of joint cogeneration and condensing activity none of the variables in the equations equals zero, but directly observed are only: Q_{CHP}, F_{plant} and E_{plant}. In order to split the latter two quantities in their CHP and non-CHP shares, additional information on the plant and process characteristics is necessary.

CEN adopts the fixed parameters of 75 percent/80 percent as η_{CHP} while I propose to measure the non-recoverable losses and Q_{Cond} at the thermal power plant to fix the *bliss point S* and the *design* power-to-heat ratio σ. As stated in Table 1, the bliss points can be multiple and virtual, so also the ratios σ can be multiple, but are always real.[15] The difference between the approaches is that CEN sets the Non-Recoverable Losses in a CHP plant always equal at 25/20 percent of the fuel input, while I propose to observe the real losses. The values in the last column of Table 2 show that overall efficiencies η_{CHP} range from 60 percent to above 90 percent, and underpin the very straightforward argument that it is better to observe the real numbers for the particular plants. Once the characterization of the non-recoverable losses is done, one knows the share of the fuel that is converted in electricity and in recoverable heat.

Figure 1 shows the method graphically with efficiency units on both axes. The full line AB assumes 100 percent efficiency with all fuel converted in electricity or recoverable heat (the fictive case of non-recoverable losses being zero). The parallel

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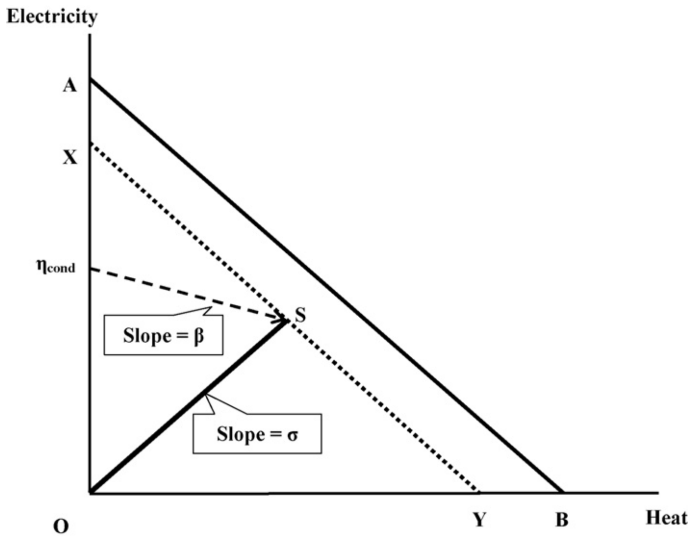

Figure 1: Fixing the Bliss Point S and Power-to-Heat Ratio σ of a CHP Activity

line XY differs from AB by subtraction of the non-recoverable losses, i.e., compared to line AB, XY represents η_{CHP} [in CEN's approach always XY = (0.75 or 0.80) AB].

The bliss point S is to be found somewhere on line XY. For fixing S one must observe the efficiency of pure condensing activity η_{cond} and the power loss factor β of the heat extraction (β may be zero). The two data define the dashed downward sloping line $\eta_{Cond} - S$, and the crossing with XY fixes point S. The design power-to-heat ratio σ is the slope of OS. The production possibility set of the CHP activity is given by the triangular area $O–\eta_{Cond}–S$.

While CEN is compatible with the methods I developed, avoiding the insertion of arbitrary threshold efficiency numbers is more accurate and transparent. Also analyzing CHP issues with the help of

The interest group Euroheat & Power was very active in developing alternative methods for the quantification problem.

production possibility sets may avoid confusion.

V. Conclusion

The EU started in 1997 a regulatory process to ensure and strengthen the position of cogeneration in the liberalizing electricity and gas markets. The drafts and even the final CHP Directive issued in February 2004 fall short in the essential task of identifying exactly what CHP activity is when embedded in a condensing thermal power plant. CEN/CENELEC, coordinating the standards institutes in Europe, took over and in September 2004 published a manual to identify and quantify CHP energy flows. This manual provides a solid approach, but joins the EU Directive in adopting arbitrary efficiency thresholds and values of 75 percent/80 percent overall CHP efficiency. This article suggests a more accurate and transparent method without recurrence to arbitrary values. When the discussion on quantifying CHP activity is settled, the one on qualifying CHP activity can be re-opened.■

Endnotes:

1. Commission of the European Communities, *Communication from the Commission to the Council and the European Parliament: A Community Strategy to Promote Combined Heat and Power (CHP) and to Dismantle Barriers to Its Development*, COM (97) 514 final, Brussels, Oct. 15, 1997, 17 pages.

2. *Directive of the European Parliament and of the Council on the Promotion of Cogeneration Based on a Useful Heat Demand in the Internal Energy Market*, COM (2002) 415 final, Brussels, July 22, 2002, 47 pages. Also, *Amended Proposal for a Directive of the European Parliament and of the Council on the Promotion of Cogeneration Based on a Useful Heat Demand in the Internal Energy Market*, COM (2003) 416 final, Brussels, July 23, 2003, 32 pages.

3. *Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the Promotion of Cogeneration Based on a Useful Heat Demand in the Internal Energy Market and Amending Directive 92/42/EEC*, Official Journal of the European Union, Feb. 21, 2004, L52/50-60.

4. For a detailed analysis, see A. Verbruggen, *Qualifying Combined Heat and Power (CHP) Activity*, Int. J. Energy Tech. & Policy, 2007, Vol. 5, No. 1, at 36–52. Also, A. Verbruggen, *CHP (Combined Heat & Power) Regulation by the EU for Facing the Liberalised Electricity Market*, in Int. Energy J., Vol. 6, No. 1, June 2005, at 29–46, discusses the problem.

5. Here the symbol *C* is maintained for the power-to-heat ratio as stated in the EU Directive, while I suggested the symbol σ to emphasize the differences in definition and actual assessment. (CEN also uses σ.)

6. *Supra* note 4.

7. Euroheat & Power manual (Oct. 2002) for calculating CHP electricity in accordance with the provision of Article 3 and Annex 1 of the Directive of the European Parliament *supra* note 2.

8. Draft Report on the proposal for a European Parliament and Council Directive on the Promotion of Cogeneration Based on a Useful Heat Demand in the Internal Energy Market (COM(2002) 415 – C5-0366/2002 – 2002/0185(COD)), Committee on Industry, External Trade, Research & Energy, Rapporteur: Norbert Glante, Nov. 13, 2002, 64 pages.

9. CEN/CENELEC: Workshop Agreement (2004) Manual for Determination of Combined Heat and Power (CHP), CWA 45547, Brussels, 78 pages.

10. A. Verbruggen, *On Qualifying CHP*, report on regulation and promotion of combined heat and power, CENERGIE, Jan.–March 2003, 83 pages. The content of this report distributed during the debate on the draft directive is presented in a more didactic way in the articles noted in notes 4 and 15.

11. There are also some other points that can be discussed, such as the definition of CHP itself and the definition of the reporting periods of data (where I suggest a difference between ''accounting'' and ''reporting'' periods).

12. CEN (at 14) considers back-pressure steam turbines as units *without* power loss, based on the argument of complementary power and heat outputs. I disagree on this classification because power loss is due to heat extraction at above ambient temperature. When designing back-pressure units and when heat is supplied at more than one pressure level, power loss factors are important.

13. Power loss is discussed widely in the technical CHP literature (see Euroheat & Power Journal), but generic statistics are published rarely because the loss factors are application-specific. See, however, Figure 1 in Harvey Danny, *Clean Building Feature*, Cogeneration & On-Site Power Production, Sept.–Oct. 2006, at 107–115.

14. E.g. A. Verbruggen, M. Wiggin, N. Dufait and A. Martens, *The Impact of CHP Generation on CO_2 Emissions*, Energy Policy, Vol. 20, No. 12, 1992, at 1209–1214, and A. Verbruggen, *An Introduction to CHP Issues*, Int. J. Global Energy Issues, Vol. 8, No. 4, 1996, at 301–318.

15. A. Verbruggen, *Quantifying Combined Heat and Power (CHP) Activity*, Int. J. Energy Tech. & Policy, 2007, Vol. 5, No. 1, at 17–35, discusses how to find the design power-to-heat ratios for the common CHP technologies.

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