Incentive regulation of CHP performance

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Abstract: Main contentious issues of public regulation to support CHP as an efficient thermal power cycle are discussed. First the merit of CHP is defined as the transformation of residual heat in conventional power plants into useful heat; this merit suffices to rank CHP activity prior to standard thermal power generation wasting the heat. Second, the main metrics of CHP performance is the amount of co-generated electricity requiring uncontested identification when CHP activity is mixed with condensing power generation (mainly in extraction-condensing steam turbines). The proper method is based on design characteristics of CHP processes, not on arbitrary averages as CEN proposes. Therefore, the novel concept of "bliss point" of a CHP activity is developed. Third it is argued why co-generated power – clearly measured – is a sufficient performance indicator. Additional qualifications based on external benchmarks (as the EU-Directive allows) may imply perverse incentives in impeding CHP development qualitatively and quantitatively. The difference between perverse and benign regulations explains the wavering position of the EU-2004 Directive on the promotion of CHP.

Keywords: *CHP quality, Power-to-heat ratio, EU Directive, Incentive Regulation, Benchmarking*

Nomenclature

E	*Electricity or power*	*MWh or MW*	*β*	*power loss factor*	
F	*Fuel energy or fuel flow*.........	*MWh or MW*	*σ*	*power-to-heat ratio*	
Q	*Heat energy or heat flow*	*MWh or MW*	*η*	*efficiency*	

Acronyms for activities CHP = Cogeneration; Cond = Condensing; Plant = both activities

1. Introduction

Cogeneration or Combined Heat & Power (CHP) is as old as its natural cradle, the thermal power plant that after power extraction dumps all residual heat in the environment. Diverse CHP technologies are applied in plants ranging from a few kW to a few hundreds MW. CHP diffusion in countries with similar economies is uneven, due to diverging energy policies and according regulations. CHP is in principle more energy efficient than its counterpart that dumps the residual heat. Public policy in favor of efficient fuel use also supports CHP. This was intended by EU-Directive 2004/8/EC [1], but not confirmed by effective and efficient regulation. This section introduces the subject. Section 2 highlights different visions on the merit of CHP, determining the acceptability of proposed policies. Quality of CHP is shown to equal quality of standard thermal power generation, and "CHP-specific" qualification is not needed. Section 3 covers the issue of defining and measuring CHP activity in a transparent and accurate way. Section 4 shows how external benchmarking of CHP plants can be the source of very perverse incentives for the development of CHP. A brief conclusion follows.

1.1. CHP support

Why should the EU support CHP in itself? Many argue that support is only warranted when CHP delivers a reduction in CO_2 emissions and/or reduction in fuel combustion because high efficiency separate heat and power generation might be better in reducing CO_2 than a low efficiency CHP facility. The latter argument points to the core issues of what about CHP is why supported. During the 2004 EU Directive's preparation phase proposals abounded to evaluate along CHP other aspects like the type of fuel used or the amount of reduced CO_2 emissions. However well intended, this debate created confusion and obliterated the attention for the core duty: what attributes or results of CHP are eligible for support? Poorly answering this question backfires on the good regulatory intentions when biased methods of CHP qualification are applied (section 4).

The core task is accurately identifying what CHP activity means, in particular in plants that simultaneously mix CHP and condensing power generation. Once CHP activities are fully characterized it is possible to discuss what aspects of that activities may be promoted and supported, and how this can be done in the most transparent and effective way.

1.2. Incentive regulation

Incentive regulation sets the factors right that improve the economics of CHP activities. It obeys the overall standards of proper regulation such as: identify precisely what is the object of regulation; select the appropriate variables to monitor and measure the object; preclude arbitrary values or averages; specify specific but similar rules for similar cases to minimize discrimination; promote stated goals by appropriate rules and incentives. The promotion of CHP as a competitive power generation practice needs consideration of salient aspects like: optimize technical characteristics and select high power-to-heat ratios; stimulate economies of scale and high capacity factors by opening a large market for both outputs of CHP plants; guarantee fair terms for exchanges of power (as surplus, make-up, or back-up flows) with the grid. The latter terms significantly impact the development of any independent and decentralized power generator. But for CHP the complexity increases because the joint outputs power and heat are delivered to separate markets. When regulations truncate CHP's freedom of operation on the power market the economics of CHP deteriorate.

One peculiar aspect of the EU CHP Directive is the adoption of external benchmarking as the basic method for qualifying the outputs of CHP plants. Generally benchmarking is '*the continuous, systematic process of comparing the current level of own performance against a predefined point of reference, the benchmark, in order to evaluate and improve the own performance*' [2]. The choice of benchmark is crucial because the own performance is measured as a 'distance-to-targets' with the benchmark characteristics as targets, and because the own activity is changed to resemble the benchmark as much as possible. When benchmarking is applied in a private context, the actor controls the selection of targets and the degree and pace of approaching the targets. The actor can accommodate fuzzy aspects in definitions, data availability and methods applied. In a public regulatory context the definitions must be based on argued, transparent and robust methods requiring indicators that are measured in an uncontested way. The first issue is whether the benchmarking framework as such makes sense, i.e.: are the benchmarks valid references for improving the regulated subject's performance? (e.g. do they belong to comparable categories?). When diversity is too high, it is problematic to screen and evaluate diverse participants (competitors) on a particular performance, in particular when followed by remunerations or penalties.

1.3. CHP performance

What variables can express CHP performance? Using the recovered heat $\mathbf{Q_{CHP}}$ as indicator is not recommended because investors and operators are not stimulated towards high-quality cogeneration activity. Also as an additional indicator there are few arguments to include the heat output variable, neither when taking the quality of the useful heat into account [3]. While heat at higher temperature corresponds to a higher availability (quality) of the energy flows, rewarding this in CHP activities counteracts the incentives to reduce the applied temperatures of heat end-uses in buildings and processes. The lower the useful end-use temperatures of heating applications can be set, the more "nearby waste" heat flows can be recuperated, the more ambient heat sources can be included (solar heating, heat pumps) and the more efficient cogeneration systems can be inserted (in particular Rankine cycles). The necessary and sufficient CHP performance indicator is the amount of co-generated electricity $\mathbf{E_{CHP}}$ when measured accurately. Because $\mathbf{E_{CHP}} = \boldsymbol{\sigma}.\ \mathbf{Q_{CHP}}$ maximizing $\mathbf{E_{CHP}}$ includes incentives to maximize heat recovery ($\mathbf{Q_{CHP}}$) and quality (power to heat ratio $\boldsymbol{\sigma}$) of the CHP activities.

2. CHP Merit and Quality

Opposite visions on the merit of CHP in the energy economy create diverging propositions about CHP's role with impact on its valuation (2.1). There is much fuss about quality of CHP processes, but does quality differ for CHP and non-CHP thermal power processes? (2.2).

2.1. Opposite visions on the merit and role of CHP

Policy starts with a vision on the subject of regulation. Visions on the merit and the role of CHP range from Promoting to Blocking CHP development (Table 1). One favors the development of CHP when taking the position that the merit of CHP is in recovering all or part of the heat being otherwise discarded to the environment in a thermal power plant. Adding additional tests upon this basic merit leads to fencing in the application of the CHP principle. For example one can require that CHP plants perform a factor X better in generating power and heat jointly than the best available references of separate generation technologies (power condensing plants and heat only facilities). External benchmarks provide valuable information to a would-be investor in CHP capacity and to the operator of existing CHP facilities, but must be handled more carefully in a regulatory context (see section 1.2).

Table 1: Promoting and blocking views on the merit and role of CHP

	Promoting CHP	Blocking CHP
CHP Merit	Use of – all or part of – the discarded fatal heat at thermal power plants	CHP has but merit when it excels above the best separate power and heat benchmarks
CHP Role: who first?	CHP dominates the condensing only thermal power generation cycle, and therefore is, ceteris paribus, preferred. Valid is also part recovery of fatal heat.	Limit CHP to full heat loading operations. As a corollary: obstruct CHP plants operating in part/full condensing mode

When the basic merit of CHP is recognized it is logical to attribute priority to the CHP mode above the condensing only mode for investing in thermal power plants[1]. The blocking vision sees the role of CHP very restrictive to particular joint power-heat load conditions where a full heat load can be guaranteed 'all the time'. This attitude also fences the entry to the power market by setting particular tariffs for power exchanged between the CHP facility and the interconnected grid. Unfair conditions for exchanging power with the grid are main barriers to a balanced development of CHP in both the heat and the power markets [4].

2.2. The quality of thermal power and of CHP

CHP is always based on some thermal power generation cycle. The latter is its natural cradle and determinant of the performance, economics and quality of the CHP process. Every thermal power process rejects residual heat in the environment. The merit of CHP is to

[1] In Denmark the 1979 Heat Supply Act has made this principle reality.

recover part or all of this heat and transform it into 'useful' heat. Some CHP processes (steam turbines) occasion a loss of power output when condenser heat is upgraded to useful heat. The power loss β is almost proportional to the temperature of the extracted heat (steam) from the turbines, and therefore it is important to minimize the required temperature of the heat applications that are supplied by CHP processes. Gas turbines, internal combustion engines, some fuel cells, do not occasion significant power loss because generally the temperature of the rejected heat is sufficiently high for the heat end-use purposes.

The quality of CHP processes is recorded by the power-to-heat ratio σ. There is no generally approved definition of this ratio. The metamorphosis of a condensing power process into CHP is happening by transforming residual heat into useful heat. Therefore the high (low) quality CHP process is embedded in a thermal power plant of high (low) electricity conversion efficiency (the linkage is further discussed in section 3.3).

3. Identifying and measuring CHP activity

The valid indicator of CHP activity is the amount of co-generated electricity $\mathbf{E_{CHP}}$ (section 1.3). For a thermal power plant without residual heat rejection, no $\mathbf{E_{CHP}}$ identification problem exists because all activity of the plant is combined and all electricity is co-generated. Defining this variable and measuring it when co-generation takes place *joined to* condensing power generation, is the problem to solve. In addition, but fully overlooked in the EU regulation, is it necessary to identify and measure the share of fuel consumed for the combined activity $\mathbf{F_{CHP}}$. The bottleneck holding up effective regulation by the EU Directive is identification, and so reliable measurement, of what precisely is CHP *activity*.

3.1. The EU CHP Directive [1] on measuring CHP activity

Annex II "Calculation of electricity from cogeneration" of the Directive 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." Then it splits the approach in two cases. First, when the overall thermal efficiency of the operations exceeds 75% 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 co-generated. Analogously, an 80% efficiency threshold applies for CCGT with heat recovery and for steam condensing extraction turbines. Second, when overall efficiency falls short of the stated thresholds of 75/80 %, co-generated electricity $\mathbf{E_{CHP}}$ should be calculated according to the formula $\mathbf{E_{CHP} = \sigma. Q_{CHP}}$ with σ the power-to-heat ratio. Article 3(k) 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". The latter expression is not specified, although most CHP units cannot operate in full cogeneration mode. Hence the Directive's method is incomplete in identifying and measuring $\mathbf{E_{CHP}}$. By lacking the correct method, Annex II offers average default values by technology group, but this is "*notably for statistical purposes*".

The wrong answer to the difficulties in quantifying $\mathbf{E_{CHP}}$ is to negate the question, and proceed without solution. The EU does this by Annex III forgetting Annex II and qualifying cogeneration performance on the basis of mixed values with perverse effects for the development of CHP (section 4). The EU skips identification of fuel consumption $\mathbf{F_{CHP}}$, necessary to assess the efficiency η_{CHP} of the cogeneration activity of a thermal power plant. Simplifying estimations of $\mathbf{E_{CHP}}$ by splitting CHP activities in two groups, as Annex II does, increases the workability, but average 75/80% default efficiencies are arbitrary, not promoting "high efficiency CHP". Field data [5] document CHP efficiency ranges between 60 and 94%. The Directive (Art.12) does not impose its immature methods, allowing member states the use of "Alternative calculations". Unsolved identification of CHP activity is not increasing harmonization, stated as a "general objective of the Directive" (Whereas n° 15). For overcoming the identification problem the novel concept of "bliss point" of a CHP process is developed in section 3.3.

3.2 The CEN manual [6] for Measuring CHP activity

The objective of the CEN Manual 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." CEN adopts the Directive Annex II proxy of splitting CHP plant outputs in above and below 75/80% average efficiency operations, the "above ones" seen as full CHP. For the "below ones", CEN addresses the disentangling of CHP from the *mixed* activity and searches to quantify both $\mathbf{E_{CHP}}$ and $\mathbf{F_{CHP}}$ values. CEN hereby distinguishes cogeneration processes *with* power output loss when recovering residual heat at the thermal power process from the ones *without* power output loss when heat is recovered. CEN focuses on extraction-condensing steam turbines[2] where mixed activity and power loss are prominent, with the added complexity that useful heat extraction may occur at several pressures (temperatures). For this most important and most complex CHP case CEN elaborates a seven-step approach [6, p.38-40], but steps 3 and 4 contain a "circular reference": $\mathbf{E_{CHP}}$ is calculated in step 4, but step 3 includes $\boldsymbol{\eta_{CHP}}$ whose assessment requires $\mathbf{E_{CHP}}$ (next to $\mathbf{Q_{CHP}}$ and $\mathbf{F_{CHP}}$). CEN escapes from its circular reference by applying "the CHP overall efficiency according to Annex II of the CHP Directive" [6, p.38], or more clearly: CEN adopts a fixed value of 75/80% for $\boldsymbol{\eta_{CHP}}$. Adopting averages does not cover the reality of CHP technologies and applications and ripples the CEN stated objective of "transparent and accurate formulae".

3.3. Closing the CHP identification and measuring gap: find the "bliss point"

A consistent regulation has no need for arbitrarily fixed parameters [7]. The first law of thermodynamics applied on a thermal power plant states: Fuel input = Electricity output + (Recoverable) Heat output + (Non-recoverable) Losses. For a CHP plant showing the split between CHP and condensing activities the law applies as (table 2):

$$\mathbf{F_{CHP} + F_{Cond} = E_{CHP} + E_{Cond} + Q_{CHP} + Q_{Cond} + \text{Non-recoverable Losses}}$$

Table 2: Energy flows in a CHP plant obey the First Law of Thermodynamics

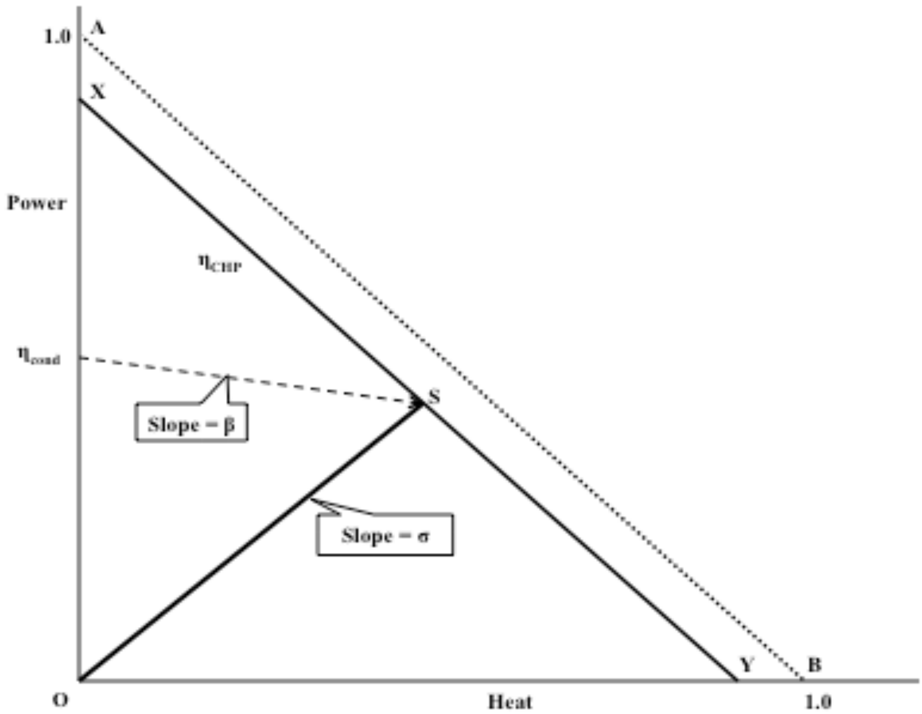
	CHP	+ Condensing	= Plant
Fuel F =	F_{CHP}	F_{Cond}	F_{plant}
Electricity E	E_{CHP}	E_{Cond}	E_{plant}
+ Heat Q	Q_{CHP}	Q_{Cond}	Q_{plant}
+ Losses non-recoverable	-	-	L_{plant}

[2] CEN/CENELEC [6, p.14] considers backpressure steam turbines as units *without* power loss, based on the argument of complementary power and heat outputs. However, power loss in steam turbines is due to heat extraction at above ambient condensing regimes.

When $\mathbf{Q_{Cond}} = 0$, it follows $\mathbf{E_{Cond}} = 0$; $\mathbf{F_{Cond}} = 0$, and $\mathbf{E_{CHP}} = \mathbf{E_{plant}}$; $\mathbf{F_{CHP}} = \mathbf{F_{plant}}$. Rather than by adopting arbitrary 75/80% efficiency thresholds, all electricity is $\mathbf{E_{CHP}}$ when the plant does not deliberately reject heat. There may be peculiar conditions why the overall efficiency of a CHP plant falls short of the 75/80% thresholds, e.g. when the plant is combusting waste fuels. The distinguishing property among "mixed" and "pure" CHP plants is whether they reject – yes or no – recoverable heat. If "no" ("pure" CHP activity) the $\mathbf{E_{CHP}}$ identification problem vanishes because all power relates to cogeneration and the 75%/80% thresholds are of no use.

When cogeneration and condensing activities take place jointly none of the variables in table 2 equals zero, but directly observed are only: $\mathbf{Q_{CHP}}$, and the total plant flows $\mathbf{F_{plant}}$, $\mathbf{E_{plant}}$, $\mathbf{Q_{plant}}$, $\mathbf{L_{plant}}$. In order to split the fuel and electricity quantities in their CHP and condensing shares, two additional process characteristics are needed: $\boldsymbol{\eta}_{\mathbf{cond}}$ or the condensing power efficiency when no cogeneration occurs, and the power loss factor[3] $\boldsymbol{\beta}$ of the transformation of $\mathbf{Q_{Cond}}$ into $\mathbf{Q_{CHP}}$ ($\boldsymbol{\beta}$ may be zero when no power is lost during that transformation, e.g. at gas turbine plants). Then all information is available to find the *bliss point* ***S*** and the *design* power-to-heat ratio $\boldsymbol{\sigma}$ of the CHP plant. The bliss points can be multiple and virtual, so also the ratio's $\boldsymbol{\sigma}$ can be multiple, but the $\boldsymbol{\sigma}$ are always real [7]. Fig. 1 shows the method graphically with efficiency units on both axes. The line AB assumes 100% efficiency with all fuel converted in electricity or recoverable heat (representing the fictive case of non-recoverable losses being zero). The parallel line XY subtracts from AB the non-recoverable losses, i.e. compared to line AB, XY represents $\boldsymbol{\eta}_{\mathbf{CHP}}$ (the CEN proposal fixes XY = 0.75AB or = 0.80AB).

*Figure 1: Finding the bliss point **S** and power-to-heat ratio **σ** of a CHP activity*



[3] Power loss is discussed widely in the technical CHP literature but generic statistics are published rarely because the loss factors are application specific. See however figure 1 in [8].

The bliss point **S** is on line XY. For finding **S** one starts at the $\boldsymbol{\eta}_{\mathbf{Cond}}$ intersection on the ordinate and follows the slope of the power loss factor $\boldsymbol{\beta}$. The two data define the dashed downward sloping line $\boldsymbol{\eta}_{\mathbf{Cond}}$ – **S**, and the crossing with XY fixes point **S**. The design power-to-heat ratio $\boldsymbol{\sigma}$ is the then found as the slope of **OS**. The production possibility set of the CHP activity is given by the triangular area **O** – $\boldsymbol{\eta}_{\mathbf{Cond}}$ – **S**. While CEN is compatible with the method of fig. 1, avoiding the insertion of arbitrary efficiency numbers is more accurate and transparent (see [7] for further detail).

4. External Benchmarking and the EU Directive Qualification

The EU CHP Directive benchmarks the outputs of CHP plants on the efficiencies of separate generation processes of power and of heat. The imposed power reference is the high efficient CCGT process and at the heat side it is a high-efficiency boiler. Next to the difficulties in pointing down the "right" efficiency values, the assumption that CHP power and CCGT power are perfectly comparable and exchangeable all time of the year[4] weakens the case for applying external benchmarking [9]. Some countries have based their regulation on external benchmarking: acceptance or exclusion of CHP plants from support depends on their performance on the *quality norm*. This *norm* links the outputs of a CHP ***plant*** to the efficiencies of reference separate heat and power generation processes. It is shown [10] that the *quality norm* entails little incentive to improve the real quality of the CHP process. This is a crucial shortcoming because the future of CHP depends on its competitive position and this in turn is dependent on the quality of the processes. The more electricity a CHP plant can generate the better for the competitiveness of CHP. The *quality norm* is not effective in stimulating CHP quality and is perverse in truncating the production possibilities of CHP plants. Investment in well-scaled and flexible CHP capacity is choked by the qualification procedure. In existing plants CHP operators are driven to produce smaller quantities of power either by partly loading or by shutting down capacities. Most of the negative effects are due to the amalgamation[5] of the cogeneration and condensing activities in the CHP plants into plant quantities, and by omitting separate identification and measurement of the actual CHP activity within such plant (see table 2).

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[4] In actual power systems, CCGT is not a marginal power supplier (high efficiency CCGT requires constant full load conditions). A common CHP plant of 35~40 percent power efficiency is of higher merit than a peak-load unit of 25~30 percent efficiency, but CHP activity will be constrained by imposing the 50~55 percent benchmark efficiency. This shows how external benchmarking becomes perverse. It obliterates the regulatory roles. Comparing power generation performance of CHP with grid power is to be done by a clear regulation of grid access pricing. Promoting CHP (as the EU wants) is to be done on the basis of the own merit of CHP.

[5] A metaphor of wrong amalgamation: a city board wants to promote cycling in the city by rewarding bike use (assumed: in the city perimeter). Some lobby imposes that bikes only get support when faster than motorized traffic. Bikes are equipped with a meter registering distance and running time. Within the city perimeter most bikers are faster than motorized traffic. However the biker's performance is the sum of all km and time (within and beyond the city perimeter) compared with the external benchmark. This obviously will not stimulate a good deployment of bike use in and around the city.

Conclusion

Public regulation obeys a number of quality standards to reach its stated objectives. Incentive regulation of CHP sets the factors right that improve the economics of investing and operating high quality processes. External benchmarking of CHP plants on separate high-efficient power and heat production processes implies perverse effects. A good CHP regulation starts at clearly stating the merit of CHP as the transformation of all or part of the residual heat of thermal power processes into useful heat. This merit assigns, ceteris paribus, to CHP activity a priority ranking above standard thermal power. The performance of CHP is fully gauged by the quantity of cogenerated electricity when identified and measured in the proper way. The latter task is tricky when the CHP activity is mingled with condensing power generation. The article offers a solid methodology based on the first law of thermodynamics; new is the definition of the "bliss point" of a CHP activity, being the crossing of the lines with as slopes respectively the power-loss and power-to-heat parameters. Bliss points are virtual in most condensing-extraction cycles and multiple when heat is recovered at various pressures,. This finding is the basis for assigning the proper power-to-heat characteristic to various CHP activities, sidelining the inaccurate use of average efficiencies as proposed by CEN [6]. Using arbitrary averages for efficiencies does not provide the right incentives to maximize real efficiencies when investment in CHP plants takes place.

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