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CHP (Combined Heat & Power) Regulation by the EU for Facing the Liberalised Electricity Market

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ABSTRACT

Liberalisation of the EU electricity market has brought little salvation for independent CHP. Fair access to the market is not guaranteed and many projects suffer from the dismantling of existing support schemes. The EU Commission publishes in 1997 a strategy to promote CHP, and in 2002 a proposal of CHP Directive. A good CHP regulation needs two issues to be solved: 1/ identify precisely what is CHP when a thermal power plant can be operated in the mixed state of partly combined and partly condensing operation; (and after 1) 2/ qualify the results for assigning particular rights or duties. The proposed Directive neglects to identify CHP precisely. As a corollary there is no firm basis for qualification. The 2002-proposal would have resulted in an obstruction of many CHP projects, but the perverse incentives are remedied in the 2003-amended proposal by accepting a variety of separate benchmarks. By assigning a lot of decisions to the Member Sates and by the shortfall in guidelines for identifying CHP well, the Directive will not reach the own stated goals of harmonisation.

However, there exists a scientific and workable methodology for identifying CHP precisely. It needs a few definitions and concepts such as production possibility set of a CHP process, design heat to power ratio, heat capacity factor. The well identified quantity of cogenerated electricity is a sufficient ground for qualifying CHP activities. It is also the solid basis for the unbiased further qualification of the results by some internal or external benchmarking. Given the 'common positions' arrived at in September 2003 by the EU institutions, the perspective that the first best method will win over the second-best approach is meagre.

1. INTRODUCTION

The development of CHP in Europe is quite unequal due to differences in industrial and urban structures, climate, natural endowments and policy choices about technologies and infra-struc-tures [19]. CHP is generally considered as a benign way of generating power, and often public authorities have promoted its development. An outspoken example of such support have been the Netherlands where CHP has grown from 2700 MW in 1987 to over 8000 MW in the year 2000, covering a market share of over 50% of power supplies [www.cogen.nl]. The growth was feasible by the overall avail-ability of natural gas, by important investment subsidies and - last but not least - by fair terms of trade with the gas and power central systems. In other countries (e.g. Belgium, France) the central suppliers were less benevolent regarding distributed and independent CHP. By imped-ing a fair access to the power markets, central power companies blocked the way for a signi-ficant growth of independent CHP. Mainly CHP plants that are owned or co-owned by the power companies were built, rather as an extension of the central system than as the development of distributed power systems.

The EU Directive 96/92/EC [5] on the Internal Electricity Market was welcomed as a means to dismantle the monopoly strongholds and to level the playing fields in the power sector with a guarantee of fair terms of access to and of trade with the grids. The expectations that liberal-ising the electricity market would boost the development of distributed sources and of CHP have not come through. On the contrary, since a few years CHP promoters complain more about barriers and reclaim support to continue activities. One of the instruments that could help CHP is the nascent EU CHP Directive [7, 8]. Whether the Directive also will help CHP, is the subject of this article.

Because CHP is a much debated but little understood principle and practice, section 2 presents some technical CHP essentials that are required to specify CHP processes and activities more precisely. Section 3 situates CHP as an economic activity in the liberalised market just to remind of the variables that determine investment and operational decision-making, and that should be considered when 'promoting' CHP as the Draft Directive wants to do. Section 4 describes the EU policy process of the last years. The proposals are commented on two major regulatory questions: the identification of CHP activities and results, and the qualification of CHP. It is argued that the approach taken by the Commission is second best, and entails the danger of obstructing the development of CHP rather than promoting it.

Because the analysis must be somewhat technical at occasions a list of symbols is included. Capacities are expressed in kW or MW and energy flows in kWh or MWh (with the hour as unit time interval, numbers representing capacities and energy flows are interchangeable).

2. CHP ESSENTIALS

CHP is a combined activity serving at once heat loads and power loads. From one process, *three* different products are delivered: recovered heat, cogenerated electricity and condensing electricity. Making the proper distinction in the generated power flows (and assessing the related fuel consumption) is the most challenging question for the follow-up of CHP. It requires a structured analysis of CHP processes.

This section introduces the basic concept of a CHP Production Possibility Set starting at the cradle of CHP, i.e. the thermal power generation plant (section 2.1). The latter always occasions "fatal" heat that is either recovered (CHP) or wasted (condensing). The merit of CHP consists essentially in converting wasted fatal heat into recovered useful heat (section 2.2). Understanding the "fatal" heat property paves the way to the definition of the Production Possibility Set of CHP plants (section 2.3), explained for the main CHP technologies in practice (steam turbines, engines and gas turbines). Modelling CHP in this way underpins the understanding of principle, practice, economics and regulation of CHP. Section 2.4 introduces the discussion about CHP quality with two candidate indicators: the "power to heat ratio" and the "quality norm".

2.1 Thermal Power and Fatal Heat

Carnot has shown that the extraction of power from heat requires to get rid of the part of the heat flow that cannot be converted into work [18]. A thermal power gener-at-ion process always discards amounts of heat we call "*fatal*" heat because it cannot be avoided. Fig. 1 represents this basic fact of physics graphically. The vertical axis represents the power output of the plant as a function of fuel input (assumed is a continuous loading from 0 to E_{max}). At every charge or load condition the generation of the electricity is accompanied by the discard of a proportional amount of fatal heat (see arrows). The amount of fatal heat is marked on the abscissa[1].

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[1] To keep the discussion simple all figures show a direct proportional link between fatal heat and power output (i.e. the dotted line in figure 1is a ray starting at the origin of the diagram). Due to efficiency losses in part load functioning of plants the actual relationship will be somewhat different. Also the relationship will shift with climatic conditions (feed air density in gas turbines; condenser cooling parameters). These practical complexities do not change the basic arguments of our analysis.

There are thermal power generation processes where the generation of one unit of electricity brings along a large quantity of fatal heat and there are processes with smaller quantities of fatal heat, as shown in Fig. 1. The smaller the quantities of fatal heat the better, because this implies that more power is extracted from the fuel (given other losses remain constant). The first law of thermodynamics indeed teaches "Fuel = Electricity + Fatal Heat + other losses".

Fig. 1 shows a process where the *ratio of electricity to heat* is high (e.g. a Combined Cycle Gas Turbine or CCGT plant) and one where this ratio is lower (e.g. a conventional coal fired steam turbine plant). Experts will recognise the concept of electric efficiency or η_E behind the pictures. Indeed a 'high quality' condensing plant has a high electricity to heat ratio, and this will be no other for a 'high quality' CHP plant. One observes that the 'quality' of a CHP process equals the 'quality' of the thermal power plant it is based upon.

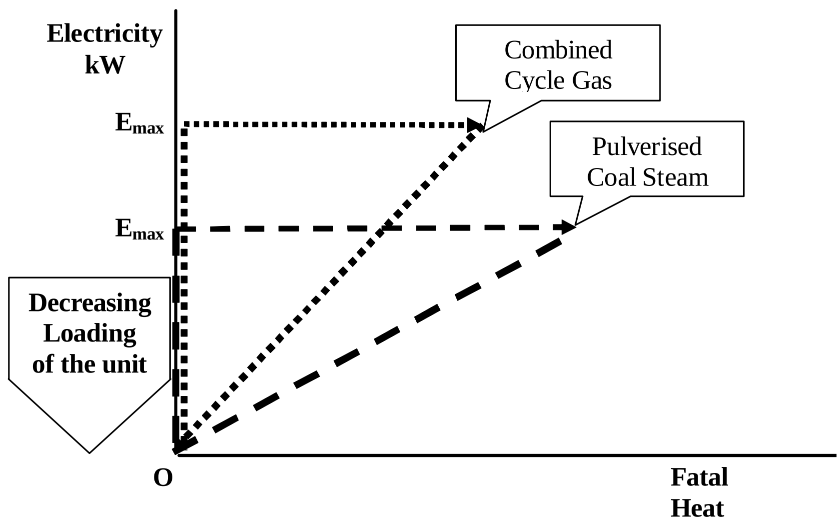

Fig. 1 Thermal power generation always brings along the output of fatal heat but technologies and processes differ in the amount of fatal heat that they discard

2.2 The Merit of CHP

The next evident question is: how is one getting rid of the fatal heat? Will it all be dissipated or wasted in the environment or can it (or part of it) been directed to a useful end-use because our cities and factories need so much heat? When (part of) the fatal heat is recovered as useful heat one enters the realm of CHP. The recovery of fatal heat is the basic merit of the CHP process, and is an argument to principally (economists would say 'ceteris paribus' – all other things being equal) prefer CHP above plain condensing power generation. On this basis present policies should be reverted in principle: today the condensing power plant is accepted as the default option and CHP is considered the exception. A reversal means that CHP becomes the rule and condensing power the exception, as was applied in Denmark and in the Netherlands since the 1980's [15, 2001; www.cogen.nl].

In some applications the CHP process is designed to recover all of the fatal heat. This is the preferred solution but not always economically feasible when there is no sufficient economic demand for the heat. Also a plant with a full fatal heat recovery capacity installed will not be demanded the full heat load continuously in time. When heat demand is lower, the plant will work more in condensing mode (when at least condensing equipment is installed) with wasting a corresponding part of the heat flows.

CHP changes the name-giving of the variable on the horizontal axis of Fig. 1. The variable is still an amount of heat (capacity or energy flow per hour), but when transiting from a single condensing plant to a Combined Heat & Power plant, the label 'useful heat', 'CHP heat' must be added to the label 'fatal heat'. The output on this axis now partly becomes a valuable economic product (also because it has the right temperature to serve particular end-uses). Therefore one generally uses the label 'heat' but one must be aware this heat may own a double character, partly useful and partly waste.

2.3 CHP Production Possibility Sets[2]

The capabilities of a particular CHP plant in providing the demanded products electricity and heat are represented by a 'Production Possibility Set'.

Fig. 2 shows a (E, Q) production possibility set of an internal combustion engine equipped with appliances to recover heat[3] (e.g. water, oil and flue gas coolers), and with appliances to reject surplus heat in the environment (condensers). When no condensers are available the possibility set is limited to the bisector ray OS (in practice truncated at the lower end because loads below e.g. a quarter or a third of the nominal capacity are not accessible). The slope of the ray OS represents the design power to heat ratio σ or E/Q quality of the CHP process, and therefore one should - ceteris paribus - opt for the steepest ray. In point S the plant is fully loaded. In all other points on OS the plant is partly loaded. In O it is out of service. In practice part-load operation may be financially inefficient limiting the actual production points of a CHP plant without cold condenser to two points: S (full load) and O (stand still).

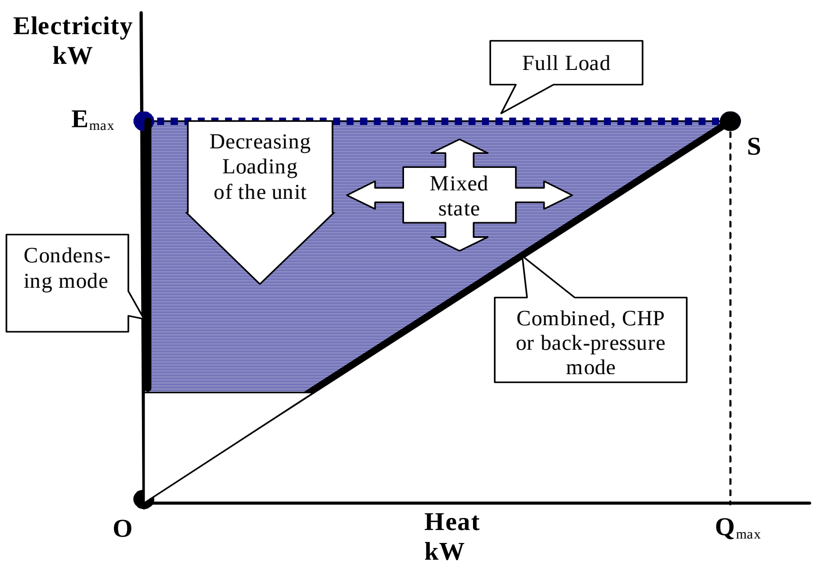

Fig. 2 Production Possibility Set of a CHP plant (example of a combustion engine with heat condensing equipment)

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[2] The analysis and modeling of CHP with the help of production possibility sets is fully developed in Verbruggen A.[20, 21]. Bach P.F [2] also mentions the idea of production sets in CHP generation. Such sets are used by different authors and developers, e.g. Anonymous [1] on the Cheng cycle (STIG).

[3] Engines are limited in their supply of higher temperature heat. Gas turbine exhausts are at very high temperature and these gases can be used either to raise steam (as e.g. in a CCGT) or to heat other flows (e.g. direct drying or heating applications).

For enlarging the CHP production possibility set from OS to a wider area, condensing equipment is necessary. When fatal heat (or cold) condensers are available, the possibility set of the CHP plant is enlarged to triangle OSE_{max}.

A typical engine with condensing capability can supply hourly (E,Q) loads in all combinations within the dashed area OSE_{max}. When operating on the top line $E_{max}S$, the engine is fully loaded. In going from E_{max} to S one recovers a larger and larger share of the heat. This continues up to the maximum amount Q_{max} at point S. Point S is defined the *bliss point* of the CHP process because at the maximum heat recovery there power output is maximised simultaneously. All points beneath the $E_{max}S$ line mean a part-load functioning of the unit.

Line OS represents the CHP operation mode. All other points of the possibility set involve a deviation from the maximum CHP principle, where part of the available heat has to be rejected because there is no useful demand for it. This operation involves (partly) *condensing* of fatal heat flows.

In CHP processes based on steam turbines (Fig. 3) there is more trade-off between power output lost and useful heat recovery making the full load line downward sloping from $E_{Condmax}$ towards S at ordinate E_{CHPmax} [2, 20, 21, 14]. The slope indicates the loss in power that occurs for releasing the steam from the turbine above cold condensing conditions. The higher the pressure and temperature of the useful heat extraction the more power is lost for every Joule of heat recovered.

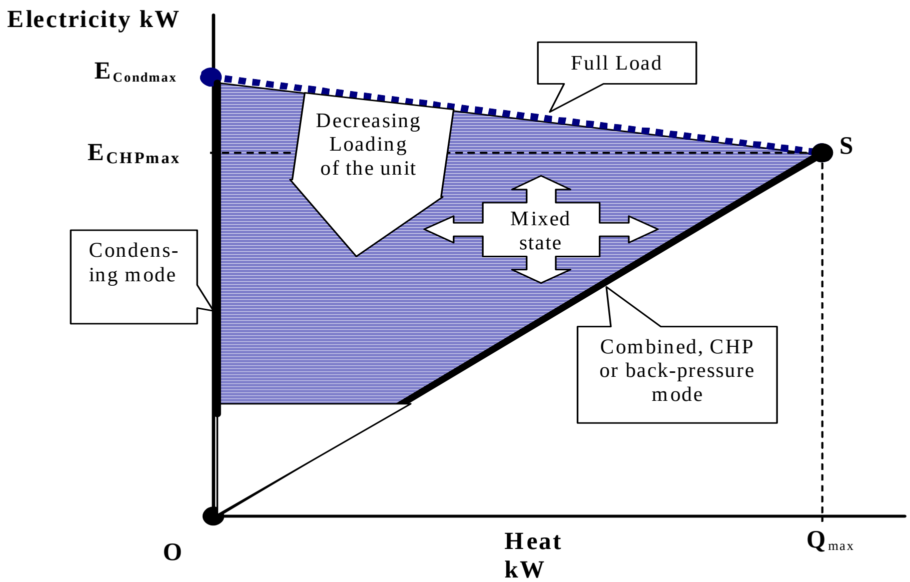

Fig. 3 Production Possibility Set of a CHP plant (example of an extraction-condensing steam turbine with full back-pressure feasibility)

One is willing to incur a power loss because now all the heat (including the latent condensing heat) in the extracted flow can be set to use. Obviously one will look for the shallowest slope of the $E_{Condmax}$-S line and can be successful in this when the temperature of the useful heat applications can be kept as low as possible.

While quality loss in steam turbine CHP units follows from the pressure-temperature exigencies of the heat end-uses, quality loss can be the result also of bad designs. The latter also can occur in engine and gas turbine driven CHP units where the useful heat pressure-temperature conditions have no significant impact on the generation of electricity.

The *design quality* of a CHP process is measured by the ratio E_{CHPmax} / Q_{max}, i.e. by the slope of the line OS. One should avoid that systems are designed poorly. Loss of quality means the substitution of amounts of (low-grade) heat for equal amounts of (high-quality) power (Fig. 1).

The discussion on CHP performance is quite simple when limited to the pure states either CHP along line O-S or condensing along line O-E_{max}, but becomes confusing when both states are mixed up (area O-S-E_{max}). One therefore must agree on a correct, transparent but also as simple as possible principle to divide or split the mixed activity into on the one hand *combined or CHP activity* and on the other hand *condensing activity*. The former has merit in recovering fatal heat flows, the latter has no such merit because it dissipates the heat in the environment.

2.4 Indicators of CHP Quality

Electricity is more valuable and – most of the time – can be valorised at higher prices than heat. In the joint products case of CHP, the CHP investor and operator must squeeze the maximum electricity out of the process. This guiding rule will maximise as well the thermo-dynamic quality as the economic quality of the process. Especially in *investing (fixing design and scale)* in CHP capacities all barriers should be removed to avoid low-quality combined processes[4]. When *operating* the plant a CHP owner must benefit from maximum flexibility to optimise the economics of the investment.

Long-term established practice is to express CHP quality with the "power to heat" ratio. There are many misunderstandings about that ratio, and two versions are in the running: an 'output' or 'work' related ratio, and a 'design' or 'capacity' based ratio. The output or work related ratio is based on outputs measured during some period, as E_{plant} / Q_{CHP}.

In case of a pure CHP process, the formula is fine because E_{plant} equals E_{CHP} and Q_{CHP} is the denominator. When however the unit is condensing a part of the heat, the nominator is the sum of two electricity flows ($E_{CHP} + E_{Cond}$), while the condensed part of the heat is no longer included in the denomin-ator. I.e. the ratio is then ($E_{CHP} + E_{Cond}$)/ Q_{CHP}, making this definition of power to heat ratio *biased and actually useless for regulatory purposes*.

The central point of discussion is how to split the electricity flows in CHP and condens-ing parts. It is our argument that the splitting should apply the design power to heat ratio s.

s is defined on the design conditions in the bliss point (or in the bliss points) of a CHP unit:

$$\frac{E_{CHP_{max}}}{Q_{max}} \tag{1}$$

The CHP discussion[5] in the 1990's has added another ratio to benchmark the performance of CHP on the efficiencies of reference separate heat and power generation plants. This bench-mark indicator, renamed the *'quality norm',* is proposed by the EU Commission as the basis for qualifying CHP [7, 8]. The 'quality norm' is given by (see nomenclature in section 7):

$$quality \quad norm = 1 - \frac{1}{\left(\frac{\alpha_E}{\eta_E} + \frac{\alpha_Q}{\eta_Q}\right)} \tag{2}$$

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[4] Low feed-in prices for CHP electricity involve incentives to CHP investors to build either a too small unit or a bad-quality unit when the dimension of the plant is based on the heat loads.

[5] See [22] and [23] for an early contribution.

The ‘quality norm’ has disturbed the understanding and confused the discussion on CHP because it aggregates *too much quantity* and *too little quality* in one number, it confuses CHP and condensing operation (as does the ill-defined ‘work’ related E/Q ratio) and it is an *external* benchmarking that needs particular choices about specific separate plant efficiencies.

The formula is useful for external benchmarking of CHP processes in comparison and in competition with reference separate processes. However it fails when used for qualifying the activities and results of CHP.

3. CHP ECONOMICS AND POWER MARKET ACCESS

CHP is an economic activity that must obey the basic principles of financial profitability in order to develop and attract new investments. Profits are the positive difference between revenues and expenses.

Revenues are the sum of product sales times the price. The heat output of a CHP project is delivered to a limited market often with fluctuating demands, and the value of heat is determ-ined by the actual prices of fuels. Electricity is technically and economically a more valuable product and the market is practically unlimited. The electricity price for the CHP project depends on the properties of the deliveries (When?, Where?, and How?) and on the terms of trade with the power grid. Revenues are maximised by large quantities of saleable outputs at the moment their prices are high. For CHP it follows that one should:

- Maximise the quality (design and operational E/Q ratio) of the process because power as an output is more valuable then heat
- Have a fair access to the electricity market for selling surplus power at low transaction costs. In particular the *flexibility to deliver* electricity at the moment it has a high return (peak load on the electricity systems) should be safeguarded.

Expenses are the sum of fixed (mainly investment and personnel) and variable (mainly fuel, buying back-up and top-up electricity at the grid, maintenance) costs. The fixed cost per unit of output generated depends on the technology, the level of automation, the scale and in particular the full load running hours (utilisation or duration) of the plant. Variable costs per unit are minimised by high thermal efficiency and by operating at or near full load conditions. Part load operation of CHP plants deteriorates their economic balance. Some technologies show bad part-load con-version efficiencies. Technologies based on rotating and especially reciprocating processes are depreciated by the running hour. The cost of maintenance and of spare parts is also charged by the running hour, indifferently whether the unit is fully or partly loaded.

For CHP it follows that one should:

- Make the proper technological choice with the highest quality (i.e. maximise the design power to heat ratio)
- Harvest economies of scale as far as one can reach
- Maximise the full load running hours of the plant

A regulation for promoting CHP is most efficient when it helps in realising the above rules of pro-fitability for a CHP project. At least one expects the regulation should not contravene the economic interests of a CHP project.

CHP lives on the crossings of heat and power markets and must guard two fronts (Fig. 4). On the one hand CHP should cover all heat market segments where one of its processes is techn-ically and economically a better choice than separate supplies. On the other hand there is the question of how much condensing power the CHP units may deliver next to and above their pure CHP functioning.

Progress on the heat and progress on the power fronts are very much interrelated. CHP will be able to cover a larger share of the heat market when the conditions for generating and selling surplus power in the electricity market are favourable.

On the one hand, electric companies have a natural drive in defending market share and in fencing off their market from competitors. This has been so and is so regarding independent power producers in particular. On the other hand, independent producers only can face the competition from incumbent, specialised, large-scale and endowed power companies when they can create a competitive advantage in a market niche. The main niche[6] for independent production in industrial-ised societies is the recovery of latent and fatal heat from thermal electricity generat-ion processes, i.e. CHP. There has been a struggle over controlling this niche and in Europe the various power companies followed different strategies. Where some of the companies have met the own CHP duties properly by developing District Heating and related CHP (e.g. Denmark), others mainly have been fighting the indepen-dent growth of the CHP market or have safeguarded and extended market control by enforce-ment of partnerships on upcoming independent producers (Belgium).

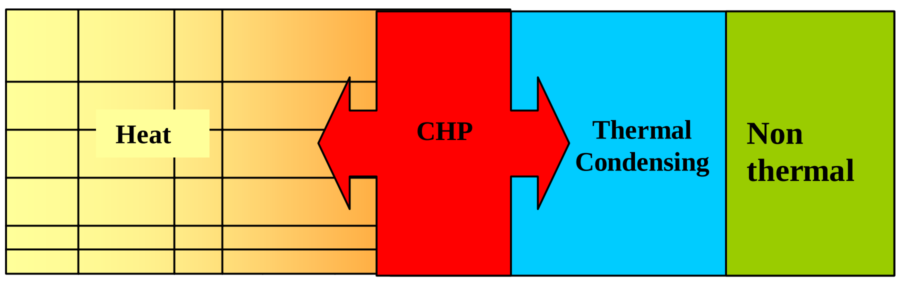

Fig. 4 CHP on the Crossing of the Geographically Segmented Heat Markets of Varying Density and Scale and of the Integrated Power Market Divided in thermal and non-thermal

Fig. 4 also illustrates that the generation of condensing power by CHP units next to and on top of their CHP duty is not a crime but a blessing, because this generation allows the saving of single condensing capacity and activity. Therefore the condensing activity by CHP plants should not be obstruct-ed by regulat-ions.

Moreover, CHP electricity substitutes for a diversity of thermal condensing power, not just for top-efficiency undisturbed CCGT plants exclusively, as the practice of external benchmarking often imposes [25].

Liberalised markets also reveal significant electricity price spikes being part of the efficiency optimisation business in markets of non-storable commodities where demand must be met instantaneously. Economists favour that the message of scarcity at peak load moments is transmitted to end-users through price signals [4]. Hughes and Parece [16, p.43] argue that ‘to obtain the benefits of competitive markets, regulat-ion should avoid “solving” price-spike problems by imposing price caps, which distort incentives and sometimes aggravate the price-spike problems they intend to solve’. For power suppliers that participate in pools and in markets with short-run pricing, price spikes are important for the financial bottom line of their activities [3]. This is also the case for CHP plants

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[6] Electricity from renewable energy is another niche under development. The issues of grid access and fair terms of trade are very similar as with independent CHP.

when they must operate in competitive power markets, not only as a supplier of surplus power, but on occasions at the demand side when the CHP plant cannot meet the own load. The latter will happen more when the flexibility of the CHP plant is aborted by the lack of condensing equipment. The lack of flexibility will also truncate the possibilities of selling surplus condensing power when the price in the market is spiking. This is not only a loss of efficiency from a public economic point of view, but in particular it will encroach on the financial viability of CHP projects. The latter effect will refrain from the expansion of CHP in the electricity market (Fig. 4) and may jeopardise the financial survival of particular CHP projects.

No regulation, and a fortiori no regulation that claims to support the development of CHP should diminish the flexibility and the degrees of freedom in CHP operation. The importance of CHP access to the condensing operational mode is not only due to the volatile and spiking prices in the electricity markets, but also for avoiding uneconomical part-load functioning. When heat loads are low, a CHP plant can maintain a sufficient level of utilisation when it shifts activity more to the generation of condensing power.

4. WILL THE EU CHP DIRECTIVE PROMOTE CHP?

'CHP electricity generation in 2000 totalled 248.7 TWh which was 9.6% of total gross electricity generation' [www.chp-info.org]. Also the Commission [13, p.8] publishes similar statistics, although there is no agreed method of measuring the CHP electricity flows in Europe. Nevertheless there is a wide feeling that CHP should be promoted.

In a "whereas" introduction to its reaction on the Commission proposals, the Council [10] provides a brief overview on what occasions the European institutions have expressed the necessity of promoting the development of CHP.

An interesting landmark is the "Community Strategy to promote CHP and to dismantle barriers to its development" [6], where an objective of doubling CHP electricity output to about 18% of total gross electricity generation by the year 2010 is considered 'realistically achievable'.

The Commission published the first draft of the CHP Directive in July 2002 [7]. The initiative was welcomed but also criticised [3, 17]. In November 2002, the European Parliament [13] amended the proposal thoroughly, mainly inspired by the EUROHEAT& POWER approach [12]. Further negotiations including the Council did not change fundamentally the July-2002 approach by the Commission, but the Common Position [10] remedied some of the perverse effects that could follow from the original draft. In July 2003 the Commission itself reacted with an amended proposal of the own draft of the previous year [8]. In a Communication from the Commission [9] the Common Position is recommended to the European Parliament as the basis for its second-reading Recommend-ation.

The debate on the Directive has been tedious. It could be clarified by a clearer problem statement. When one wants to regulate or promote something it is worthwhile to specify and identify the 'thing' first. Because the applicable variant of the manager's maxim "*You cannot manage what you do not measure*" here is "*You cannot regulate what you do not specify*", it is important to emphasise the necessity of identifying and specifying CHP activity in an accurate way. Next one can consider the identified thing as sufficient to qualify directly for support, or one can add more conditions, e.g. based on a benchmarking on relevant references.

Here the 'thing' is CHP, and the variables to identify are the quantities of co-generated electricity E_{CHP}, recovered heat Q and fuel converted in the combined process F_{CHP}. If one omits to identify precisely the 'thing' (as the draft Directive does), one has to rely on second-best remedies to keep the qualifying method acceptable (as the amended proposal of Directive also does).

In section 4.1 is discussed the identification issue and in section 4.2 the qualification issue. In every section first the Directive's proposals are commented, followed by our approach.

4.1 Identifying CHP Activity and Results

Annex 2 (p.27-28) of the EU Directive amended proposal [July 2003] identifies combined power output E_{CHP} with the formula $E_{CHP} = C \cdot Q_{net}$ with C stated as the power to heat ratio.

This basic formula is correct, under two conditions. First the ratio C should be defined exactly as the design power to heat ratio σ ending in the bliss point(s) of the CHP process (see section 2). Secondly the method to define and apply σ for the range of CHP technologies and processes, should be clarified, discussed and accepted [24, pp. 41-64].

In Article 3 (n), p.15, the Commission [8] defines the power to heat ratio as follows: *'"Power to Heat Ratio" of a cogeneration plant is the quotient of the electricity production from cogeneration and the heat production from cogeneration at full capacity over a measuring period*'.

This definition brings us in a circle: it uses the variable "electricity production from cogeneration" (E_{CHP}) as *independent* variable, but this is exactly the *dependent* variable one has to find (see left hand side of the Annex 2 expression). Clearly, one must know C - or more precisely σ - in order to assess E_{CHP}, not the other way around!

Annex 2 [8, p.27] reveals that the Commission sees Identification only for 'statistical purposes' and suggests a table with default C values 'when the actual power to heat ratio is not known'. Because the draft Directive does not use the right CHP energy flows in qualifying CHP perfor-mance (Annex 3 of the Directive) there is only superficial attention for the Identification problem (Annex 2).

Our extensive proposition [24, pp.41-64] to solve the problem of identifying E_{CHP} and F_{CHP} is summarised here.

The first step is to distinguish CHP units that do not own condensing facili-ties from the ones that own such facilities. All electricity forthcoming from the former group of CHP plants can be labelled univocally as CHP power and all fuel consumed as CHP fuel, without any further consideration on efficiency or whatever, because there may have been good reasons that a high efficiency could not been reached (e.g. the combustion of very difficult but otherwise lost recovery fuels).

The real problem of the division of the power flows and the fuel consumed comes up when the CHP and the condensing generation modes co-exist. Fuel in a CHP plant with mixed operat-ional states is converted into *three* products: E_{CHP} (back-pressure or combined power), E_{Cond} (condensing power) and Q_{CHP} (recovered heat).

Section 3 argued that one should promote the possibility for a CHP plant to also function in a non-fully combined mode. So for every given accounting period the batch of elec-tricity generated can consist of any proportion combined versus condensing power (varying from 0 to 100% for both types). CHP qualification however can only be based on the part of combined power and on the fuel used for the combined activity.

The regulatory rule in drawing the line between the two types of power and fuel should be just and reliable, but also simple, robust and understandable by every CHP investor and operator. Applying the rule must stimulate *investors* to choose the best quality CHP of the right scale and *operators* to operate it in a way to conserve the maximum of energy.

In establishing such a Division rule for splitting power and fuel flows, two variables have a decisive impact (the order of the variables is chosen for clarity of the discussion):

- The technology and equipment involved. It is important that *CHP investors build high-quality units of sufficient scale*. Once available, *a rational operator always will maximise the useful heat output because there is no profit in wasting heat when it is possible to recover it*.
- The trenching of the year in distinct sub-periods (Hours? Days? Weeks? Months? Seasons? Year?). These function as the reference time spans for adding the energy flows on which the regulation applies. The Division rule is little dependent on the sub-period choice but finer time resolution (e.g. monthly) provides regulatory benefit.

The basic Division rule to be applied on the electricity batches per unit period uses the *design* power to heat ratio s of the CHP process. Marking this ratio s as E_{CHPmax} / Q_{max} one derives the amount of CHP power by multiplying the useful heat flow during the same period with this ratio[7].

So the basic Division rule is:

$$E_{CHP} = \sigma \cdot Q_{CHP} \tag{3}$$

The principle of the Division Rule is shown in Fig. 5. It is based on the equal portioning rule[8] or:

$$\frac{Q_{CHP}}{Q_{Cond}} = \frac{E_{CHP}}{E_{Comd}} \tag{4}$$

or

$$\frac{E_{CHP}}{Q_{CHP}} = \frac{E_{Cond}}{Q_{Comd}} \tag{5}$$

In addition the *design power to heat ratio s* is equal to these ratios or:

$$\frac{E_{CHP}}{Q_{CHP}} = \sigma \tag{6}$$

or

$$E_{CHP} = \sigma \cdot Q_{CHP} \tag{7}$$

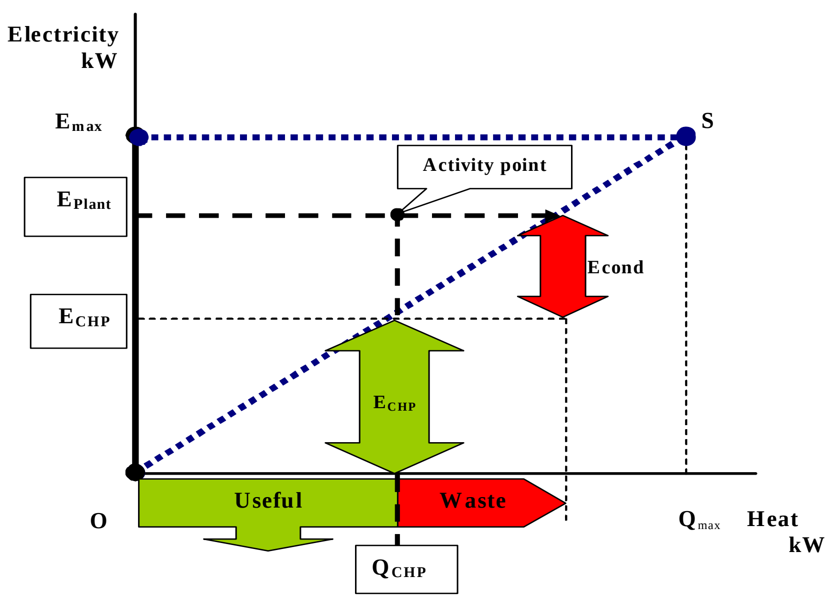

Fig. 5 Splitting the mixed activity of a CHP plant into a combined or CHP part and into a condensing part

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[7] Symbol s different from the Directive symbol C emphasises the difference in definition between both.

[8] The portioning as proposed is accurate when the E_{max}-S line is horizontal (i.e. heat recovery does not entail loss of electric output). When the E_{max}-S line is downward sloping (extraction-condensing steam turbines), one still can argue that E_{CHP}= s.Q_{CHP}, because the loss in electricity output is transformed into recovered heat.

Further:

$$E_{Cond} = E_{plant} - E_{CHP} \tag{8}$$

One also must split the fuel input of the plant into a part for the combined activity and a part for the condensing activity, by:

$$F_{CHP} = F_{plant} - \left(\frac{E_{cond}}{\eta_{cond}} \right) \tag{9}$$

When E_{max}-S is sloping downward (Fig. 3) the allocation of the fuel consumption is only accurate when the substitution of heat for power is accounted for, as is done in the above expression.

By *measuring* the recovered heat flows Q_{CHP} from a CHP plant and by *stating and certifying* the design power to heat ratio σ of the plant and the condensing efficiency η_{cond} , one can *assess* the combined power output E_{CHP} , the condensing share E_{cond} and the fuel consumption F_{CHP} in a reliable, transparent and quite accurate way.

Discussion on the Division rule will concentrate on the existence, uniqueness and measurement of the design ratio σ in the bliss point S of production possibility sets of CHP processes. The method is robust for all situations that can occur in real CHP life, but in some occurrences extensions to the basic method are required. There are situations of shifting, of multi-ple and of virtual bliss points and where σ is not a constant but a function of load conditions. The extended Division rule is:

$$E_{CHP} = \sum_i \left[\sigma_i (q_i) \cdot Q_{CHP_i} \right] \tag{10}$$

where, the power to heat ratio is represented as an analytical function $\sigma_i(q_i)$ with as argument q_i being the heat load factor of heat flow i or $q_i = Q_{CHPi} / (h_i \,.\, Q_{maxi})$ with h_i the number of hours the hot condenser or extraction point i is operated.

The general formula addresses all cases in a technical and correct way. In case of CCGT cogenerat-ion where two thermodynamic cycles are integrated into one plant, one must convene on the way how to interpret the cycle integration [for more detail: see 24, pp.53-64].

4.2 Qualifying CHP Results

One could stop the CHP regulation after having identified accurately the CHP activity of thermal power generation plants. The merit of CHP is in the recovery of (part of) the fatal heat of the thermal power processes (see section 2.2) and this could be considered as sufficient for qualifying CHP. However, most observers want to benchmark the CHP results obtained by a particular plant against established reference standards.

The 'quality norm' (section 2.4) is a good candidate as external[9] benchmarking formula, but only when applied correctly, i.e. on the identified cogeneration flows E_{CHP}, F_{CHP} and Q or Q_{CHP}. The main problem is that the Commission in Annex 3 of the draft Directive applies the formula on mixed electricity and fuel flows E_{plant} and F_{plant}. Perhaps the statement in the Directive text p.29 that the formula is based on "cogeneration production defined in accordance with Annex 2" may raise other

[9] The discussion has dealt exclusively with external benchmarking. In January 2003 we also proposed internal benchmarking (this means CHP processes on reference CHP processes), what avoids biases easier.

interpretations, but they are emptied quickly when one refers to the shortfall in identification Annex 2 offers. For all clarity we therefore complete the terminology here to 'mixed quality norm'.

Verbruggen [24, pp.67-80] reveals step by step the perverse effects of the draft Directive and all similar qualification rules, especially when positioned in the reality of the power markets and compet-ition and when the reference separate technologies and the CHP plant technology do not match. For the latter problem the Commission offers a remedy in specifying adapted reference separate processes and efficiencies for a variety of CHP technologies.

Our conclusions are summarised here:

'Mixed quality norm' benchmarking is not effective in differentiating low quality CHP designs from high quality ones. All CHP designs will pass the test. To remedy this short-coming in discret-ionary capability the proponents of the mixed norm apply mark-ups of an arbitrary percentage (5% for existing and 10% for new plants in the Directive proposal [8, p.29] above the break-even energy consumption, and some stretch the efficiencies of the reference separate plants above warranted values [3].

While the 'mixed quality norm' does not differentiate real CHP quality, it is effective in truncat-ing the production possibility sets of CHP units. Obeying the 'mixed quality norm' limits the operational choices of a CHP unit and drives the unit towards part-load operation. When a CHP operator follows the incentives embedded in the 'mixed quality norm' the financial bottom line of CHP is jeopardised. As a corol-lary, the CHP operator is placed before a lacerating choice. Either try to get the quali-fi-cation on the basis of the 'mixed quality norm' and accept the constraints on an economic exploit-at-ion of the plant, or keep the freedom to operate while increasing the probability of falling short to the 'mixed quality norm'. Which choice will be the best cannot be decided in general. The outcome depends mainly on the conditions for power exchange with the grid and on the time resolution of accounting the CHP performance stipulated in the qualification regulation. Making the best economic decision requires a clear insight in all the complex mechanisms and it loads a lot of effort and transaction costs on the CHP operator in data monitoring and evaluation.

The analysis of the incentives embedded in a qualification on the basis of the proposed 'mixed quality norm' regulation, highlights that the norm:

- Provides incentives to reduce the investment in CHP capacities. Investors are brought to down-scaling the CHP plants to their minimum level. Added to the other perverse incentives this loss in economies of scale will end many times in no investment at all.
- Induces operators of the plants to run the plant with a small electricity output as result. Either because the overall qualification imposes the shut down of the unit during periods of the year when heat demands are smaller, or because the operator is lead to part-load charging adjusted to the heat demand. Both induced effects have a significant negative impact on the financial bottom line of a CHP project[10].

From the analysis it is apparent that qualifying CHP with the 'mixed quality norm' is contravening the development of CHP. It provides the wrong incentives for CHP investment and it fences CHP into a regime that makes a lot of operations uneconomical. The basic reason of the perverse effects[11] of

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[10] In CEC [7, p.6] both elements that jeopardise the financial viability of CHP (economies of scale and number of operating hours) are recognised. But there is no further analysis that would conclude that the 'mixed quality norm' fortifies these effects and that CHP should not be refrained from overcoming these handicaps by deploying more activity in the power condensing market.

[11] Proponents of the biased use of the 'mixed quality norm' in the past have used this norm as an instrument to attack full development of CHP in some nations and to present the underdevelopment of CHP in the own country as a merit [11].

CHP qualification with the 'mixed quality norm' are the mixing of CHP activity and condensing activity and the benchmarking of the mixed results on extremely performing reference separate technologies. 'Mixed quality norm' qualification is an example of 'external' benchmarking. As in all bench-mark-ing it imposes on the evaluated activities (here CHP) to resemble the fixed references as much as possible. When the CCGT is fixed as reference separate power plant it forces the CHP world to adopt that technology. To avoid particular technology promotion and to soften the perverse effects of qualification with the 'mixed quality norm', a second best approach classifies the CHP plants into technology groups (gas turbines, steam turbines, gas engines, diesels, fuel cells, etc.). One also classifies heat generation technologies (mainly by temperature class). Then one must fix the relevant reference efficiencies of the best separate power and heat plants to benchmark the aggregated results of the various CHP plants by category of technology. The Commission proposes this second-best remedy. Finally the accounting periods for assessing the performance of CHP plants should be the months (or shorter periods) instead of the year.

Our proposition is triple:

- First, given the merit of CHP is in recovering (part of) the fatal heat, the amount of well-identified co-generated power E_{CHP} by the Division rule is a sufficient ground for qualification. This method entails the right incentives to the CHP plant designers and CHP plant operators. When designing and investing in CHP units the investor gets a stimulus to search for the plant with the highest σ or quality. When operating the plant the operator will recover the maximum of heat Q_{CHP} to give it a useful destination.
- Second, we developed a proposal for internal benchmarking, i.e. the results of a CHP plant should be measured on the buoy of a 'best practice' CHP process in the same category.
- Third, one can benchmark CHP results externally with the use of the 'quality norm' formula, but applied correctly on the exclusive CHP activity and results, i.e. making use of E_{CHP} and F_{CHP}, and not of E_{plant} and F_{plant}. One then finds the exact primary energy savings the CHP activity contributes compared to reference separate processes.

5. CONCLUSIONS

The criticism on the first draft CHP Directive (2002) has been harsh. The amended version of 2003 is a clear reaction on several of the critics. The perverse effects of the qualification rule as proposed in Annex 3 of CEC2002 are remedied by accepting in CEC2003 a broad range of reference separate production processes. The new proposal 'subsidiarises' many choices to the Member states, and this will not harmonise the conditions and markets for CHP. Next to other observers [12], we have worked on another approach we consider as more useful. The differences between the Directive and our proposals are highlighted in Table 1.

Table 1 EU Directive proposals (2002, 2003) compared with our approach [24]

Two Responses:	Two Issues: IDENTIFICATION	QUALIFICATION
Draft Directive COM (2002) 415 final COM (2003) 416 final	• Approximate assessment of ECHP for statistical purposes • No assessment of FCHP • Use of default power to heat capacity ratio's = NO REAL EFFORT in identifying CHP activities and results.	• Based on the 'mixed quality norm' because ECHP and FCHP are not properly identified and assessed • Biases and perverse effects of using the 'mixed quality norm' are reduced by accepting a broad range of reference separate processes for the external benchmarking • The method is opaque; its adopters often do not understand its meaning and effects.
Division rule and CHP Energy Saver Index [24]	• Accurate measurement of QCHP flows and certified statement of technical design parameters of the CHP processes • Reliable assessment of ECHP and FCHP = ALL EFFORT put in good Identification applicable on all CHP technologies	• The well-identified amount of ECHP is a sufficient ground for CHP qualification. It stimulates investors to high-quality CHP designs and operators to maximise useful heat recovery • Internal or external benchmarking can be added without biases or perverse effects because of the solid identification before of the CHP variables

The common position of the EU organisms [10, 9] is less harmful for CHP than the original propos-itions [7] were. This is the result of twice approximate solutions for two central issues: identification and qualification. With a clear identification of CHP activities and results, this second best approach could have been foreclosed. Now, a lot of regulatory discretion is assigned to the Member States. When the EU is not willing to solve the identification problem, only few Member States will do rightly on their own [12]. In any case this is not conform seeking "to level the playing field and harmonise the definitions of cogeneration in order to increase the transparency" as stated in CEC [9, p.2]. The danger is real that every Member State will continue to follow its domestic policy in promoting or obstructing CHP as it was in the past. The Flanders region (Belgium) already implemented the first draft proposal of Directive [7, 25, 26] with all its perverse effects]. Instead of regulating the promotion of CHP, the Flemish region enacted regulation to subsidise large-scale industrial gas turbines, the CHP application that warrants the least support of all.

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7. NOMANCLATURE

E	=	Power flow (MWh) or power capacity (MW)
E_{CHP}	=	Power output from combined or back-pressure activity of the CHP plant
E_{Cond}	=	Power output from condensing activity of the CHP plant
E_{plant}	=	Power output of the CHP plant i.e. $E_{CHP} + E_{Cond}$
Q	=	eat flow (MWh) or heat capacity (MW)
Q_{CHP}	=	Heat recovered for an end-use; also $Q_{net} = Q_{useful}$; often the subscripts are dropped
Q_{Cond}	=	Heat dissipated in the environment related to condensing power; also $= Q_{waste}$
Q_{plant}	=	Heat set free at the thermal power plant (also called 'fatal' heat); $= Q_{CHP} + Q_{Cond}$
F	=	Fuel flow (MWh) or fuel capacity (MW)
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; $= F_{CHP} + F_{Cond}$
E_{max}	=	Maximum power output (capacity) at full fuel load of a unit, either in pure condens-ing $E_{Condmax}$ or in maximum CHP or back-pressure mode E_{CHPmax} (see point S)
Q_{max}	=	Maximum useful heat output (capacity) of the unit at point S.
S	=	Bliss point of a CHP process, where at maximum useful heat output the generated power output is also maximised. One cogeneration unit can have more than one bliss point (e.g. steam turbines with two hot condensers).
σ	=	Design power to heat ratio of the cogeneration process.
η_E	=	The electric output of the reference separate power generation process when fuel input equals 1
η_Q	=	The heat output of the reference separate heat or steam boiler when fuel input equals 1
α_E	=	The electric output of the CHP plant (E_{plant}) when fuel input (F_{plant}) equals 1
α_Q	=	The useful heat recovery at the CHP plant (Q_{CHP}) when fuel input (F_{plant}) equals 1

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