Qualifying Combined Heat and Power (CHP) activity

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Abstract: The EU 2002 draft and 2004 final CHP Directives propose qualifying CHP activity with the *quality norm*. This norm benchmarks the energy efficiency of CHP plant outputs on external reference power and heat efficiencies. Because the quality norm amalgamates cogeneration and condensing activity its application entails particular perverse effects for high-quality and adapted scale investment in CHP capacities and for operating available units. Operators get incentives to part-load or shut down their capacities and to avoid condensing activity (lucrative at spiky price conditions in the power market). The formula of the quality norm is only useful when CHP activity (heat recovery, cogenerated electricity, fuel consumption for cogeneration) is first quantified reliably.

Keywords: combined heat and power; CHP; cogeneration; incentive regulation; quality norm; production possibility set; power to heat ratio.

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Biographical notes: Aviel Verbruggen studied Engineering Sciences at the Catholic University of Louvain, and economics at the University of Antwerp, where he got his PhD in 1979. He researches energy and environmental issues from an applied and interdisciplinary perspective, covering topics, such as power generation, cogeneration, regulation and pricing, energy efficiency. In the 1990s he was the first President of the Flemish Environmental Council. He designed and edited the state-of-the-environment reports in Flanders, and served for two years in the cabinet for environmental policy. He is contributing to IPCC, WGIII (third and fourth assessments), and also member, supervisor or chairman of a number of research groups and networks on energy and environmental issues.

1 Introduction

A regulatory policy for CHP is based on variables (indicators) that measure the performance of CHP activities. Such variables allow a regulatory construct to gauge the wanted (beneficial) effects of CHP activities. The choice of variables and the regulatory construct are named 'qualifying' CHP activity. The choice of the variables and the constructs are not neutral for regulatory effectiveness and efficiency.

The merit of CHP is in the recovery of (part of) the fatal heat of thermal power generation (see CHP essentials). Thus, the first yardstick for measuring CHP performance is the total amount of recovered heat Q_{CHP}. This indicator has no incentives built-in to safeguard and improve the thermodynamic quality of the process. A second indicator, the quantity of cogenerated electricity E_{CHP}, therefore monitors CHP performance. Because this indicator encompasses the first one given the relationship $E_{CHP} = \sigma . Q_{CHP}$ (see quantifying CHP activity), it is a more complete and powerful indicator. E_{CHP} is a sufficient measure of the merit of CHP activity, because it takes into account the (eventual) power loss owing to the recovery of useful heat Q_{CHP}. Qualification can be based on E_{CHP} directly without additional regulatory constructs.

Annex III of the 2002 draft EU Directive (CEC, 2002) adds the *quality norm* (see CHP essentials) as a qualifying tool that benchmarks CHP plant outputs on external separate power and heat generation efficiencies. The European Parliament (2002) rejected this additional qualifying step, leading to the 2004 Directive (EP, 2004) being more prudent on the external benchmark propositions. This prudence was the result of better understanding the perverse effects the qualification construct of the 2002 draft version could have on the development of CHP. Because the perverse approach still has its advocates and because the 2004 Directive itself is not clear about it yet, this paper explains the mechanisms the draft version of the *quality norm* regulation embodies.

Section 2 introduces external benchmarking. The 2002 draft Directive's qualifying method is presented in Section 3. Next is investigated, what the meaning and effects are of such qualification rule, especially when positioned in the reality of the power markets and competition and when the reference separate technologies and the CHP plant technology do not match. Section 4 shows the weakness of the *quality norm* in revealing true power-to-heat quality of CHP processes. The effect of applying the *quality norm* may be the fencing in of cogeneration activities (Section 5). The incentives incorporated in the construct are detailed in Section 6. The conclusions about qualifying CHP based on the wrong use of the *quality norm* are offered in Section 7. How to use the external benchmarking tool in a right way is expressed by the Energy Saver Index (ESI) (Section 8). The paper concludes (Section 9) with showing how the 2004 Directive avoids many pitfalls of the 2002 draft, but still falls short of a solid regulation for CHP. A common set of symbols is used throughout the analysis (Table 1).

Table 1 CHP nomenclature

Q	Heat flow (Wh)†
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)†
E_{CHP}	Electricity output from combined or 'back-pressure' 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)†
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., $F_{CHP} + F_{Cond}$
CQ	Heat recovery capacity (W)†
CQ_{CHP}	Maximum heat recovery capacity given the parameters of the CHP process
CQ_{real}	Realised heat recovery capacity of the CHP process

Table 1 CHP nomenclature (continued)

CE	Electricity supply capacity (W)[†]
CE_{Cond}	Electric capacity in pure condensing operation
CE_{CHP}	Electric capacity in CHP operation, for a given level of heat recovery
h	Number of hours of cogeneration activity within a given accounting period
q	Heat load factor = $Q_{\text{CHP}}/(h.CQ_{\text{real}})$
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 maximised. 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 $(E_{\text{plant}} + Q_{\text{CHP}})/F_{\text{plant}}$
η_{CHP}	Energy efficiency of CHP activity or $(E_{\text{CHP}} + Q_{\text{CHP}})/F_{\text{CHP}}$
η_{Cond}	Efficiency of the pure condensing activity of the CHP plant $(E_{\text{Cond}}/F_{\text{plant}})$ when $Q_{\text{CHP}} = 0$
β	Power loss factor by a heat extraction at a steam turbine (directly linked to σ through η_{Cond} and η_{CHP})
α_E	The electric efficiency of the CHP plant $E_{\text{plant}}/F_{\text{plant}}$
α_Q	The heat efficiency the CHP plant $Q_{\text{useful}}/F_{\text{plant}}$
η_{ERS}	The electric efficiency of the *reference separate* electricity generation process
η_{QRS}	The heat efficiency of the *reference separate* heat process

[†]With capacities in W (Watt) and energy in Wh, the axes of the Electricity-Heat graphs can represent both capacities and energy flows per hour (momentary or average values).

2 Benchmarking CHP performance

In a business context benchmarking is

> "the continuous, systematic process of comparing the current level of performance against a predefined point of reference, the benchmark, in order to evaluate and improve performance." (Couder and Verbruggen, 2003)

Benchmarking is mostly applied by private or public agents for assessing the own performance and improving it. Fuzzy aspects in definitions, data availability and methods applied, are ironed out by the benchmarking organisation and its management.

A variety of benchmarks can be adopted: internal or external to the own organisation or to the activity sector, local, national or international in reach, focused on a part or the whole of the organisation, in a short-term or a long-term time perspective. The choice of the benchmark is of crucial importance because one's own performance is measured as a 'distance-to-targets' where the benchmark characteristics function as the targets, and because the own activity is changed to resemble the benchmark as much as possible. In particular, when the benchmark is *external* to one's own activity, one must carefully question whether one's own activity can or should resemble as much as possible the external reference benchmark. *Internal* benchmarking references are drawn from within the same organisation or activity branch and are more akin to the own activity.

Compared to benchmarking by limited organisations, the perspective is dramatically different when benchmarking is applied in a regulatory policy context (EU Directive). Then, a wide range of participants (competitors) are screened and evaluated on a particular performance and remunerated or penalised in one way or another on the basis of the measured performance. In such a context the definitions must be based on argued, transparent and robust methods requiring data that are measurable in an uncontested way.

The EU CHP Directive benchmarks the energy conversion performance of CHP plants on the efficiencies of processes of separate generation of power and of heat. This is *external* benchmarking because CHP is compared with non-CHP processes. The imposed reference at the power side 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 weakens this type of external benchmarking (Franke, 2004). *Internal* benchmarking (particular CHP activities on reference CHP processes) is more reliable but requires also the clear identification of the CHP activity of every plant.

3 EU draft directive on qualifying CHP

For clarity of the argument and because some countries based their regulation on the 2002 draft, we first analyse the qualification construct of this draft Directive (Annex III of CEC, 2002). This was meant to provide an instrument to the Member States and their regulators to accept or to exclude particular CHP activity from qualification and support because they fall short of exigencies of the *quality norm*. But the construct entails particular incentives for CHP development (investment, technology, design, scale) and for the operation of existing units that can be labelled perverse.[1]

For assessing the incentives implied in *quality norm* qualification and for assessing the likely effects of these incentives, the concept of CHP production possibility sets is useful (see CHP Essentials). To the possibility set concept is added a graphical analysis that pictures the *quality norm* and is helpful in monitoring the energy performance of CHP and the external benchmarking of CHP on separate heat and power processes (Verbruggen et al., 1992).

The *quality norm* links the outputs of a CHP *plant* to the efficiencies of reference separate heat and power generation processes and is defined as (see Table of Symbols):

$$1 - 1/\{\alpha_E/\eta_{\text{ERS}} + \alpha_Q/\eta_{\text{QRS}}\}.$$

Section 4 shows that the *quality norm* entails little incentive to improve the 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.

While the *quality norm* is not effective in stimulating CHP quality it is perverse in truncating the production possibilities of CHP plants, as is elicited in Section 5. Fencing in CHP operators is also a perverse effect that will lead to less CHP power and less CHP investment.

In Section 6 follows a detailed analysis of the incentives and likely effects embedded in the use of the *quality norm* as a qualification instrument. By performing the investigation step by step it is revealed that the *quality norm* will not promote CHP at all but will nip CHP development in the bud. Investment in well-scaled and flexible CHP capacity is choked by the qualification proposal. In existing plants CHP operators are driven to produce small quantities of power either by part-loading or shutting down capacities.

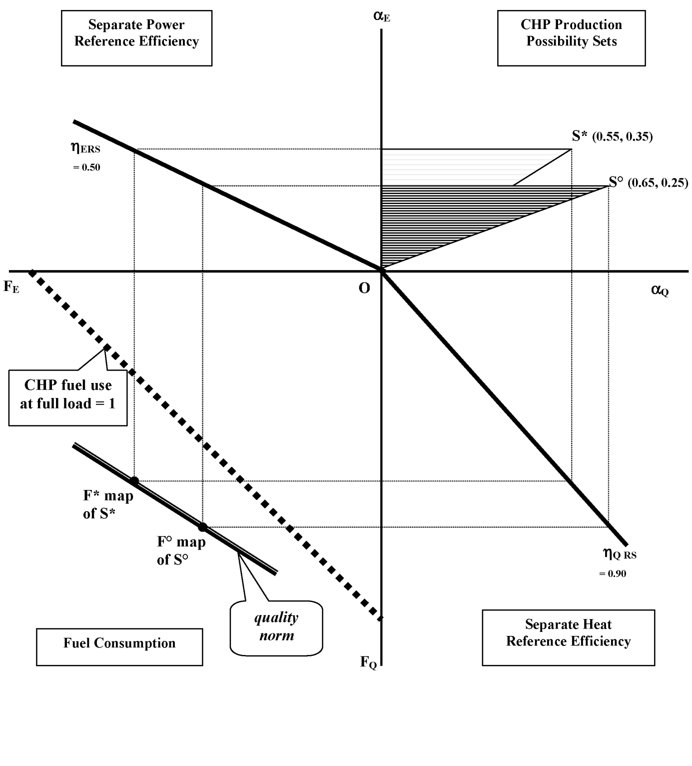
The analysis is presented with real-world numerical examples. The shown perverse effects can be amplified or can be softened by selecting more extreme or softer numerical values. A (second-best) amendment of the draft Directive by the final Directive consists in the selection of more suitable numerical reference values per CHP technology.

4 The *quality norm* does not differentiate real quality of CHP designs

A formula really measures the quality of CHP when it differentiates technologies and applications in conformity with the true quality yardstick of CHP, being the design power-to-heat ratio. The question is whether the *quality norm* owns that differentiating capability.

Figure 1 shows the mechanism of the *quality norm* benchmark. To the graph of the possibility set of a CHP plant is added the benchmarking of the plant's outputs on separate power and heat generation references. For complying with the *quality norm* symbols the heat and power outputs of the CHP-plant are normalised on the basis of one unit fuel input ($F_{\text{plant}} = 1$ and CE_{CHP} is replaced by $\alpha_{E\text{-max}}$ and CQ_{CHP} by $\alpha_{Q\text{-max}}$).

Figure 1 Benchmarking CHP activity on separate power and heat generation processes leads to the *quality norm*



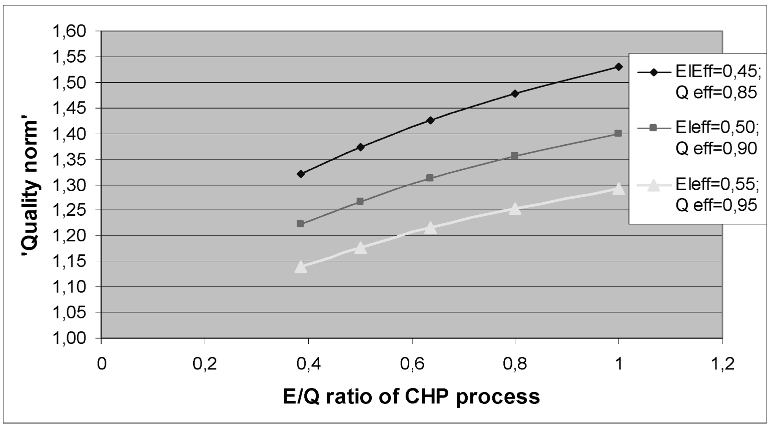
The conversion efficiency of a separate power generation reference process is added in the North Western quadrant and analogously for the separate heat reference boilers in the South Eastern quadrant (Figure 1). So doing one can finally compare in the South Western quadrant the fuel consumption of every (E, Q)-output pair that belongs to the CHP-feasibility set with the fuel consumption of the separate reference processes.

The example in Figure 1 shows two different CHP processes: a medium quality one with bliss point S^* ($\alpha_E = 0.35$ and $\alpha_Q = 0.55$ with $\sigma = 0.64$) and a low-quality one with bliss point S° ($\alpha_E = 0.25$ and $\alpha_Q = 0.65$ with $\sigma = 0.38$). The efficiencies of the reference processes are set at $\eta_{\text{ERS}} = 0.50$ and $\eta_{\text{QRS}} = 0.90$ (CEC, 2002).

The points S^* and $S°$ are mapped on F^* and $F°$ showing the fuel consumption that would be necessary when the CHP heat and power outputs would have been generated by separate units with the aforementioned efficiencies. Because the points F^* and $F°$ fall above the CHP fuel use line (here at full load), the CHP process saves energy compared to the mentioned reference processes.

It is of course expected and warranted that CHP units in their *design bliss point* save energy when benchmarked on separate technologies that are valid as true reference plants for the CHP plant considered (KWK, 2002). So both projected points F^* and $F°$ reflecting the CHP energy consumption levels at the *design bliss* points (full load) are at a safe distance from the dotted curve, and therefore pass the test of the *quality norm*. The latter is represented in Figure 1 by the curve that passes both points F^* and $F°$ (a better picture of the *quality norm* as a function of the design power-to-heat quality 'σ' of a CHP process is given in Figure 2).

Figure 2 *Quality norm* performance above benchmark 1.00 (=CHP plant fuel input) as a function of the power-to-heat quality of a 90% thermal efficient CHP process (and for three assumption sets about the efficiencies of the reference separate plants)



From Figure 1 follows that imposing the *quality norm* entails some incentive to ameliorate the power-to-heat quality of the CHP process design, but that this incentive is not strong.

When the overall conversion efficiency of the CHP unit equals 0.90 or 0.80, all CHP designs would pass the test even when the power-to-heat ratio deteriorates to a very low value. So, the *quality norm* has little differentiating capability to distinguish bad and good quality CHP.

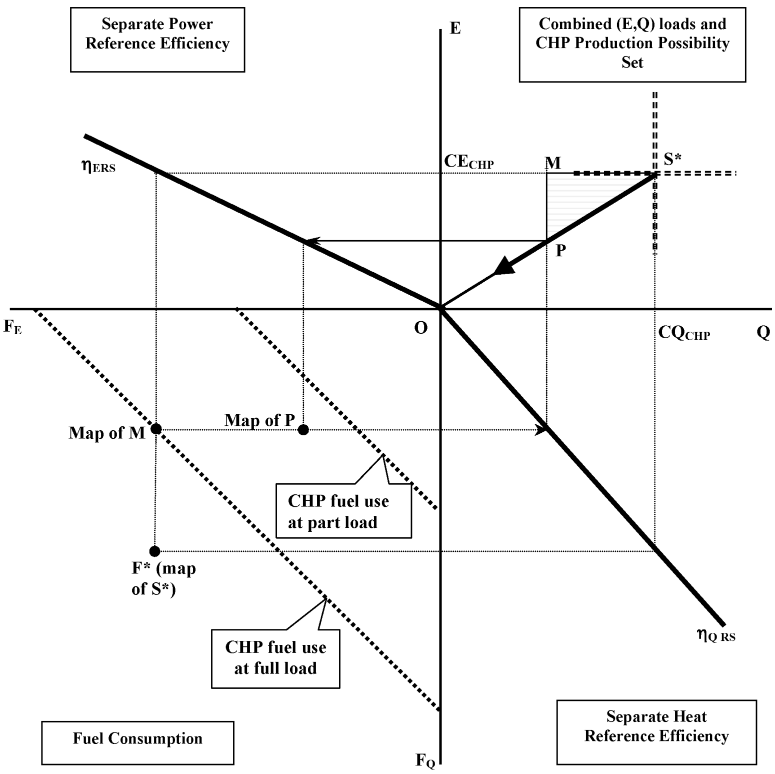
This shortcoming is also felt by the proponents of the *quality norm*, and second-best corrections are used to retain the norm as a qualification instrument. One way to make the *quality norm* exclude CHP-designs of real low quality is *raising the threshold* in qualifying CHP. Instead of requiring that CHP is as efficient as the reference separate plants one than requires that CHP performs better by 5%, 10% 20%, etc. The choice of such a number is arbitrary, and in order to exclude *low-quality* CHP the percentage mark-up must be quite high when also the *quantitative* efficiency of the CHP plant is quite high and when CHP plants operate only at their design bliss points.

5 The *quality norm* truncates CHP production possibilities

Section 4 focused on the incentives for *designing* CHP units. Here the impact of the *quality norm* on the *operation* of CHP plants is analysed. It is shown that the production possibility sets of CHP processes are fenced in when the outputs have satisfied the *quality norm*. This truncation itself triggers a number of biased incentives that limit the deployment of CHP.

Figure 3 copies the medium quality CHP process of Figure 1. When the unit is operated at full load, the imposed *quality norm* is only met for operations on segment *S*M*. When useful heat demand is to the left of M and the maximum electric output is delivered, the *quality norm* cannot be met.

Figure 3 The *quality norm* shrinks the operational CHP production possibility sets



The way to loosen the fencing in constraints imposed by the norm is to shift to part-load operation of the plant. If the operator runs the unit in point P, it generates the same amount of useful heat and an amount of PM electricity less than at full load in point M. While operating in point P the *quality norm* is surpassed (see southwest quadrant in Figure 3). Also (E, Q) outputs further down on the OS* ray will meet the *quality norm* in a technical way. But the perverse effect of driving an operator to part-load working is that less power is generated, and that the unit is driven in part-load at the same operational (except fuel) costs as in full load. This deteriorates the competitive position of CHP.

The application of the *quality norm* for qualifying CHP truncates the production possibility sets and the operational flexibility of existent CHP units. The operator is driven to part-load operation, and when it is not economical to operate the unit at part-loaded conditions, the incentive is to stop the plant running. The truncation of the possibility sets and the drive to part-load operation hurts the financial viability of CHP projects.

6 What incentives for CHP development are provided by the *quality norm*?

Analysis of the embedded incentives and therefore likely effects of *quality norm* regulation is based on distinguishing four representative occurrences of combined (E, Q) loads that may be faced by a CHP plant with given production possibility set. The four occurrences are typified in the following table with reference to the four quarters that split the (E, Q) quadrant of Figure 3 in four areas with S^* as the centre point:

Situation	*E = electric load*	*Q = heat load*	*Area in Figure 3*
1	$E > CE_{\text{CHP}}$	$Q > CQ_{\text{CHP}}$	North East of S^*
2	$E < CE_{\text{CHP}}$	$Q > CQ_{\text{CHP}}$	South East of S^*
3	$E > CE_{\text{CHP}}$	$Q > CQ_{\text{CHP}}$	North West of S^*
4	$E < CE_{\text{CHP}}$	$Q < CQ_{\text{CHP}}$	South West of S^*

One could argue that situation 2 can be transformed into situation 1 and 4 into 3, when the grid is available as an infinite demand to a single distributed generator. In practice these transformations occur when the price for surplus power is attractive.

6.1 Situation 1: lost CHP opportunities

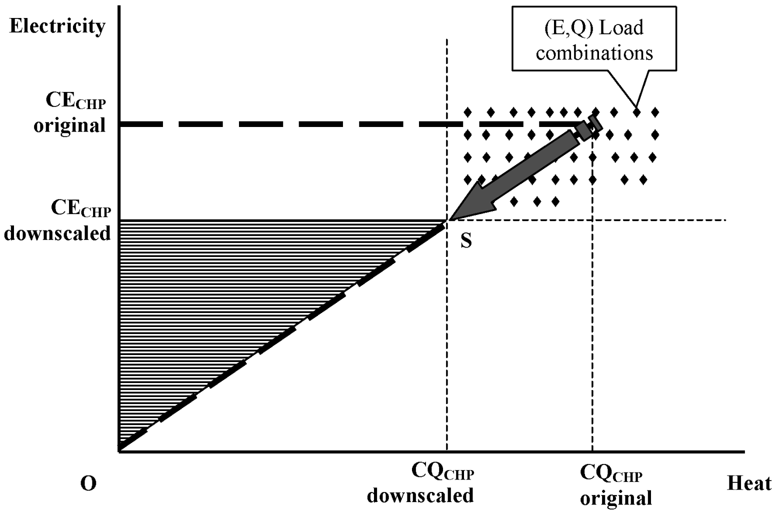
When the power-heat load combinations (E, Q) fall North East of point S^*, the CHP unit remains every hour fully loaded at CE_{CHP}, CQ_{CHP}. This situation is characterised as "lost or missed CHP opportunities" because only part of every load combination is met in a CHP way. The differentials ($[E - CE_{\text{CHP}}]$ and $[Q - CQ_{\text{CHP}}]$) have to be generated elsewhere.

CEC (2002, p.11) specifies "the cogeneration plants should be designed and sized for the actual heat demand present or foreseen *with certainty*". The emphasis on *certain* useful heat demand entails an incentive to enlarge the area of lost CHP opportunities. In order to increase the likelihood (called 'certainty' in the EU text) of a useful heat demand to occur, the CHP-investor will shift the design point S^* to the West in Figure 3.

In principle he would like to shift S^* horizontally to the West, but this is technologically not feasible when S^* is already the bliss point of the best technology with the maximum design power-to-heat ratio 'σ'. He will have to shift S^* along the bisector ray in the South West direction. This will downscale the CHP unit and shrink the CHP possibility set.

The effect is shown in Figure 4. The original plan of CHP investment is given by the large triangle (heavy black dashed border). This CHP capacity would cover most of the load combinations, however, with some wasting of heat for all combinations to the left of the design heat capacity CQ_{CHP}-original of the unit. The plant also would have excess power to deliver to the grid for all load combinations beneath the electric capacity CE_{CHP}-original of the unit.

Figure 4 "Designing and sizing CHP plants for the actual heat demand present or foreseen with certainty" shrinks the Production Possibilities of CHP causing 'lost CHP opportunities'



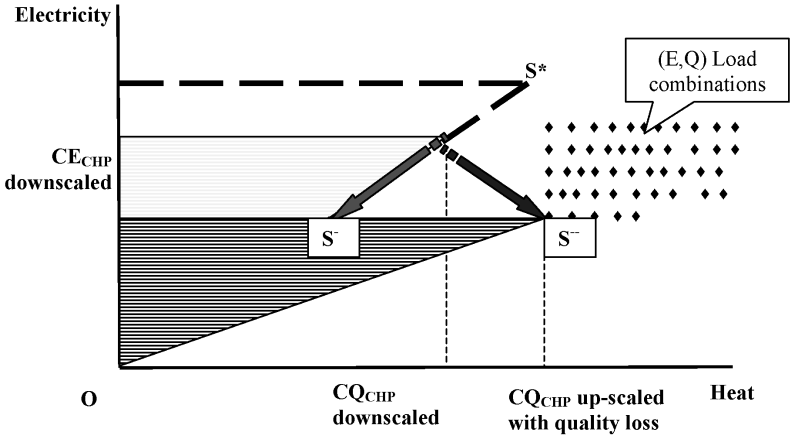
By reducing the dimension of the unit to a scale that guarantees a 'certainty' of useful heat all the time the unit is reduced in size. This is shown in Figure 4 by the downscaled CE_{CHP} and CQ_{CHP} values compared to the original ones. The downscaled plant will only meet part of the loads and it will have to buy make-up power at the grid and to consume fuels in the heat only boilers all the time to meet the load combinations.

6.2 Situation 2: downscaling CHP and real CHP quality in danger

When the power–heat combinations fall South East from point S^*, the operator normally would run the unit at full load in the bliss point S^*, generating simultaneously power equal to CE_{CHP} and heat equal to CQ_{CHP}. Because $E < CE_{CHP}$ there would be surplus electricity on the CHP site that must be exported (delivered to the grid). With a fair price of surplus power, this would be the right decision.

However, the problem is acknowledged that in many cases independent CHP producers receive a (too) low price for surplus electricity (DEFRA, 2004, p.11). This occasions negative effects as well on the design as on the operation of CHP plants. Operationally speaking, the independent owner will try to match his electricity needs by modulating the plant to part load. Graphically (see Figure 5) from each load combination on, a horizontal line has to be drawn to the West until it hits the possibility set at the part-load ray. The CHP unit generates then exactly the electric load, while a larger part of the heat load must come from heat-only boilers. Moreover, the unit works in part load which is technically but mainly economically bad for most CHP technologies.

Figure 5 Low valorisation prices for surplus electricity and the indifference of the *quality norm* for power-to-heat quality, executes a downward pressure on CHP quality investment



In order to avoid such bad operational working conditions, the independent investor in CHP will downscale the plant. In addition there is a perverse incentive for deterioration of the power-to-heat quality (Figure 5). Again the pressure exists to bring all load combinations to the North East corner from the design point S of the unit. This can be done in two ways: either further down-scaling the plant from *S** to S^{-} (see arrow pointing to the origin of the graph in Figure 5), or downscaling and *in addition substituting low power-to-heat quality* OS^{--} *for the better one* OS^{-} (*on OS**), see arrow pointing rightwards in Figure 5. None of these choices is good for CHP, but giving up the power-to-heat quality standard is the worst. As shown above (e.g., Figures 1 and 2), the proposed *quality norm* does not withhold investors from this bad choice.

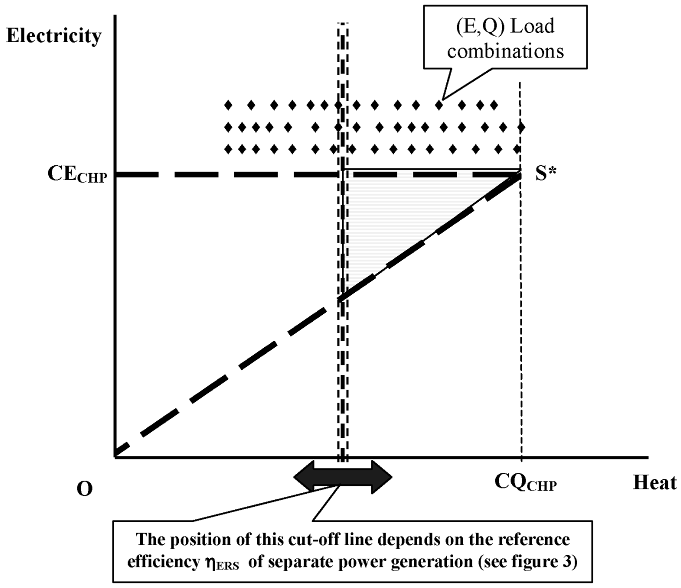
Summarising so far: both situations 1 and 2 meet the criterion of sufficient heat demand because the (*E*, *Q*) load combinations set is located at the East side on the 'Heat' axis. However, also in these conditions, the *quality norm* regulation entails the wrong incentives. Once it will shrink the CHP production possibilities and raise the lost CHP opportunities. Once it will in addition decrease the real quality of the CHP process by pressing the design power-to-heat ratio 'σ' downwards. The latter effect is added when no fair valorisation price of surplus electricity can be obtained (a non-imaginary phenomenon for independent CHP plants). And, as shown in Section 4 the *quality norm* is quasi 'neutral' with respect to the power-to-heat quality design, and so does not help in offsetting this challenge.

6.3 Situation 3: truncating production and jeopardising financial viability of CHP

Consider now an *existent* CHP plant with a design not affected by the proposed regulations based on the *quality norm* (see situations 1 and 2). In such plant the useful heat loads may fall short of the design heat capacity CQ_{CHP} of the plant. This is so in the situations 3 and 4, where the *quality norm* gives rise to effects that are similar in both situations.

Figure 6 shows what happens in situation 3, where all load combinations entail a demand for power higher than the electric capacity of the plant.

Figure 6 The CHP production possibility set is truncated by the *quality norm*



Normally the plant owner will want to operate the unit at maximum load, generating CE_{CHP} along the top line $CE_{CHP} - S^*$ of the possibility set. In addition, he will have to buy some make-up power at the grid (shown by the vertical distance from the load point to line $CE_{CHP} - S^*$). He also will have to waste[2] some of the available heat (shown by the horizontal distance between the load point and the vertical line $CQ_{CHP} - S^*$).

However, the *quality norm* will make an inroad on this functioning. Depending on the set value for the separate, reference power generation technology the possibility set accepted for qualification is truncated to the smaller tip of the technically feasible set (Figures 3 and 6).[3] Only load combinations to the East of the vertical demarcation line pass the *quality norm*. The combinations at the West side of the demarcation line fail.

Now the actual operation of the CHP plant will depend on the detailed accounting period regulation of the CHP qualification rules. When the load combinations are treated individually, the operator can function as a qualified operator on the loads to the East of the demarcation line. The output will be non-qualified for the loads to the West of the demarcation line. An individual treatment means that the division of the year or month in accounting sub-periods is fine-tuned, and that the *quality norm* is applied independently on each sub-period.

When the performances on the load combinations are aggregated, the bonuses collected at the East side loads are compensating the shortfalls at the West side loads. When bonuses are used up, the operator must choose between either loosing the qualification either shutting down the plant. This decision will become more difficult in real life conditions, when the future build-up of bonuses has to be assessed in advance because it is not provided that shortfalls should follow bonuses in time. Preserving security margins on this account will further downturn the operation of the CHP plant.

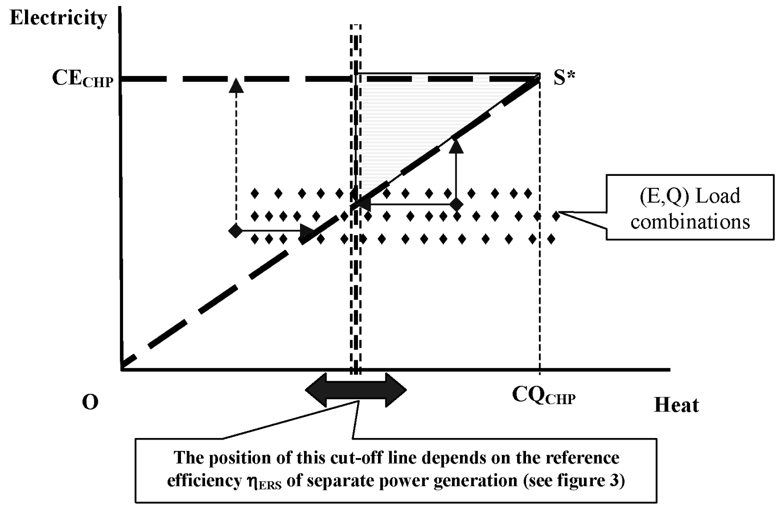
On the one hand, it is argued that the downturn of CHP units is good when they do not pass the *quality norm* and that in this way the regulation meets its purpose. On the other hand it kills (independent) CHP opportunities, because the CHP owner cannot any longer deliver guaranteed power or capacity.[4] Given the liberalisation of the electricity market, flexibility to respond quickly and unfettered on the requests of the market is important to operate in an economic way (see Section 8 of CHP essentials).

6.4 Situation 4: quality norm drives CHP operator towards non-economical part-load operation

In situation 4 electric loads and heat loads fall beneath the available capacities of the unit. This can happen because the unit became oversized owing to heat and electricity savings on the site or it can happen simply during particular periods of the year, e.g., in summertime. Operation of the plant can follow and match heat loads, but the main issue is whether the plant will be driven at full load or at part-load.

In full-load mode it will generate CE_{CHP} power for every heat load, reject part of the surplus heat and sell the surplus power to the grid (i.e., operation on top-line $CE_{CHP} - S^*$ in Figure 7).

Figure 7 The CHP production possibility set is truncated and part-load operation stimulated by the *quality norm*



In part-load mode it will modulate the unit along ray OS^*. Here the operational choices are more ambiguous dependent on the position of the load combination above or below ray OS^* (Figure 7). When the (E, Q) load falls below OS^*, CHP outputs can match the heat load (from the load point one follows a vertical line to hit the OS^* ray) or the electricity load (from the load point one follows a horizontal line to hit the OS^* ray). The direction depends on the terms of trade with the grid: when good, heat load is met by the CHP process and surplus power sold to the grid. When terms are bad, the CHP plant will match the power load and generate make-up heat in a boiler plant. When the heat load combination (*E*, *Q*) lies above ray *OS**, the CHP process can match the loads but will have to reject some heat. Part-load operation, however, is inferior to full load with more surplus power and surplus heat (dashed pointing up arrow).

The part-load or modulating operation is far more complex than the full-load operation. The CHP operator must steer the operational choices in 'real time' as a function of loads, value of power, cost of fuel and cost of boiler make-up, cost of running the CHP unit during one hour, etc. Mostly, part-load operation will prove to be less economical than full-load operation, at least when a fair price is paid for surplus power.

The quality norm, however, stimulates the part-load mode of operation (see Section 5). By the part-load operation the plant will fulfil the *quality norm* but part-load operation is less economical than the full-load operation along line $CE_{\mathrm{CHP}} - S^*$ involving the condensing of surplus heat.

7 Conclusion on the incentives and effects caused by the *quality norm*

The *quality norm* blends several efficiency aspects of CHP and of selected reference plants for separate power and heat generation into a single indicator. *It overrides the distinction between cogeneration activity and condensing activity* of a CHP plant that is equipped with condensers. This alchemy aggregates too much quantity and too little quality in one number. The *quality norm* reflects little the quality of CHP being measured truly by the design power-to-heat ratio 'σ'.

The *quality norm* is not effective in differentiating low-quality CHP *designs* from high-quality ones. Most CHP designs will pass the test. To remedy this shortfall in discretionary capability the proponents of the norm apply mark-ups of an arbitrary percentage (5%, 10%) above the break-even energy consumption, and stretch the efficiencies of the reference separate plants above warranted values.

While the *quality norm* does not differentiate real CHP quality, it is perverse in truncating the production possibility sets of CHP units. Obeying the *quality norm* limits the operational choices of a CHP unit and drives the unit towards part-load operation. When a CHP operator follows the *quality norm* incentives the financial bottom line of CHP is jeopardised. As a corollary, the CHP operator is placed before a lacerating choice. Either try to get the qualification on the basis of the *quality norm* and accept the constraints on an economic exploitation of the plant, or keep the freedom to operate and increase the probability of failing the *quality norm*. Which choice will be best cannot be predicted in general because it mainly depends 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 burdens the CHP operator with data monitoring and evaluation.

The analysis of the incentives embedded in a qualification on the basis of the proposed *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 often 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 matching the heat demand. Both induced effects have a significant negative impact on the financial bottom line of a CHP project.[5]

Qualifying CHP with the *quality norm* is apparently contravening the development of CHP. It provides the wrong incentives for CHP investment and it fences CHP into a regime that makes cogeneration activities uneconomic. Proponents of the biased use of the *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 (Degrève and Dreessen, 2002).

However, there is no objection against the *quality norm* as an external benchmarking instrument for economic performance of the own unit in the hands of individual companies and operators. But as with all benchmarking one must be very cautious in the choice of the reference points and in the interpretation of the results. And above all: a suitable instrument for one purpose (economic benchmarking from the point of view of the individual CHP owner) is therefore not suitable for another purpose (generic benchmarking for regulatory ends) that needs a different instrument.

The basic reason of the perverse effects of CHP qualification with the *quality norm* is the mixing of cogeneration activity and condensing activity, and the use of single (extreme) efficiencies of separate power and heat generation reference processes.

To soften the perverse effects of qualification with the *quality norm* one can develop a second best approach by classifying the CHP plants into technology groups (gas turbines, steam turbines, gas engines, diesels, fuel cells, etc. …). One should also classify 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. Finally, the accounting periods for assessing the performance of CHP plants should be much shorter periods than the year.

8 Qualifying CHP performance by the CHP Energy Saver Index (ESI)

CHP results can be qualified when CHP activity is correctly separated from condensing activity in a CHP plant, and when an 'internal' benchmarking is executed.

On the one hand, it is possible to stop the qualification process at the end of the right quantification process and to adopt the single amount of cogenerated power E_{CHP} as the yardstick for assessing and qualifying CHP activity. Because E_{CHP} is the product of the power-to-heat ratio 'σ' (quality index of thermal power generation) with the quantity of recovered heat Q_{CHP} (the merit of CHP), it is a sufficient yardstick of CHP performance.

On the other hand, several organisations – environmental NGOs, in particular WWF – want that energy/CO_2 savings by CHP should be maintained as the reference criterion for supporting CHP. Such savings are assessed by comparing CHP results to particular energy conversion efficiencies in generating power and heat. The fixing of such efficiencies is always somewhat arbitrary, but one can adopt as references the 'most efficient' power generation and the 'most efficient' heat generation processes, or one can adopt average numbers.

Qualifying CHP activity can be executed by the "*CHP ESI*". One can also add a measurement of the reduction in carbon emissions by the CHP activity but here it becomes rather difficult to point down valid reference values of carbon intensities of the power and heat benchmarks.

Fuel in a CHP-plant with mixed operational states is converted into *three* products: E_{CHP} (cogenerated power), E_{Cond} (condensing power) and Q_{CHP} (recovered heat). To find out how the CHP activity is performing, one also splits the fuel consumption over the cogeneration and condensing states (see Quantifying CHP Activity).

The fuel required to generate elsewhere the same outputs of the CHP activity (with exclusion of the condensing activity) is found with the formula of the quality norm, *however, applied only on the cogenerated electric output* E_{CHP} *not on the total electric output* E_{plant}, or:

Fuel of separate plants or $F_{SEP} = E_{CHP}/\eta_{ERS} + Q_{CHP}/\eta_{QRS}$

Energy Saved by the CHP activity equals: $F_{SEP} - F_{CHP}$.

The "CHP ESI" is the ratio F_{SEP}/F_{CHP}, expressing the percentage generation by the benchmarks is more (>1) or less (<1) energy intensive than the considered CHP activity. The latter variable is a valid yardstick for measuring the CHP energy performance benchmarked on selected benchmark generation opportunities.

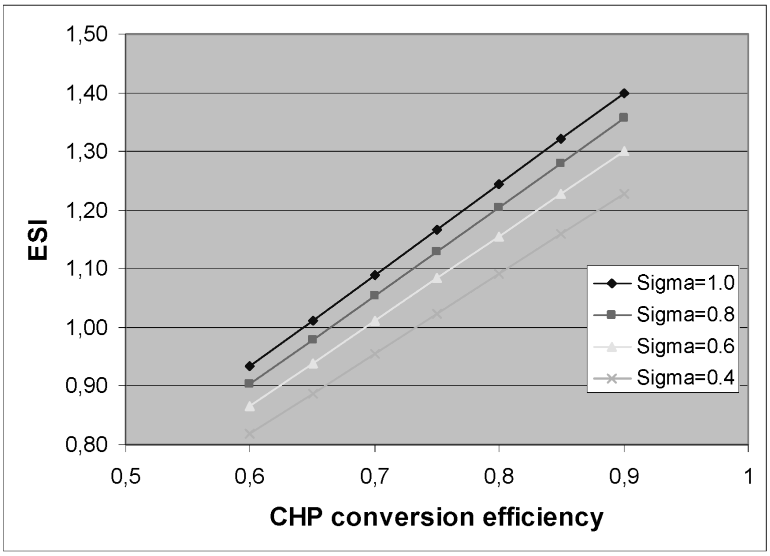
The policy problem in implementing this formula depends on the choice of the reference efficiencies of separate plants. CHP power can substitute power of all plants along the merit order of integrated power systems. Therefore, the choice of the average fossil fired generated kWh as the reference can be argued. The hypothesis that CHP power replaces only CCGT output cannot be maintained firmly.

To show the impact of particular choices, one can make diagrams that relate the four main variables being Sigma 'σ' (the power-to-heat design ratio), η_{CHP} (the thermal conversion efficiency of the CHP process excluding condensing activities being equal to $(E_{CHP} + Q_{CHP})/F_{CHP}$), η_{ERS} (reference efficiency separate power) and η_{QRS} (reference efficiency separate heat). For didactic purposes, one accepts as fixed point of the numbers the quantity of one unit of fuel consumed by the CHP process or $F_{CHP} = 1$.

Figure 8 shows the relationships between the four main parameters, with the reference efficiencies constant at $\eta_{ERS} = 0.50$ and $\eta_{QRS} = 0.9$. These values can be considered as over the year 'best practice' separate generation efficiencies. The variables under CHP control are put to change in the diagram: η_{CHP} on the abscissa and 'σ' on the curves of the bundle.

Figure 8 shows that the energy saving position of CHP operation can be realised under good CHP performance. It can be quantified quite precisely *if and only if the division between CHP power and condensing power in mixed activities is done precisely* (see Quantifying CHP Activity), and if a realistic choice of the reference efficiencies of separate heat and power generation opportunities is made. The usefulness of the "CHP ESI" is the relative positioning of CHP activities in a heat and power conversion efficiency framework.

Figure 8 Energy savings realised by CHP for varying η_{CHP}-values and four different CHP qualities (σ = 1.0, 0.8, 0.6, 0.4), with constant η_{ERS} = 0.50 and η_{QRS} = 0.9



9 CHP qualifying in the 2004 EU CHP directive

The 2004 Directive (EP, 2004) has avoided many pitfalls built into the 2002 draft version. Annex III provides a "Methodology for determining the efficiency of the cogeneration process". At first sight Annex III is still dominated by the formula of the *quality norm* but the Member States are now free to choose between two menus:

- the ESI that we proposed (see Section 8)
- the old version of the *quality norm* based on the plant outputs instead of the cogeneration results.

So the Member States can choose between a good and a wrong method, but *the good method prerequisites correct CHP quantification* results (also of the fuel consumption related to CHP activity, an issue not addressed in the final Directive).

There is also full flexibility in the choice of the accounting and reporting periods for inventorying CHP plant activities. Also the external benchmark references are now less distant from the actual plants and technologies, reducing further the perverse impact of the wrong method when this is adopted by a Member State.

Although the main threats to CHP are removed from the Directive, it remains a lost opportunity in harmonising this part of the energy market. Most crucial for this is coming up with a method for quantifying cogeneration activity in a robust and correct way that supports qualification entailing the right incentives for investing in high-quality CHP units.

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Notes

[1]This analysis assumes CHP activity be constrained exactly up to the norm. When tighter norms are imposed, e.g., CHP only qualifies when it does 1.10 times better than the norm (a 10% stricter requirement as the final 2004 Directive imposes), the truncation and perverse effects described in this article are amplified.

[2]Instead of wasting the heat it is possible to provide short-term heat storage tanks, when the characteristics of the heat end-uses allow such storage (commonly temperatures below evaporation at atmospheric pressure) and when the heat demand follows particular profiles. Storage increases the operational flexibility of the CHP plants and is not very expensive to build, and should be considered whenever physically and technically feasible.

[3]The truncation of the possibility set is a little different from the one shown, owing to a somewhat wider area at part load operation. Adding this detail increases the complexity of the graphs and adds little value here.

[4]One will remind the statements in the tariff discussions on the price of CHP surplus power: 'non-guaranteed' capacities and deliveries are a main argument to keep the valorisation price of feed-in power low. Also when the CHP owner cannot cover the own loads, this will increase the bill of the make-up power to buy at the grid.

[5]In COM (2002) 415 final (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 *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 (see also Section 8 in CHP Essentials).