

Internalising Externalities: Are Cogeneration Subsidies High Enough?

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1. Introduction

Whether electrical energy is produced by nuclear, wind-generated or cogenerative methods, there is always an external cost per kWh involved.¹ This environmental cost is not internalised by the firms responsible, and therefore, the private cost of electricity production does not really reflect the social cost involved. Internalising this cost is not easy; in the first place, an exact calculation is needed, in monetary terms, of the damage generated by the different types of pollution caused by the production of electricity. Additionally, if taxation were used in order to include the external cost in electricity prices, this would also lead to a price increase, which would in turn bring about a rise in most production costs. Ignoring environmental cost by not internalising it, however, is not a reasonable alternative; far from being neutral, it actually works against cleaner methods, by acting as a further barrier to their more widespread use.

Taxation is not the only possible type of regulation, subsidisation systems provide an alternative solution to the problem. Instead of penalising the more contaminating electricity production processes via increased taxation, a subsidisation system could encourage the use of the least polluting methods of production. This is the approach used in Spain. The law 2818/1998 of December 23rd, 1998² fixes the rates for subsidising different “alternative” methods of electricity production. These rates include, for example, a subsidy of 3.20 ptas. per kWh to cogenerated energy from combined heat and power plants of less than 10 MW of power; a subsidy of 5.26 ptas. per kWh for wind-generated energy; and a subsidy of 60 ptas. per kWh of solar energy produced.³ Though there is no question over the fact that wind-generated and solar energy should be subsidised, discussion arises with respect to cogenerated energy. Two arguments have been used against subsidising combined heat and power technology. First, since cogeneration systems have proven themselves to be highly efficient, it has been argued that the energy produced by this technology ought to be able to compete in the market without subsidies. Second, it has been asserted that cogeneration is not an environmentally friendly electricity production system. The process of cogeneration may use non-renewable primary inputs such as coal, oil and natural gas, that generate harmful emissions, including CO₂ and other greenhouse gases. We, however, demonstrate the inaccuracy of these two arguments.

The term cogeneration describes the use of a single source of primary energy to produce both

¹ When energy is produced in a nuclear power station, it would be necessary to add, for example, the cost arising from the increased probability of cancer among the population that would be affected in the event of a nuclear accident or leak. When power is being produced via cogeneration, it is necessary to calculate the cost arising from the increase in the pollution being released into the atmosphere. Finally, the internalisation of the cost involved in producing wind-generated power ought to include the monetary value calculated for increased mortality in birds and adverse effects on the landscape.

² In particular, the *Real Decreto* 2818/1998, published in the *Boletín Oficial del Estado* of December 30, 1998.

³ This subsidy only applies to generation plants of 50 MW or less.

electricity and heat at the same time. Cogeneration can be implemented in industrial processes, such as paper manufacturing, in which a certain amount of thermal energy is required to produce the output. It can also be used in heating and air conditioning systems for shopping centres or housing complexes. In these processes the installation of a cogenerating plant makes it possible to produce a certain amount of electricity as a by-product of heat production. The electricity generated in this way may be used either to save on the amount bought from the grid, or for sale to the grid, when an amount of surplus energy is generated. Whereas conventional electricity systems release large quantities of heat, cogeneration plants, reuse their surplus heat, thereby increasing their efficiency. The energy efficiency of a combined heat and power plant can be as high as 90%, as compared with the 30 to 40% of conventional power stations, and the 55% of the new combined cycle generation plants. We show, however, that even though the efficiency of cogeneration plants is high, it may be necessary for the sake of social welfare to subsidise this method of generating electricity, as long as public aid is also rendered to conventional electricity producers.

Cogeneration processes are not only doubly efficient, since they generate electricity and heat from a single input, they also present environmental advantages. An average cogeneration plant, fuelled by natural gas, generates a non-internalised environmental cost of about .0050 € per kWh.⁴ However, the non-internalised environmental cost per kWh for those power stations that are fuelled by black lignite (which is the fuel that causes most pollution) stands at approximately .17 € (28.05 ptas.) per kWh.⁵ The environmental cost of combustion plants fuelled by natural gas is only .01 € (1.63 pesetas) per kWh,⁶ which is still double the cost of the damage caused by cogeneration plants. We show that, even though the primary inputs used in cogeneration are fuel-oil and natural gas, the amount of environmental damage per kWh produced by a cogeneration plant is much lower than that resulting from other traditional methods.

The European Commission⁷ also favours cogeneration, specifically the target it recommends is that, by the year 2010, 18% of all the energy produced in Europe should be cogenerated. The Commission recognises that cogeneration should be encouraged in the European Union, in order to increase efficiency in the use of fossil fuels, reduce the emission of greenhouse gases and promote liberalisation in the European electricity market. Despite this recommendation, however, difficulties prevail for implementing it. The installation of cogeneration has met with a great number of barriers in Europe. Electricity markets are yet to be completely liberalised, and in most countries there are

⁴ The references are natural gas fired combined cycle plants with condensing turbines. Data facilitated by CIEMAT.

⁵ This data corresponds to power plants fuelled by Spanish coal. See Linares *et al.*

⁶ Note that these are conventional stations fuelled by natural gas, not cogenerating stations.

⁷ In its document COM(97) 514 of October 15, 1997.

bureaucratic barriers that add to the difficulties involved in their development. Some of the problems encountered are, among others: i) lack of free access to the grid; ii) non-existent or time-consuming procedures for obtaining the required authorisations; iii) excessive aid assigned to traditional electricity utilities; iv) insufficient payment for sales of surplus capacity to the grid; v) inadequate transport tariffs that do not take into account that decentralised combined heat and power should, in most cases, not pay the full transportation price; and vi) the fact that environmental cost of producing energy is not adequately reflected in energy prices.

This paper evaluates the Spanish system of environmental subsidies for cogeneration processes and analyses their capacity to overcome these barriers. In particular, we focus on the role and relevance of the monetary aids paid to traditional electricity producers - such as aid to national coal and competition transition charges – in creating a barrier to the development of cogeneration. As we shall see, subsidising cogeneration systems results in welfare gains that could be increased if the aid rendered to conventional electricity producers were reduced or discontinued. Next, we compare the environmental cost of the different methods of producing electricity. We then present the system of cogeneration subsidies contemplated by Spanish legislation, before going on to examine the economic incentives and effects to which this system gives rise and study the implications for energy consumption. Finally, we conclude with a series of recommendations that may prove useful for other European countries.

2. The Environmental Cost of Producing Electrical Energy

The European Union has been aware since the late 80's that decisions over power generation methods should take into account both internal and external costs. Therefore, a study to design methods for estimating the full cycle cost of energy production was developed. The objective was to evaluate within a single framework the external cost of each technology and fuel. This would include a common approach to both quantification and interpretation, in order to facilitate policy decisions at the European level. These efforts led to the development of the Externe Project, conducted and designed under the Directorate-General XII of the European Commission.

This project, launched in combination with the Joule Project, used a "bottom up" approach to evaluating the external damage caused by energy production. It developed a unified methodology for the quantification of the externalities of different power generation technologies. It is considered "bottom-up" because it can be included among those approaches that provide information concerning a

number of characteristics specific to the site where pollution originates and the characteristics of the locations where the damage occurs. They can be easily differentiated from "top down" approaches where damage is estimated in terms of average values, irrespective of site-specific features. To make costs fully comparable across countries, however, it was necessary to develop a common approach for all members of the Union. This goal resulted in the development of the Externe National Implementation Project, aimed at compiling an adequate set of data for different European countries and building up expertise in all member states to assist policy and decision makers in the use of these results. The application of the Externe methodology in each country implied the creation of a comprehensive and comparable set of data on externalities for each member state. The evaluation of these costs presents numerous difficulties and it is not exempt from criticism, see for example, Eto and Helcké (1991); Freedman III (1996); Rowe *at al.* (1996) and Krupnick and Burtraw (1996). However, they are the best approximations available and are believed to respect the relative cost ranking of the different methods analysed. By 1997 the National Implementation Project had generated a large set of comparable data covering 15 countries and 12 fuel cycles.

The estimations for Spain carried out by the CIEMAT for the Executive Summary of the Externe National Implementation Project show that the environmental cost of electric power stations using some form of coal or lignite as the primary fuel is far higher than for power stations fuelled by natural gas. Table 1 shows the figures for these costs for the different methods of electric power production⁸.

Recommended location Table 1

As Table 1 shows, there is a noticeable difference in the amount of damage per kWh caused by each of the fuels used. Indeed in most cases, the external cost of producing electricity is equal to or greater than private production cost. This means that if this cost were internalised, the cost of producing electric power from fuels such as domestic coal or lignite would more than double. External costs are so high that, if they were taken into account, they would alter the dispatch ranking of electric power stations. If this were to influence dispatch orders, most of the coal-fuelled stations would come into operation only after those that are gas-fuelled.⁹

⁸ No estimations are available of the environmental cost involved in nuclear and hydroelectric power production in Spain.

⁹ Another point worth noting is that Table 1 does not include the cost arising from the greenhouse effect. The reason is the great diversity in the estimation of damage caused by this type of pollution. The executive summary itself, for example, suggests that the cost per kWh due to the greenhouse effect can vary between .64 and 22.5 pesetas per kWh (.004 and .14 €). The inclusion of this cost from the greenhouse effect would only increase the differences, however.

It is reasonable to conclude, therefore, that the assessment of environmental damage differs greatly according to the method used to produce electricity. Table 1 makes no specific reference to the cogeneration system since there are no available estimations of the environmental damage caused by cogenerating plants in Spain. As part of the Externe project, however, an assessment has been made of the environmental damage caused by various European cogenerating plants, by the same means used to assess the damage caused by standard production technologies. The results of these assessments are shown in Table 2.¹⁰

Recommended location Table 2

The fuel most widely used in cogenerating systems is natural gas, which gives off fewer emissions than coal or fuel oil. But, in addition to using cleaner primary power sources, cogeneration processes are also more energy-efficient (from the same amount of primary fuel the cogenerating process obtains up to a 90% yield compared to one of 30% by ordinary production methods) resulting in lower levels of pollution per kWh. In other words, cogeneration systems are twice as efficient, environmentally speaking, they use cleaner fuel and they produce more energy. This means that the environmental cost of producing each kWh of electricity by this method is also lower than by traditional methods. Therefore, internalising environmental cost would benefit cogeneration, by reducing its total cost compared with other production methods. This solution could be implemented via pigouvian taxation. Such taxes would have to be added to the private production cost and would raise the selling price of each kW accordingly. Taking the external cost figures calculated by the CIEMAT in Table 1, for example, power stations where the primary fuel was black lignite would see production costs rise by .1753 €/kWh (28.05 ptas). This does not seem feasible as a short-term solution, since there would be an immediate rise in the price of electricity.

A portion of these costs or losses could, however, be avoided by encouraging the use of cleaner methods to produce electricity. This could be achieved also via a subsidisation system that would favour the use of the least contaminating methods of electricity generation. The lesser the external damage caused per kWh, the higher the subsidy should be. By organising subsidies along these lines, it would be possible to achieve one of the effects of taxation, that is, to reflect the relative costs of the various methods used to produce electric power. Furthermore, from the data presented above it can be

¹⁰ The great diversity among the different types of cogenerating technologies makes it necessary to include the technical details of these stations. The first plant is a hypothetical cogenerating station with a combined cycle condensing turbine in Stuttgart. The same is true for the second cogenerating plant in Mannheim that is fuelled with atmospheric coal dust and also has a condensing turbine. The third consists of two 150MW gas-fuelled GT V94.2 turbines and was built at a chemical company in Milan .

concluded that although cogeneration is not the cleanest production method (wind-generated and solar energy are without doubt environmentally less costly), the difference in the environmental cost involved, compared to that of conventional utilities, is significant enough to justify subsidising cogeneration for environmental reasons. Spain has implemented a subsidy system for cogeneration, based on the afore-mentioned law 2818/1998 which makes it compulsory for *Red Eléctrica Española* (REE) to acquire the cogenerated energy sold to the grid and assigns a subsidy of 3.20 ptas. to each kWh sold, irrespective of the type of plant and fuel used. We will now examine this system in more detail and discuss its advantages and limitations.

3. Analysis of the Present System for Subsidising the Cogeneration Process

Every cogeneration process gives rise to two types of externalities: one is referred to in the literature as productive efficiency, the other type is known as environmentally related externalities. To represent the externality resulting from productive efficiency, we follow Harberger's (1993) approach.

¹¹ We use α to represent the amount of by-product (in kWh of electricity) generated for each thermal unit produced to meet the needs of the manufacturing process, α can be roughly calculated by the ratio between the (actual or potential) kWh cogenerated and the kWh of energy needed by the manufacturing process. If the firm did not cogenerate electricity it would acquire primary energy inputs, such as natural gas, fuel or coal, to produce enough thermal power to carry out its own output production process, for example, paper production. The existence of a cogenerating process means, however, that with the same volume of primary energy, it is possible to achieve the same amount of thermal energy and output, while also generating electricity. In other words, α represents the degree of the externality resulting from productive efficiency. If the amount of electricity generated as a by-product is greater than that needed by the firm, we assume that $\alpha > 1$. If, on the other hand, the firm still needs to purchase electricity to cover its requirements, we assume that $\alpha < 1$. In Spain the value of α is usually above 1.¹²

Let PC_e be the private variable cost involved in producing a kWh of electric power with a traditional power plant. It represents the cost of increasing by one unit the amount of power produced by a traditional electricity generating method. We take traditional methods of electricity production to be large generating power plants of any type, such as hydroelectric, nuclear and thermal, among others. Let PC_c be the private cost of producing a kWh of electricity with a cogenerating plant.¹³ This cost

¹¹ Harberger, 1993, refers to this by-product of the cogenerating process as "externality due to energy-producing efficiency " which is the interpretation I have used in this study.

¹² Author's own estimated from CNSE data on energy self-produced and self-consumed by cogenerators. Reported in *Energía consumida por autogeneradores y/o minicentrales acogidos a la ley 82/80 clasificada por actividades económicas*, mimeo.

¹³ For our present purposes we will assume that the cost of the production of electricity, both by standard methods and via cogeneration are linear; the average and marginal costs, therefore, coincide.

includes only the increase in the production cost necessary to make the cogeneration process possible, in other words, the additional investment and increased variable cost needed to convert a heat-generating process into a cogenerating process.¹⁴

During valley periods, the standard utilities with the lowest operating cost enter into operation and sell electricity at the lowest possible price. That is, during valley periods, the cost of cogenerated energy is more likely to exceed that of energy generated by standard production methods, in other words, it is more likely that $PC_c > PC_e$. In the Spanish case, the plants with the lowest electricity production costs are the hydraulic and nuclear plants, as can be seen in Table 3. In this Table we show the cost of energy generation per kWh for 1997. The operating cost of hydroelectric energy is .0072 € (1.20 ptas.) per kWh. Moreover the variable cost of nuclear energy is .0145 € (2.40 ptas.) per kWh. The cogenerating cost of an average combined heat-and-power plant varies between .0304 and .0369 € (5.04 to 6.12 ptas.) per kWh.¹⁵ That is, during valley periods, it is highly likely that the variable cost associated with cogeneration will exceed those involved in conventional production.

During peak periods, however, as the power stations with the highest production costs have to come into operation, cogenerated energy is more likely to become more competitive. In Table 3 we present the average production cost of coal, natural gas and oil-fired power plants. In the case of black lignite, for example, the unitary cost is equal to .0350 € (5.75 ptas.) and to .0320 € (5.25 ptas.) for oil-fired power plants. Note that the reported cost is the average production cost for all generating plants of a specific type in Spain and, therefore, the real and plant-specific production costs would differ from those presented in the table. That is, there would exist power plants with both lower and higher than average unitary production costs. Now, therefore, the operating cost of cogeneration plants (approximately .0304 € per kWh) may be lower than the operating cost of traditional production methods. In other words, it is more likely that $PC_c < PC_e$. Therefore, the difference between the average private cost of cogenerated energy PC_c and the average private cost of standard energy PC_e depends crucially on the hour of the day and the day of the week that the production process is taking place.

Recommended Location Table 3

Recall, nevertheless, that so far we have only considered the private cost of electricity

¹⁴ The costs involved in a cogeneration process will be of two types, those arising from the production of the output plus the extra cost involved in the cogenerating process. If the firm did not cogenerate power, for every unit of primary energy it would generate the thermal energy needed to produce y units of output at a unit cost equal to PC_1 . This would include the production cost for the thermal energy needed to carry out the production process. With a cogeneration system, for every unit of primary energy, this firm would produce not only y units of output but also α units of electric power. The unit cost would in this case be equal to $PC_2 = PC_1 + PC_c$.

production. Let us now take a look at the environmental or external cost. The effect of these externalities greatly differs, as we have seen in Tables 1 and 2, according to the type of production process and fuel used. At present, environmental cost is not internalised in either case. It, therefore, falls to society to, directly or indirectly, bear the environmental cost. Let the social cost for standard-type producers be expressed as $SC_e = PC_e + EC_e$, where EC_e represents the environmental external cost per kWh produced. The social cost for a typical cogenerating company is $SC_c = PC_c + EC_c$, where EC_c represents the environmental external cost per kWh cogenerated. In order to internalise this environmental cost (both EC_c and EC_e) it would be necessary to include them when computing the price of electricity. If this were to take place, it would mean, for example, that SC_e and SC_c would become relevant when deciding the dispatch order. The introduction of environmental cost would affect the relative positions of the various electricity production methods. Ignoring them implies that socially costlier methods are called on to produce electricity prior to other less socially costly ones.

Although cogeneration does, of course, cause pollution, the fact that the external cost arising from standard production is higher than that arising from cogeneration, means that standard producers receive a "net environmental aid" actually greater than that received by cogenerators. If prices were to cover the real (social) cost of electricity production, standard producer prices would be higher than cogenerator prices. That is, the non-inclusion of environmental cost in electric power prices represents a net additional "aid" for standard producers. In order to partially offset the effect of the non-inclusion of environmental cost in electricity prices, Spanish legislation regulated a set of subsidies to provide an incentive to use alternative electricity-generating methods. This Law was passed on 23rd December 1998 and it assigned a subsidy rate or tariff of 3.20 ptas. for each kWh of electricity cogenerated and sold to the grid by plants of less than 50 MW of power. Cogeneration plants larger than this, therefore, are not subsidised at all, while those that are receive it only for kWh sold to the grid.¹⁶ Next, we will determine whether these subsidies for cogenerated electricity are justifiable for environmental reasons.

4. The Environmental Reasons for Subsidising Cogenerated Electricity

During valley periods the utilities with the lowest operating costs, that is, hydroelectric and nuclear plants, produce electricity; thus it becomes more likely that the private cost of cogeneration will exceed the private cost associated with such conventional electricity producers. In this case, one of two different situations can arise. First, if the external costs of combined heat and power producers are

¹⁵ See CNSE (1998).

¹⁶ It also regulated the subsidy rate for other types of electricity production we will not present them, however, as they are not relevant for this

higher than the external cost of conventional producers (*i.e.* $EC_c > EC_e$) the inclusion of environmental external costs would not bring about any change in dispatch decisions. In other words, it would be simultaneously true that $PC_c > PC_e$ and $SC_c > SC_e$, and it would not be necessary to subsidise cogeneration, since the production method with the lowest private cost is also the one with the lowest social cost. Any subsidy offered for cogeneration would be both unnecessary and inefficient. This is likely to be the case for hydroelectric power plants. Recall that these power plants generate electricity at the lowest private cost while also involving less social cost than cogenerated energy.

Second, if the external cost of combined heat and power producers is less than the external cost of conventional producers (*i.e.* $EC_c < EC_e$), the inclusion of environmental external costs will alter dispatch decisions. This is presumably true for nuclear power plants that present the second lowest private operating cost but are likely to involve high external costs.¹⁷ If this were the case, the external cost associated with nuclear power plants would be higher than that associated with cogenerators, *i.e.* $SC_c < SC_e$, and, despite the high productive efficiency of cogeneration, it could be justifiable (as we will see later) to subsidise cogenerators.

During peak periods, as the power plants with higher unitary costs come into operation, cogeneration becomes a more competitive production method. As coal and oil-fired conventional power plants enter into operation, the marginal cost of electricity production increases and so does the market price for electricity. In this case, both the private and social costs of cogenerators are more likely to remain below those of conventional producers, thus $PC_c < PC_e$, and, $SC_c < SC_e$. As before, it could be argued that no subsidy is necessary for cogeneration as the production method with the lowest private production cost is also the socially less costly. This would be true, however, only if conventional electricity producers were not to receive any additional transfer payment from the government that might allow them to sell more cheaply. Unfortunately, this is not the case in Spain where conventional electricity producers have received and continue to receive large sums of government aid under several compensation packages.

Protecting the Spanish national coal industry has led to a long tradition of subsidising the electricity produced by coal-burning plants. As Loredó and Suárez (2000) point out: "successive governments, from the 1940s to the 1980s, promoted thermoelectric development in the coalfields, in spite of the non-competitive nature of domestic coal." This mine-mouth thermoelectric development

paper.

¹⁷ The *Externe Project* has not yet evaluated the external costs of nuclear power plants. They are likely to be high, however, because they should include, among others, the storage cost of all nuclear debris and the cost associated with the possible loss of human lives in case of accident or leakage.

has been maintained thanks only to the existence of a high degree of government support for this industry (Del Rosal, 2000). It was this support that brought about the establishment of the obligation, for coal-burning power plants, to use national coal instead of a cheaper foreign product. The utilities were compensated by electricity tariffs that generously repaid this expenditure, and by giving dispatch priority to coal-burning power plants. Nowadays, following the implementation of liberalising reforms in the electricity industry, some of these policies still prevail and, on average, the production of a kWh by a coal-burning plant using national coal is subsidised at a rate of 1 pta. per kWh of generated power.

This subsidy has the effect of reducing the supply price in the daily electricity market and increasing the dispatch priority of this type of electricity.

Unfortunately, this is not the only type of aid currently received by conventional electricity producers. In 1998, the government authorised compensation to offset the cost that these firms would have to face in the process of transition to competition. That is, all utilities that were operating before 31st December 1997, have the right to compensation - in ptas. per kWh - for the cost of transition to the competitive regime (known as CTC). This compensation is justified as being the only means of recovering the stranded cost incurred by these firms during the previous, more strictly regulated regime. Although no utility was ever obliged to invest in mine-mouth generating power plants, it is widely recognised that in the past there were strong political incentives for this type of investment to take place. Also, since such investments would not be viable in a pure competitive scenario, it has been widely accepted that utilities should be compensated. The amount of compensation and the way in which it is calculated, however, have given rise to widespread controversy.¹⁸ The amount of aid that has been granted, about 1200 million €, was considered excessive by the National Commission for the Electric Sector.¹⁹ Arocena *et al.* (1999) and Kühn and Regibeau, (1998) have argued that this compensation clearly favours conventional electricity producers and recognises the recovery of CTC as a right, without taking into consideration that this may be grossly overestimated, since the real cost of transition towards a competitive regime would be unknown, until a fully competitive situation were reached. That is, overcompensation for stranded cost and transfers to the utilities of payments as compensation for using national coal could distort the functioning of the spot market and delay competition. Next, we show how overcompensation decreases the competitiveness of cogenerated electric energy and justifies the need for subsidies to cogenerators for environmental reasons.

4.1 Subsidies in the Valleys

¹⁸ In fact, dispute continues at the European Commission as to whether this aid could be considered illegal.

¹⁹ That is, the Comisión Nacional del Sector Eléctrico, which was integrated into the Comisión Nacional de la Energía in 1999.

A private firm with a combined heat and power plant can either obtain the electricity it needs from the grid or it can produce its own supply by cogeneration. During valley periods, the private costs of cogeneration are higher than the private costs of traditional utilities. Additionally, if the private costs of cogenerating are higher than the wholesale market price for electricity, that is if $PC_c > P_m$,²⁰ the most efficient option for the firm is to buy the amount required from the grid. Cogenerating firms, hence, are left with no incentive to produce electricity,

If the cogenerating firm were fully self-sufficient (i.e. when $\alpha > 1$) the net private costs of the cogenerated electricity would be equal to the costs involved in cogenerating this power, minus the profits obtained from the sale of the surplus $(\alpha - 1)$ kWh. If the surplus kWh could be sold for P_m ptas. per kWh, the actual private cost of power production for the cogenerating firm would be:

$$NPC_c = PC_c - (\alpha - 1) (P_m - PC_c) = P_m - \alpha(P_m - PC_c) > P_m, \quad (1)$$

and, therefore, the firm would have no incentive to cogenerate a single unit of energy. That is, even if the firm were to install a combined head and power process, the unitary cost of this cogenerated energy would continue to exceed the cost of the energy produced by conventional generators.

If, on the other hand, $\alpha < 1$, the private cost of the electricity consumed by the firm would be the weighted average of the direct cost of the cogenerated power PC_c and of the cost of the electricity purchased from the grid, that is,

$$NPC_c = \alpha PC_c + (1 - \alpha) P_m = P_m - \alpha (P_m - PC_c) > P_m, \quad (2)$$

also greater than P_m . Therefore, in this case also, the firm would lose any incentive to cogenerate a single unit of energy. In short, we can conclude that, if the private costs faced by cogenerators are higher than those of conventional producers, no kWh will be cogenerated. This would be a socially optimal result if the social cost of cogenerators were also higher than the social cost of conventional producers. In such a case, and in the absence of any form of incentive, the economic signals given by private cost will correspond to the electricity production method with the lowest social cost.

²⁰ We assume, however, that P_m reflects the true cost involved in the generation and transportation of electricity, in other words, that P_m equals the electricity production cost, that is, that $P_m = PC_c$. If this were not the case, and P_m were strictly higher than the true cost of energy production and transportation (i.e. $P_m > PC_c$) inefficiency would appear. On the one hand, there would be a transfer of consumers to standard electricity producers, because of the high price they charge for their product. But, at the same time, these arbitrarily high prices could lead cogenerators to produce electricity at times when the true cost of cogenerating PC_c is higher than the standard production cost, PC_c . If, on the other hand, standard producers of electricity were subsidised, that is, P_m were strictly lower than the true cost of energy production (i.e. $P_m < PC_c$), inefficiency would still appear. There would now be an indirect transfer of consumers to standard electricity producers, through the subsidies. At the same time, these arbitrarily low prices would make it even more unlikely for cogenerators to produce electricity. We will comment further on these distortions later.

Let us now consider the opposite case where, as before, the private costs of conventional producers are lower than those of cogenerators, but where the social costs involved in conventional electricity production are higher than those arising from cogeneration. In this case, the dispatch decisions will differ, according to whether they are based on social or private costs. When deciding the amount of electric power to produce, both standard producers and cogenerators would take into account only private costs and, therefore, the latter would demand electricity from the grid, since the private costs of standard producers are lower than their own. But now, unlike in the case discussed previously, the social costs associated with conventional producers are higher than those associated with cogenerators. In situations such as this, the best option may be to subsidise cogeneration, since this would restore the dispatch ranking based on social costs.

In Spanish legislation only the kWh cogenerated *and sold* to the grid are subsidised. A subsidy P_r for each kWh cogenerated and sold to the grid would result in a selling price for cogenerators of $R = P_m + P_r$ ptas. Recall that during valley periods, we are assuming that $PC_e < PC_c$ and $PC_e = P_m$, therefore $P_m < PC_c$. For the subsidy P_r to be effective in encouraging cogeneration, the unitary cost of cogenerated energy, after the subsidy (*i.e.* NPC_c), should be lower than P_m . The final cost of cogenerating a kWh would be equal to the private cost of producing it minus the revenues obtained from the surplus production sold at R ptas. per kWh:

$$NPC_c = PC_c - (\alpha - 1)(R - PC_c) < P_m. \quad (3)$$

If this were the case, more cogenerated electricity would be produced, thereby reducing the social cost of energy generation and increasing welfare. Society would have to bear the cost of the subsidy, since this policy would involve a transfer of income to cogenerators, but, at the same time, the social costs of electricity production would fall.

Note that if $\alpha > 1$, firms cogenerate energy in excess of the kWhs needed for their production process. The excess kWh ($\alpha - 1$) are sold to the grid and therefore, an equal number of kWh that would have been produced by conventional producers are no longer produced and the social costs associated with them are thus avoided. That is, the social cost of the cogenerated kWh is equal to:

$$SSC1 = SC_c - (\alpha - 1)(SC_e - SC_c) < SC_c < SC_e. \quad (4)$$

On the other hand, if $\alpha < 1$, the social costs of the energy consumed by a cogenerator are equal

to the weighted average of the power cogenerated by the firms and the power obtained from the grid:

$$SSC2 = \alpha SC_c + (1-\alpha)SC_e < SC_e \quad (5)$$

where α is the proportion of power cogenerated by the firm over the total power consumed per period of time. Therefore, if $SC_c < SC_e$, the more energy that is cogenerated, the lower the social cost of the electricity consumed during the production process.

We represent this situation in Figure 1. E^* is the optimal level of electricity required by the cogenerator, but, since $PC_e < PC_c$, the cogenerator's real demand is E_z . The welfare loss is represented by [abdc], plus an additional [befd] resulting from excess production. Avoidance or reduction of this loss would require the introduction of a subsidy P_r , such that $NPC_c < PC_e$. If this were the case, E_c kWh would be cogenerated. Note that P_r could be designed so as to make the difference $E_z - E_c$ arbitrarily small, thereby bringing about a net saving in environmental costs. In such a case, if $E_c \rightarrow E_z$, then E_z kWh would be cogenerated, bringing about a reduction in social cost equal to [aegc]. The optimal allocation will not be reached, however, and therefore there will still be a loss due to excess production equal to [dgf], but this is lower than it would have been if cogeneration had not been subsidised, since standard production gives rise to greater environmental costs than does cogeneration. In short, when the private costs involved in cogeneration are higher than those involved in conventional production, but the social costs of the former are lower, then cogeneration can be justifiably subsidised, since it will restore the dispatch ranking based on social cost.

Also, the optimality of Spanish legislation is limited by the fact that it only allows the payment of subsidies when the electricity is sold to the grid. If the grid purchasing price, P_m , is lower than the private cost of cogenerated power (without subsidies) PC_c , those cogenerators that are unable to produce enough power to completely cover their energy requirements, and therefore need to purchase additional electricity from the grid, will have no incentive to cogenerate any electric power at all. That is, those producers that do not cogenerate enough power to cover their own needs would completely cease cogenerating power, even if the socially optimal strategy were to cogenerate the power needed. Second, the installation of excess cogeneration capacity would be encouraged. In short, therefore, when, during valley periods, the social costs of standard producers are higher than those arising from cogeneration, the welfare level can be increased by subsidising cogeneration. However, the Spanish subsidy system fails to attain full optimality because subsidies are only applied to the energy that is cogenerated and sold, thereby creating incentives for the installation of excess capacity.

4.2 Subsidies in the Peaks

On the other hand, during peak periods it is highly likely that the private costs of cogenerators are lower than those of traditional producers such as power plants using coal or other fossil fuels, that is, $PC_c < PC_e$. In this case, since the inclusion of environmental external costs does not alter dispatch decisions or incentives for cogenerators, subsidies are unnecessary in principle. Both private and external costs are lower when the cogenerating process is applied. The best option from the social point of view is to cogenerate electricity. Moreover, even though the external costs are not internalised, it will not, in theory, be necessary to subsidise combined heat and power plants for environmental reasons, because they will continue to produce electricity by cogeneration, because it is also "privately" the cheapest way to do so. Estimation of the cost per kWh of several combined heat and power plants are presented in Table 4.

Recommended Location Table 4

This situation, however, may alter if standard producers receive transfer payments from the administration. If the market price P_m reflects the private cost of electricity production, that is, if $P_m = PC_e$, the correct incentives will be maintained and cogenerators will be not tempted to buy from the grid. This, however, is not usually the case in the European Union. A wide range of different types of aid to conventional producers enables them to sell electricity at prices lower than would otherwise be possible. Even the European Commission, in its statement on the promotion of combined heat and power issued on October 15th, 1997²¹ says that the current level of electricity cogenerated in Europe is far below the optimal level because, i) of the lack of incentives embodied in national energy policies, ii) the real environmental cost of large utilities is not reflected in the price and iii) the prices paid to cogenerators for surplus sold to the grid are too low. In the Spanish case, the aid given to national coal, and the aid to offset the cost of transition to competition are another two specific reasons.

Let us take a closer look at this case, where both private and social costs are cheaper for cogenerators than for traditional producers, but conventional producers receive a transfer of Z_e ptas. per kWh. From equation (4), if $\alpha > 0$, the social cost of the electricity cogenerated by a heat and power plant can be expressed as:

$$\begin{aligned} SSC1 &= SC_c - (\alpha - 1)(SC_e - SC_c) \\ &= (PC_c + EC_c) - (\alpha - 1)[(PC_e + EC_e) - (PC_c + EC_c)] \end{aligned} \quad (6)$$

$$\begin{aligned}
&= PC_e - \alpha(PC_e - PC_c) + EC_e - \alpha(EC_e - EC_c) \\
&= PC_e - \alpha X_p + EC_e - \alpha X_e
\end{aligned}$$

where we have substituted the social cost with the sum of the private and external costs.

Note that $X_p = \alpha(PC_e - PC_c)$ is the profit resulting from the productive efficiency achieved when a certain amount of primary energy is used to fuel a cogenerating process. The private cost of cogenerating this power is the amount it would have cost to produce a kWh by standard methods, PC_e minus $\alpha(PC_e - PC_c)$, the saving in power production costs which is achieved when an amount of primary energy is assigned to a cogenerator able to produce α units at a cost of PC_c . And $X_e = \alpha(EC_e - EC_c)$ is the environmental benefit, that is the savings in external costs resulting from cogeneration.

If $\alpha < 1$ then, following equation (5), the social cost of the electricity consumed by a cogenerator can be re-written as:

$$\begin{aligned}
SSC2 &= \alpha SC_c - (1 - \alpha)SC_e & (7) \\
&= \alpha(PC_c + EC_c) - (1 - \alpha)(PC_e + EC_e) \\
&= PC_e - \alpha(PC_e - PC_c) + EC_e - \alpha(EC_e - EC_c) \\
&= PC_e - \alpha X_p + EC_e - \alpha X_e
\end{aligned}$$

where X_p and X_e can be interpreted as above. Note that equations (6) and (7) are equal, the only difference being the value of α . Thus, when $\alpha > 1$, the saving in the social cost of electricity production resulting from cogeneration would be greater than otherwise.

Furthermore, the aid received by standard producers amounts to Z_e pesetas per kWh, which enables standard producers to sell electricity at a price of $P_m = PC_e - Z_e$, that is, less than its production cost. In this case P_m not only fails to reflect the social costs of standard producers, SC_e , it also fails to reflect their private costs, in other words, $P_m < PC_e$.

The net private cost of the electricity generated by a conventional producer is $NPC_e = PC_e - Z_e$. This aid allows conventional producers to sell the kWh at a price of $P_m = PC_e - Z_e$. Also recall that, from equation (1), the net private costs of cogenerating can be expressed as: $NPC_c = P_m - \alpha(P_m - PC_c)$.

²¹ Document number COM(97) 514 final

So the difference between NPC_e and NPC_c can be represented as:

$$\begin{aligned}
 NPC_e - NPC_c &= (PC_e - Z_e) - (P_m - \alpha (P_m - PC_c)) \\
 &= (PC_e - Z_e) - [(PC_e - Z_e) - \alpha ((PC_e - Z_e) - PC_c)] \quad (8) \\
 &= \alpha (X_p - Z_e)
 \end{aligned}$$

First, if $Z_e \leq X_p$ then $NPC_e > NPC_c$, in other words if the "aid" per kWh received by large-scale producers is lower than the gain obtained in productive efficiency by the cogenerators, the net private costs of conventional power plants are higher than the net private costs of combined heat and power plants. In such circumstances, the market is already providing cogenerating firms with sufficient incentives to produce electricity. Owing to the high efficiency of combined heat and power plants, and in spite of the aids to standard producers, it is cheaper for cogenerating firms to produce their own supply of power than it is to buy from the grid. Furthermore, as the social costs of cogeneration are lower than those of standard producers, the dispatch order resulting from private costs coincides with the dispatch order based on social costs. Therefore, in this case, the high productive efficiency achieved by combined heat and power plants removes the need to subsidise cogeneration, even if conventional producers receive aid. Note, however, that the external costs are not internalised, in other words, it could still be justifiable to subsidise cogeneration for environmental reasons, in order to attain the socially optimal allocation.

In short, if $Z_e \leq X_p$, the increase in efficiency due to cogeneration is sufficient to remove the need for a subsidy. From the private sector standpoint, the best option is to cogenerate, the price system provides its own incentives to firms acting along these lines. This is shown in Figure 2. The optimum level of cogenerated power corresponds to E^* . The best social strategy is to cogenerate electric power, since the social costs (SC_c) involved are lower than those incurred when power is produced by standard methods (SC_e). The amount of electricity to be produced is determined by taking into account only the private production cost, however. Standard producers receive a transfer payment of Z_e ptas., so cogenerating firms could buy kWh from the grid at a price P_m . If the productive efficiency of cogeneration (X_p) were not high enough to neutralise the effect of this aid to standard producers, cogenerators would buy E_z from the grid. However, if the increase in efficiency of cogeneration is high enough, *i.e.* $Z_e \leq X_p$, cogenerating firms would produce E_s kWh. There is still a loss in social welfare represented by the triangle (egh). It is the net loss resulting from the non-internalisation of the environmental costs caused by the cogeneration of power. We are producing with the socially optimal production method, but we are producing in excess because we are not considering

the environmental cost caused by cogeneration. If X_p is chosen such that $E_c \rightarrow E_z$, this loss would be small. Another solution, however, would have resulted in increased social costs. In conclusion, therefore, we are able to deduce that, if $Z_c < X_p$, then it is not necessary to subsidise cogeneration in order to ensure that electricity is produced via the method with the lowest social cost.

If, however, $Z_c > X_p$, the productive efficiency of combined heat and power is not high enough to neutralise the effect of providing aid for standard producers. In such circumstances, the privately optimal strategy for the cogenerating firm is to refrain from cogenerating any energy, in spite of this being the best strategy for the interests of society. Society is giving too much "aid" to standard producers and thereby bringing about a situation in which cogenerated electricity must be subsidised in order to make it sellable. The net private costs of standard producers are $NPC_e = PC_e - Z_c$ which enables the kWh produced to be sold at a price, $P_m = PC_e - Z_c$. No electricity will be cogenerated, because the new subsidised price of conventionally produced power is cheaper than what it would cost to cogenerate it (NPC_e). A closer look at Figure 3 will illustrate this point. If the purchasing price of a kWh of standard production is P_m , the cogenerating firm will demand of E_s units from the standard producer. The true social cost of these units, however, is SC_e . The loss resulting from this inefficiency is represented by the sum of areas (abcd) and (ech). In this case, we are not only generating kWh in excess of the optimum $E_s - E^*$, but we are also failing to produce electricity at the lowest possible social cost. Subsidising cogeneration would result in a reduction in private production costs for the cogenerating firm. The introduction of a subsidy, therefore, would make it more likely for power to be cogenerated. This subsidy Z_c would have to be great enough for $NPC_c - Z_c < P_m$, and simultaneously to be able to keep the amount of cogenerated power E_c as close to E_s as possible. If $E_c \rightarrow E_s$, then E_s would be cogenerated, bringing about a reduction in social costs equal [abcd]. In conclusion, we may deduce that, if $Z_c > X_p$, then it is necessary to subsidise cogeneration in order to ensure that electricity is produced at the lowest possible social cost.

It should also be realised, however, that excessively generous subsidies could bring down the net private cost of cogeneration to below the private cost of socially cheaper production methods, such as hydroelectric power, thereby distorting the dispatch order based on social costs. Therefore, subsidies should be designed to avoid this happening. Moreover, note that, in the Spanish case, it is possible to design a set of subsidies, such as those described above, that would reduce the net private cost of cogeneration to below the private cost of coal-powered plants, though they would not drop as far as the private cost of socially cheaper production methods (such as hydroelectric power). If the subsidy rate were to satisfy this property, then cogenerators would produce energy only when power plants with higher unitary costs (oil and coal fuelled power plants) come into operation. If, however, the contrary

were true, that is, the operating costs of coal-powered plants were lower than those of hydroelectric stations then such a straightforward set of subsidies could not be applied. In such a case, any subsidy designed to reduce the private costs of cogenerated power to below those of coal-fuelled power plants would also reduce them to below the operating cost of hydroelectric power. In the Spanish case, power plants fuelled by coal and oil, clearly present both social and private costs greater than those associated with hydroelectric power, making it possible to design a subsidy rate that would lower the private costs of cogeneration without reducing them to below those of hydroelectric production, or other less contaminating methods. The problem with Spanish subsidies is not that they are too high but that, on the contrary, they seem quite low, especially if we consider recent oil price increases.

In order to be effective, subsidies should be designed while taking into account the changing characteristics of the production process to which they apply. Note, for example, that, the productive efficiency of cogenerators, $X_p = \alpha(PC_e - PC_c)$, decreases as the difference between PC_e and PC_c narrows. Oil and natural gas are the main primary inputs used by cogenerators, therefore increases in the prices of these inputs will reduce their productive efficiency. If conventional producers are to use mainly national coal (instead of oil) as a primary input, the productive efficiency of cogenerators will decrease as the cost of oil increases. Therefore, as the price of oil or natural gas increases, the advantage resulting from the productive efficiency of cogenerators narrows, the private costs of standard producers remain constant and it becomes increasingly profitable for cogenerators to buy energy from the grid. As noted before, only private costs are taken into account in the dispatch process and therefore, in such a situation, it is highly likely that cogeneration will be discontinued, even though the social costs of cogeneration are lower than those of standard production. Therefore, cogeneration subsidies should be reviewed, for example, during periods of rising natural gas and oil prices, otherwise, cogenerators will stop production and only plants with heavy social costs will generate electricity.

5. Conclusions

We have analysed the optimality of cogeneration subsidies and shown that they will improve social welfare when the dispatch ranking based on social costs differs from that based on private costs. Cogeneration subsidies should be used to restore the social cost ranking. These subsidies would increase social welfare; primarily, during valley periods, when the social costs of standard production are heavier than those of cogeneration, even though their private costs are lower. Recall that dispatch decisions are always based on private cost, therefore, under such conditions, standard producers will be dispatched first. Their social cost, however, not being internalised, could be very high. By subsidising combined heat and power producers, the net private costs of cogenerated power would be reduced,

resulting in more energy being cogenerated, thus reducing the amount being produced by conventional producers, and minimising environmental costs. Secondly, if, on the other hand, both the private and social costs involved in cogeneration are lower than for standard production, subsidies are necessary only if the amount of "aid" given to conventional producers is greater than the cogenerator's gains in productive efficiency. A subsidy system could reduce the net private cost of cogenerators to below the net private cost of standard producers, therefore, increasing the amount of energy cogenerated.

On the other hand, subsidies are inadvisable also when cogenerated power is socially more expensive than power from standard production, or when the productive efficiency of cogenerators is internalised through the market, that is, when the amount of aid received by standard producers is no greater than the cogenerator's gains in productive efficiency. In such a case, cogeneration subsidies are not worthwhile, even if the social costs of standard producers are higher than those of cogenerators, because the greater productive efficiency of combined heat and power producers reduces their net production costs to below the subsidised price of standard producers. The dispatch order remains the same whether it is based on the private or on the social cost. This, however, is unlikely to be the case in Spain, due to the large amount of aid received on several counts by coal-fuelled power plants.

Before concluding, we would like to mention several points that deserve further attention. First, we should point out that, in order to improve the Spanish subsidy system, subsidy rates would need to take into account the type of primary fuel and the technology used in the cogenerating process. Since the pollution levels given off by each type of fuel and technology differ, distinct environmental subsidy rates would be better tailored to the social cost. Obviously, we would expect subsidy rates to be higher for less contaminating technologies.

The importance of transport costs must also be stressed, not only in decision-making over whether to cogenerate electricity or not, but also to compare the full pollution potential of the various methods of producing electricity. The transportation of electric power gives rise to environmental costs that must be taken into consideration when determining not only the price but also the final cost of the power involved. These costs may mean that –as well as energy being lost in transporting it through the network - methods of producing electricity at environmental costs that are relatively low in the generation phase may prove environmentally much less advantageous once transportation costs are taken into consideration. This would be the case if electric energy had to travel long distances before being used. Cogeneration plants located near consumers minimise these environmental costs.

Finally, a further advantage not only of cogeneration, but also of all small-scale methods of

generating electricity, that should be taken into account is the possible dispersion of generating installations. Their small size, and the fact that they may be widely dispersed, makes it possible to spread the negative external costs of having a generating plant nearby uniformly throughout the population, without detriment to specific areas.

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Table 1
Environment-related external costs for the Spanish Electricity System.

Type of Primary fuel	Damage in €/kWh
Domestic Coal	.078
Imported Coal	.036
Black Lignite	.175
Brown Lignite	.106
Fuel Oil	.038
Natural Gas	.012
Electricity System Average	.037

Source: Linares *et al.*, Externe National Implementation Project. December 1997, CIEMAT Spain. This estimation is based on 1996 data.

Table 2
Environmental Costs for Cogenerating Plants

Type of Plant	€/kWh
Combined Natural Gas Cycle	.0067
Atmospheric Coal Dust and Turbine	.0105
Natural Gas and Turbine	.0049

Source: Externe Implementation Project

Table 3: Operating Cost per kWh in €

Power Plant Type	Subsidy rate per kWh	Cost per kWh with subsidy	Cost per kWh without subsidy
Hydroelectric	-	.0072	.0072
Nuclear	-	.0145	.0145
Hulla + Anthracite	.0040	.0250	.0290
Black Lignite	.0057	.0300	.0350
Brown Lignite	.0060	.0280	.0340
Imported Coal	-	.0250	.0250
Oil	-	.0320	.0320
Natural Gas	-	.0330	.0330

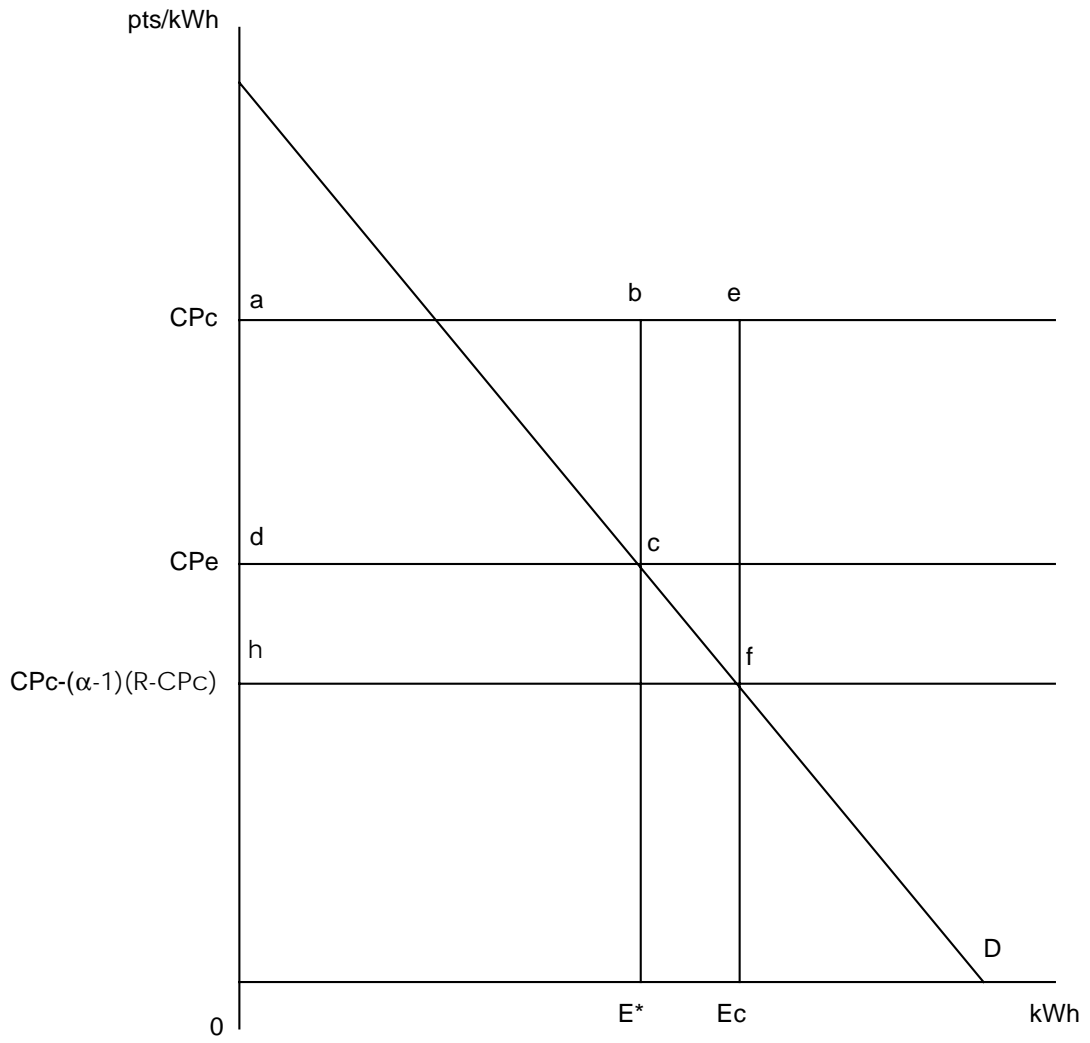
Source: Comisión Nacional del Sector Eléctrico (1998).

Table 4: Variable Cost of Cogeneration Plants per kWh in €

Type of Cogeneration Plant	Variable Cost
1 MW Gas Turbine	0.036
From 3.5 to 4.5 MW Gas Turbine	0.033
From 13 to 21 MW Gas Turbine	0.032
20 MW Combined Cycle	0,030
25 MW Combined Cycle	0.028

Source: Comisión Nacional de Sector Eléctrico "Análisis del coste del kWh en proyectos de cogeneración," Febrero 1997.

FIGURA 1



FIGURA

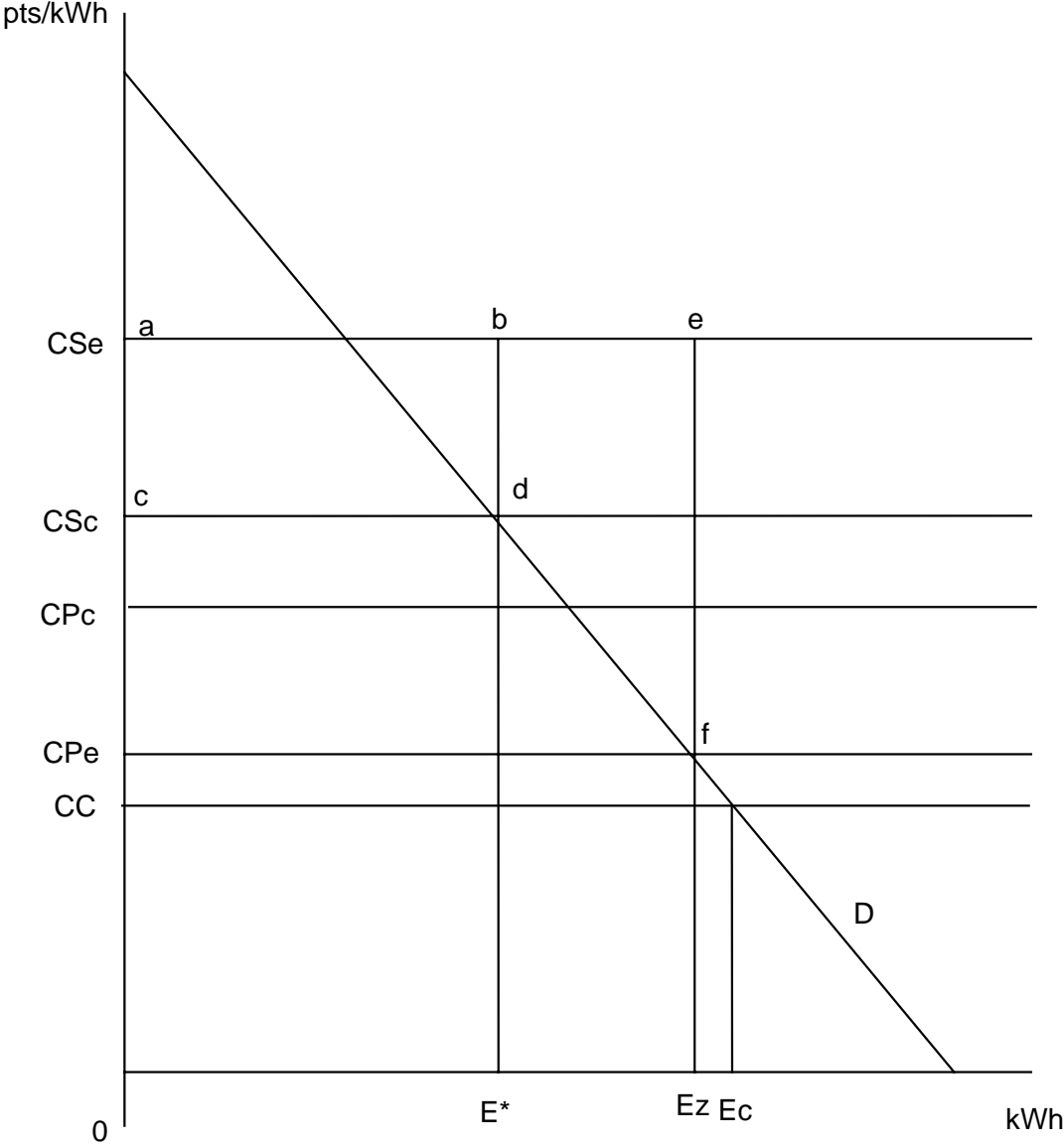


FIGURA 3

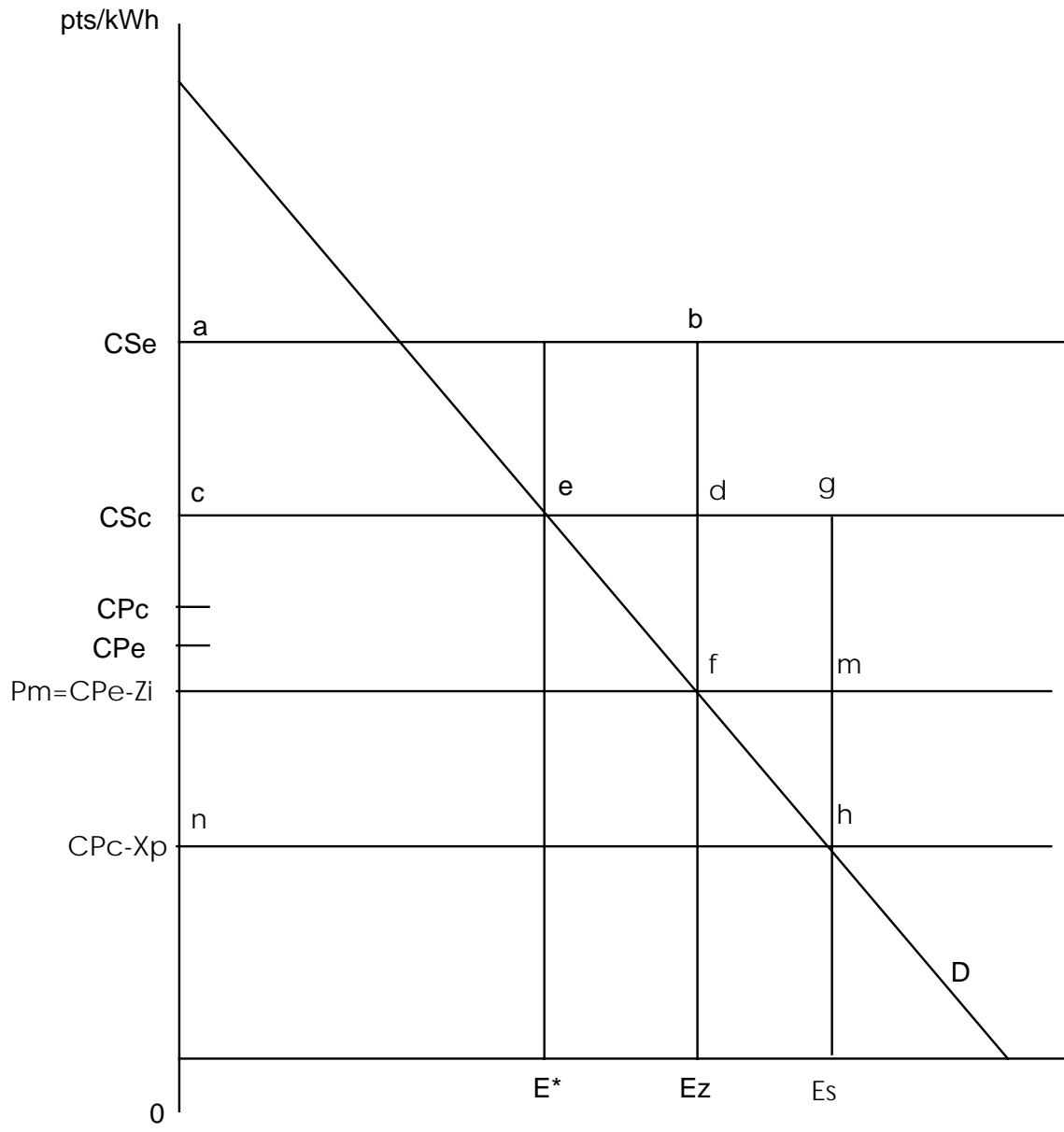


FIGURA 4

