Empirical Estimation of the Avoided Costs of Coal-Fired Electric Energy Cogeneration

J. J. Cao-Alvira, *Assistant Professor UPR-RP*, and
R. J. Cao-García, *Retired Full Professor UPR-RP & Asesoría y Consulta, Inc.*

Abstract--**The U.S. Public Utility Regulatory Policies Act requires the state electric company of Puerto Rico (PREPA) to establish Power Purchasing Agreements with qualified private generation facilities for purchasing electric energy and reliable capacity at a price equal to its avoided cost of additional generation and capacity creation. Consequently, PREPA signed long term agreements with two private companies that currently supply thirty percent of Puerto Rico's net electrical output. This paper intends to calculate PREPA's cogeneration avoided costs using privileged compensational data from the cogeneration companies. Using a Component Method, PREPA's avoided costs estimates lie within the bounds denoted by the average variable cost and the marginal cost of the cogeneration facility with the lowest marginal cost. Combining the operational data of this company's electrical production, its compensation schedule and industrial organization theory, it is possible to reverse-engineer the cost structure of the cogeneration facility and, with it, PREPA's avoided costs.**

***Index Terms*—Coal, Economics, Finance, Cogeneration, Natural Gas, Avoided Costs**

I. INTRODUCTION

The Public Utilities Regulatory Act (PURPA, hereafter) of 1978 resulted in significant changes to the operations of the U.S. states electricity companies, requiring them to consider the production of private cogeneration companies in its supply function. PURPA specifically states that it applies Puerto Rico [ref: PURPA, 2602(15)], and consequently the Puerto Rico Electric Power Authority (PREPA) is obliged to purchase electricity from small local producers if offered, and purchase electricity and reliable generation capacity from cogenerating companies qualified by the Federal Energy Regulatory Commission (FERC). PURPA requires that the purchase price of electricity and reliable energy capacity cannot exceed the *avoided cost* of the local power company, where *avoided cost* is defined as the cost that would be incurred by the local power company if it generated itself the electricity and reliable energy capacity is acquiring from private suppliers.

The concept of avoided cost is critical under PURPA provisions; among its requirements, PURPA ordered state power companies to set rates for purchases of electricity and generating capacity provided by qualified cogeneration facilities that: (i) Are fair and reasonable to the subscriber and the public interest; (ii) Do not discriminate against qualified cogeneration; and (iii) Do not exceed the avoided cost that would be incurred by the state electricity company if it instead would be providing this capacity and energy.

The FERC delegates to each state the responsibility of selecting the calculation method with which the avoided costs of the electric companies operating within their jurisdictions are estimated. This delegation of responsibility to the individual states results in an absence of a standard criterion for calculating the avoided costs of cogeneration. In general, two main contractual agreements are considered when calculating the avoided costs of private electric energy cogeneration; these are (i) short-term contracts, and (ii) long-term contracts.

Contracts for short-term cogeneration agreements, established between the local power company and private suppliers, apply to cogeneration companies with limited generating capacity; that is with a capacity of 100 kW or less. These companies are not exclusively devoted on generating power to supplement the local power company; they are usually established for other purposes and sell their excessive net electrical output to the local power company, as available. In this case, the avoided cost is basically defined as the average variable cost per kWh.

Contracts for long-term cogeneration are established with private suppliers that are dedicated solely on the generation of energy for supplying the local power company. In these cases, the avoided cost not only includes the variable cost, but also the fixed cost incurred by the supplier to establish their operations. There are variations among states as to how design long-term contracts between the local power company and private cogeneration companies. Nevertheless, the different types of contracts can be grouped into three categories:

1. The "Proxy" Method or Committed Unit Method: operates under the assumption that the establishment of a qualified cogeneration facility would delay, for a long-

---

This work was supported in part by the 2011 UPR-FAE Researching Faculty Initiative Grant to J. J. Cao Alvira.

J. J. Cao Alvira is Assistant Professor at the Department of Finance and Graduate School of Business of the University of Puerto Rico, Río Piedras, PR 00931 USA (e-mail: josejulian.cao@upr.edu).

R. J. Cao García is Retired Professor at the Department of Economics of the University of Puerto Rico, Río Piedras, PR 00931 and CEO of Asesoría y Consulta, Inc., San Juan, PR 00931 USA (e-mail: ramonjcao@gmail.com).

term, the costs associated with the construction and operation of what would approximately (or "proxy") be the next generating unit acquired by the local power company. The methodology simulates the capacity and generation cost structure of the next power plant that the local power company would build, for the duration of the contract. The avoided costs by the installation and operation of the cogeneration facility will then be the estimates of the present value of the costs of generating capacity plus the estimated generation costs from the generation company that will not be produced by the local power company.

2. The Component or Maximum Capacity Method: considers the avoided cost of generation and capacity by a cogeneration facility as the value of the less expensive generating capacity available to the local electric company plus the marginal cost of generating electricity from this generator. The method assumes that, during the duration of the contract, the local power company replaced its production of electricity with the highest marginal cost for the production of the added facility that would provide a qualified cogeneration. The method then considers the avoided cost as the estimated marginal cost of production per hour from the power company plus the fixed cost of generating unit that uses the local company when operating at full capacity.

3. Difference in Required Remuneration Method: under this method, two scenarios are made for estimating the total cost of generation and capacity of the local power company, where the first estimate is one of the company's total costs over the long-run and the second is one where the company's total costs are calculated for the same term but instead acquiring the generation capacity of the proposed cogeneration facility free of costs. This methodology requires projecting the future costs on the avoided reliable capacity and generation due to the construction and operation of the cogeneration facility. The difference between the present values of total generation costs between the two scenarios is the avoided cost of the reliable capacity and generation of the qualified cogeneration facility. It must be noted that the way in which this estimate of avoided cost of cogeneration is calculated does not allow separating the avoided costs of capacity from the avoided costs of generation.

Further details of short-term cogeneration agreements and the Proxy method of calculating avoided cost estimates can be found in Graves, et. al (2006). For detail reference on the Component and the Difference in Required Remuneration Method see, for instance, Tellus Institute (1995).

Under the terms established by PURPA, PREPA entered into long term contracts or Power Purchasing Agreements for electricity cogeneration and provision of reliable energy capacity with two private cogeneration companies. These are EcoElectrica, LP (EE), then a subsidiary of Enron, and AES de Puerto Rico, LP (AES). EE began to produce and supply electricity to PREPA using natural gas as fuel on March 2000, with an energy capacity is 501.0 MW, and a base rate of heat generation of 0.0075 MMBTU per kWh. AES did the same using fluidized bed coal combustion on December 2002, with an energy capacity of 454.3 MW and a 0.0098 MMBTU per kWh heat generation base rate.

The monthly compensation structure accorded by PREPA and the two cogeneration facilities is based on the terms established by PURPA and is determined following closely a Proxy Method of avoided costs calculation. The compensation schedule discussed next is extracted from the Power Purchasing Agreements between PREPA and the private cogeneration facilities. Equation (1) represents the monthly compensation structure of PREPA to both cogeneration companies. While the basic tariff structure is the same for both cogeneration companies, e.g. a compensation for electricity generation, a compensation corresponding to reliable energy capacity provision and a remuneration for the startup of an ordered shutdown of the generators, the details of each payment component are specific to the corresponding cogenerating company. The latter is explained by a combination of technological, market, and circumstantial factors that were relevant during the negotiation of the Power Purchasing Agreements. Cao-Alvira and Cao-García (2009) provides an assessment on the historical tariff pressures and the overall welfare impact of these cogeneration agreements.

$$\mathrm{P}_{\mathrm{t}}^{\mathrm{i}} = \mathrm{P}_{\mathrm{E,t}}^{\mathrm{i}} + \mathrm{P}_{\mathrm{C,t}}^{\mathrm{i}} + \mathrm{P}_{\mathrm{0,t}}^{\mathrm{i}} \tag{1}$$

Where:

$\mathrm{P}_{\mathrm{t}}^{\mathrm{i}}$:	Full payment to company i at time t.
$\mathrm{P}_{\mathrm{E,t}}^{\mathrm{i}}$:	Payment for electricity supplied by company i to PREPA in period t.
$\mathrm{P}_{\mathrm{C,t}}^{\mathrm{i}}$:	Payment for reliable capacity provided by company i to PREPA in period t.
$\mathrm{P}_{\mathrm{0,t}}^{\mathrm{i}}$:	Compensation payment to restart an electricity generation unit of company i, when PREPA ordered its turn off for some time during period t.
i:	AES, EE.

A. Compensation for electric energy generation

Equation (2) describes the general formula of PREPA's monthly payment to the private cogeneration companies for the purpose of power generation.

$$\mathrm{P}_{\mathrm{E,t}}^{\mathrm{i}} = \mathrm{p}_{\mathrm{E,t}}^{\mathrm{i}} \cdot \mathrm{NEO}_{\mathrm{t}}^{\mathrm{i}} \tag{2}$$

p_{E} is the purchase price for each kWh supplied by company i to PREPA, NEO is the net electrical production output of company i.

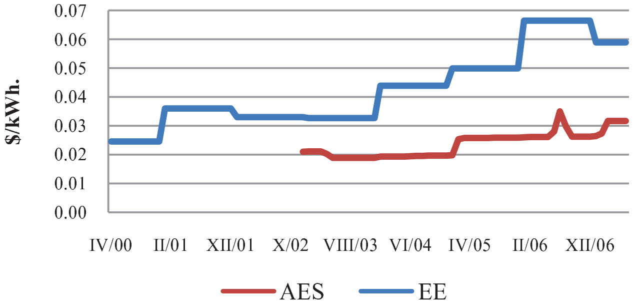
Equation (3) contains the pricing formula per kWh produced by the cogeneration companies.

$$\mathrm{p}_{\mathrm{E,t}}^{\mathrm{i}} = \alpha_1^{\mathrm{i}} \cdot \mathrm{z}_{\mathrm{p,t}}^{\mathrm{i}} \cdot \mathrm{ACF}_{\mathrm{p,t}}^{\mathrm{i}} + \alpha_2^{\mathrm{i}} \cdot \mathrm{z}_{\mathrm{f,t}}^{\mathrm{i}} \cdot \mathrm{ACF}_{\mathrm{f,t}}^{\mathrm{i}} \tag{3}$$

The α's are constants associated with each cogeneration company and are related to their variable cost of generation.

$\alpha_1^{EE} = 0.000091644$, $\alpha_2^{EE} = 0.004894196$, $\alpha_1^{AES} = 0.0000293$ and $\alpha_2^{AES} = 0.0098$. z_p and z_f are price indexes correspondent to each billing period, and concern the general inflation level in the economy and the cost of fuel used by each cogeneration company, respectively. ACF_p and ACF_f are adjustments to the generating revenue component for those periods in which the cogeneration company produced at capacity levels lower than those of full capacity. Diagram 1 depicts the realized values of the purchase prices p_E for the historical net electrical outputs of EE and AES.

DIAGRAM 1
PRICE PER KWH OF SUPPLIED ELECTRIC ENERGY



Diag. 1. Purchase prices p_E for the historical net electrical outputs of EE and AES.

B. *Compensation for reliable energy capacity*

Equation (4) describes the general formula of PREPA's monthly payment to the private cogeneration companies for providing reliable energy capacity at billing period t.

$$P_{C,t}^{i} = (p_{C,t}^{i} + \omega_t^{i}) \cdot DC_t^{i} \qquad (4)$$

p_C indicates the price for each kW of energy capacity provided by company i, DC represents the actual amount of energy capacity, measured in kW, provided by the cogeneration company in each billing period t and ω is a financing adjustment. Equation (5) defines the pricing formula by which PREPA buys the reliable energy capacity, made available by each cogeneration company.

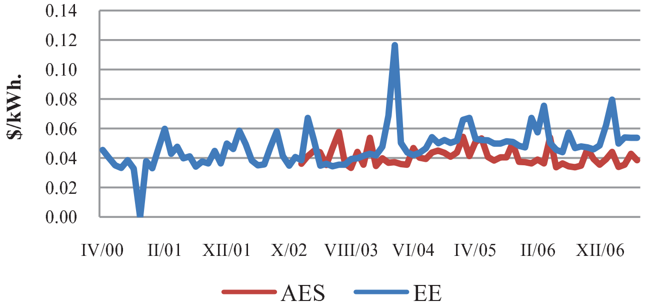
$$p_{C,t}^{i} = \gamma^{i} \cdot z_{d,t}^{i} + \delta^{i} \cdot z_{c,t}^{i} \qquad (5)$$

γ and δ are constants associated with each company's fixed generation cost. $\gamma^{EE} = 14.483259$, $\delta^{EE} = 0.039712$, $\gamma^{AES} = 1.024511$ y $\delta^{AES} = 0.026853$. Moreover, γ refers to the continuous impact of inflation on the company's fixed investment and δ incorporates operational and maintenance fixed costs. z_d represents a scaling factor in energy demand charge, and z_c is a scaling factor for fixed costs. Equation (6) shows the tabulation of reliable energy capacity provided by each cogeneration company during a billing period.

$$DC_t^{i} = FMAF_t^{i} \cdot EAAF_t^{i} \cdot C^{i} \qquad (6)$$

Where C^i is the energy capacity of cogeneration company i. For EE, this corresponds to 501,000 kW and for AES 454.300 kW. FMAF is an adjustment factor by Force Majeure, and EAAF is an adjustment factor for the cogeneration company's power availability at each billing period t. The product of $FMAF_t^i$ and $EAAF_t^i$ yields what could be considered a Capacity Dependability Index, i.e. $DEP_t^i = FMAF_t^i \cdot EAAF_t^i$. Diagram 2 depicts the realized values of the purchase prices p_C in terms of kWh for the historical reliable capacity of EE and AES.

DIAGRAM 2
PRICE PER KWH OF SUPPLIED RELIABLE CAPACITY



Diag. 2. Purchase prices p_C in terms of kWh for the historical reliable capacity of EE and AES.

C. *Compensation for restarting a generating unit*

On occasions it may occur that PREPA orders a cogeneration company to shutdown a generation unit to prevent excessive output during a period of time. The compensation payable by PREPA follows a similar structure in both contracts, with slight variations, resulting from technological differences. The compensation structure depends on the time during which a generator was turned off and the costs incurred by the generating company to re-ignite, synchronize and commence operations again.

II. COGENERATION AND PRICING DATA

The available data on the coal combustion cogeneration company AES is of monthly frequency and it extends from XII/02 to VI/07.[1] During this time period, the average monthly capacity usage of the company was 80.7%; that is equivalent to a monthly average net electric output of 267.9 million kWh. The average remuneration to AES during this time period is 6.47¢ per kWh. Of the total per kWh remuneration, 2.38¢ correspond to a payment for electricity supplied and 4.09¢ for dependable capacity provided.

TABLE 1

Average Values of Production and Pricing Parameters		Average Values of Cost Indexes	
Usage / Kwh	80.7% / 2.7E+8	Z_f	1.860
(Pe+Pc) / kWh	6.47¢	Z_f	185.93
Pe per kWh	2.38¢	Z_d	19.263
Pc per kWh	4.09¢	Z_c	19.263

The fuel cost index z_f used in AES pricing function is that of the price of coal in terms of dollars per million BTUs, the demand charge index z_d is calculated according to the monthly amortization for a twenty year period at a 5.288% interest rate of a principal equal to $1,600 per kW of AES' dependable capacity, and the inflation indexes z_p and z_c correspond to the US-CPI. The average value of index z_f for

---

[1] The data corresponding to the months VI/03 and XI/03 are not included in the analysis because the usage capacity of AES fell below 60% of its total available capacity.

the considered time period is 1.86, of index z_d is 19.26 and for z_p and z_c is 185.92.

Table 1 summarizes the previously described average values of the cogeneration output and cost indexes.

III. METHODOLOGY

The methodology developed aims at creating estimates of the current and historical avoided cost of PREPA. The Component Method is the avoided cost estimation methodology employed, and operates under the assumption that the generation capacity of EE and AES are integrated to PREPA's total energy capacity. Recall, the Component Method considers the avoided cost of generation and capacity by a cogeneration facility as the value of the least expensive generating capacity available to the local electric company plus the marginal cost of generating electricity from this generator; this is the case of AES in Puerto Rico with its cogeneration capabilities through fluidized bed coal combustion. The proposed methodology derives the cost structure of the cogeneration output of AES and, with it, derives estimates of PREPA's current avoided cost. The available data contains all elements of the compensation schedule of PREPA to the private cogeneration facilities described in Equations (1) – (6).

AES is assumed to operate as a monopoly. Such assumption is sensible because the facility's compensation structure contains a pricing function dependant exclusively on its own level of production. Even though other electricity producers exist in the regulated market, e.g. EE and PREPA, the production choice of AES is determined via the solution of a monopolist's profit maximization problem with a well-defined pricing function independent of the production level of any other market participants. It is well established that a profit maximizing monopolist determines its production amount q^M at the output level where the marginal revenue of production equates its marginal cost. This relationship is represented in Equation (7). See Mas-Colell et. al (1995) and Salanie (2000) for further reference.

$$q^M : MR(q^M) = MC(q^M) \tag{7}$$

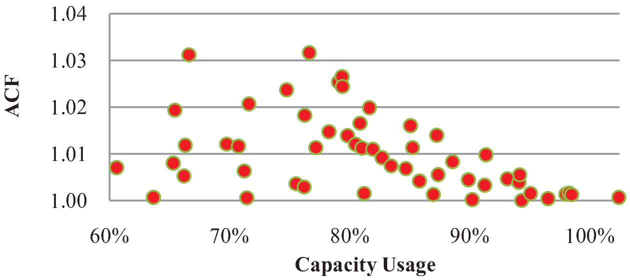
Considering that the cogeneration company is a profit maximizing monopolist and the fact that direct observation of the cost structure of the company is not possible, e.g. only its observable the compensation schedule, the estimation of the marginal cost function $MC(q^M)$ requires the use of the equilibrium condition in Equation (7). Equation (8) contains the marginal revenue equation, derived from totally differentiating the total revenue function with respect to q^M.

$$MR(q^M|z_f, z_d, z_c) = p'(q^M|z_f, z_d, z_c) \cdot q^M + p(q^M|z_f, z_d, z_c) \tag{8}$$

$p(q^M|-)$ is the pricing function from Equation (1). Assembling the pricing function $p(q^M|-)$ requires all its components be expressed in terms of its level of production and the price of its production inputs. For this purpose, the adjustments on the compensation for generation and capacity $ACF^{AES}_{p,t}$ and DEP^{AES}_t are regressed on these independent variables. Diagram 3 depicts the actual values of ACF_p with respect to the percentage usage of AES's energy capacity, and Diagram 4 the historical values assumed by DEP^{AES}_t.

DIAGRAM 3

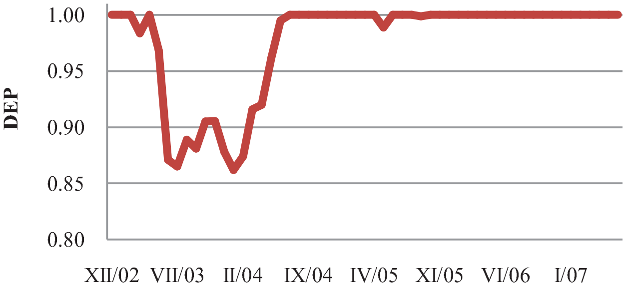
AES: COMPENSATION ADJUSTMENT WRT USAGE



Diag. 3. Ordered pairs of the adjustment factor ACF and the percentage usage of AES's energy capacity.

DIAGRAM 4

AES: HISTORICAL VALUES OF DEP



Diag. 4. Historical values assumed by the dependability index DEP

The estimated value of adjustment ACF_p is calculated using ordinary least squares, regressing the actual value of the adjustment against the monthly percentage usage of the company's energy capacity (use_t) and the monthly fuel cost index (z_{ft}). use_t is defined as the monthly's percentage capacity utilization of AES; i.e. $use_t = q_t/(C \cdot h_t)$, where h_t is the amount of hours in monthly period t. Equation (9) contains the regression representation of ACF_p; this equation conserves the convex nature of the adjustment, observed in Diagram 3. Table 2 contains the OLS parameter estimates of Equation (9).

$$ACF^{AES}_t = \beta^{AES}_0 + \beta^{AES}_1 \cdot use^{AES}_t + \beta^{AES}_2 \cdot \left(use^{AES}_t\right)^{-1} + \cdots$$
$$\ldots + \beta^{AES}_3 \cdot z^{AES}_{ft} + \varepsilon^{ACF}_t \tag{9}$$

TABLE 2

Dependent Variable: ACF N = 53

Variable	Coeff.	Std.Err	t-Stat	Prob.
β^{AES}_0	1.247	0.112	11.14	0.000
β^{AES}_1	-0.149	0.072	-2.06	0.044
β^{AES}_2	-0.081	0.044	-1.83	0.073
β^{AES}_3	-0.007	0.003	-2.84	0.001
R^2	0.420	Mean dep. Var.		1.010
Adj R^2	0.385	S.D. dep. Var.		0.008

The estimated value of adjustment DEP is also calculated using an ordinary least squares regression of the actual value of the adjustment against use_t. Equation (10) represents the OLS equation representation of DEP and Table 3 its parameter estimates.

$$\text{DEP}_t^{AES} = \theta_0^{AES} + \theta_1^{AES} \cdot \text{use}_t^{AES} + \varepsilon_t^{DEP} \tag{10}$$

TABLE 3

Dependent Variable: DEP N = 53

Variable	Coeff.	Std.Err	t-Stat	Prob.
θ_0^{AES}	0.906	0.047	19.34	0.000
θ_1^{AES}	0.089	0.057	1.568	0.123
R^2	0.046	Mean dep var		0.979
Adj R^2	0.030	S.D. depvar		0.043

Equation (11) is obtained combining Equations (8), (9) & (10), and after considerable mathematical manipulation. Equation (11) is a closed form solution for the estimated value of the marginal revenue of production.

$$\begin{aligned}\widehat{MR}_t^{AES} &= \alpha_2^{AES} \cdot z_{f,t}^{i} + \alpha_1^{AES} \cdot z_{p,t}^{AES} \cdot [\hat{\beta}_0^{AES} + \cdots \\ &\ldots + \hat{\beta}_1^{AES} \cdot (C \cdot h_t)^{-1} \cdot q_t^{AES} + \hat{\beta}_3^{AES} \cdot z_{ft}^{AES} + \varepsilon_t^{ACF}] + \cdots \\ &\ldots + \left[\gamma^{AES} \cdot z_{d,t}^{AESi} + \delta^{AES} \cdot z_{c,t}^{AES}\right] \cdot {h_t}^{-1} \cdot \theta_1^{AES}\end{aligned} \tag{11}$$

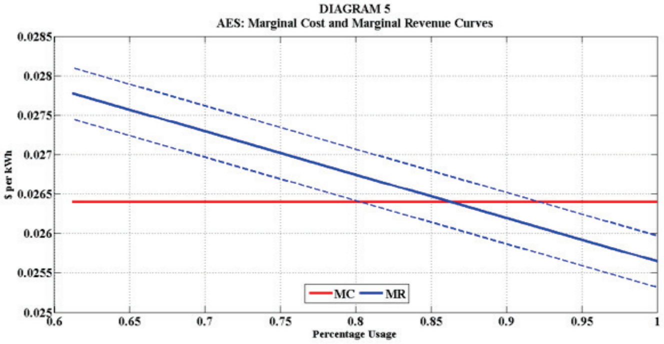
Considering the equilibrium condition of the monopolist's profit maximization problem in Equation (7), it is possible to construct the time series of the actual net electrical output marginal cost of AES. This time series represents PREPA's current avoided cost per kWh due to the electric energy cogeneration of AES. Consequently, by integrating Equation (11) with respect to AES' net electrical output (q_t^{AES}) it is possible to construct a historical total cost function of electrical cogeneration using fluidized bed coal combustion. The calculated total cost function is presented in Equation (12), and is consistent with those presented in Christensen & Greene (1976) and Evans & Heckman (1984).

$$\begin{aligned}\widehat{TC}_t^{AES} &= \Phi_0 + \Phi_1 z_{p,t}^{AES} q_t^{AES} + \Phi_2 z_{f,t}^{AES} q_t^{AES} + \cdots \\ &\ldots + \Phi_3 z_{p,t}^{AES} z_{f,t}^{AES} q_t^{AES} + \Phi_4 {h_t}^{-1} z_{d,t}^{AES} q_t^{AES} + \cdots \\ &\ldots + \Phi_5 {h_t}^{-1} z_{c,t}^{AES} q_t^{AES} + \Phi_6 {h_t}^{-1} z_{p,t}^{AES} \left(q_t^{AES}\right)^2 + \cdots \\ &\ldots + \Phi_7 z_{p,t}^{AES} q_t^{AES} \varepsilon_t^{ACF}\end{aligned} \tag{12}$$

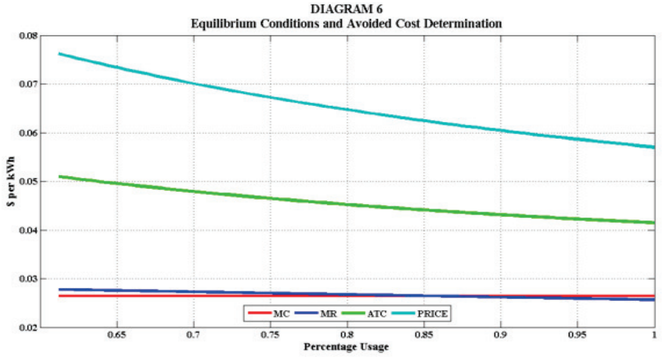
Where $\Phi_1 = \alpha_1^{AES} \hat{\beta}_0^{AES}$, $\Phi_2 = \alpha_2^{AES}$, $\Phi_3 = \alpha_1^{AES} \hat{\beta}_3^{AES}$, $\Phi_4 = \gamma^{AES} \theta_1^{AES}$, $\Phi_5 = \delta^{AES} \theta_1^{AES}$, $\Phi_6 = \alpha_1^{AES} \hat{\beta}_1^{AES} (2 \cdot C)^{-1}$ and $\Phi_7 = \alpha_1^{AES}$. Φ_0 is the constant of integration and an estimate of the fixed cost of production of AES. According to the Power Purchase Agreement between PREPA and AES, the best estimate for the value of Φ_0 is \$1,600 per kW. The variable cost of production is obtained by subtracting the total cost of production minus the fixed cost, e.g. $\widehat{VC}_t^{AES} = \widehat{TC}_t^{AES} - \Phi_0$. Dividing $\widehat{VC}_t^{AES}$ by its production amount q_t^{AES} yields the average variable cost of production.

IV. RESULTS ON THE ANALYSIS OF AES

The equilibrium mechanism with which the profit-maximizing net electrical output level of AES is determined, at average values of the cost indexes z_f, z_d, z_p and z_c, is depicted in Diagram (5) and Diagram (6). At the intersection of the Marginal Revenue and the Marginal Cost curves, AES fixes the utilization of its electric energy capacity and, concurrently, determines its net electrical output. The Marginal Revenue curve is illustrated considering its 99% confidence interval. The intersection domain of both curves includes the average value of AES' capacity usage for the considered time period. Considering the average values of the cost indexes z_f, z_d, z_p and z_c, at the intersection of the Marginal Revenue and Marginal Cost curves, the total remuneration for AES is 6.2¢ per kWh, the average total production cost is 4.4¢ per kWh, and the marginal production cost is 2.6¢ per kWh.



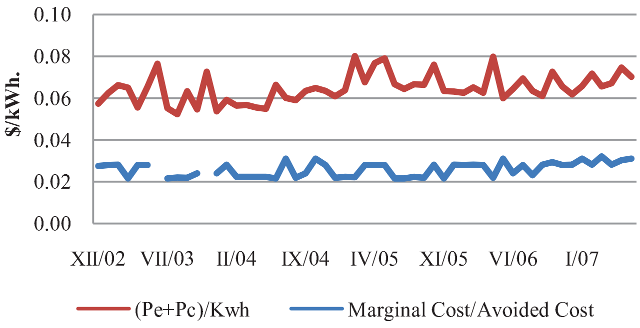
Diag. 5. Marginal Revenue and the Marginal Cost curves of AES for the average values of the cost indexes z_f, z_d, z_p and z_c,



Diag. 6. Demand function, Average Total Cost, Marginal Revenue and the Marginal Cost curves of AES for the average values of the cost indexes z_f, z_d, z_p and z_c,

DIAGRAM 7

AES: PRICING FUNCT., AND MARGINAL & AVOIDED COSTS



Diag. 7. Historical AES' Prices and Marginal Cost per kWh

Diagram (7) portrays the price per kWh with which AES has been historically remunerated and the Marginal Cost per kWh of such net electrical output. The Marginal Cost per kWh of AES is the Component Method estimate of the Avoided Cost per kWh of an additional qualified cogeneration facility that would substitute the electrical output and dependable capacity supplied by PREPA's generation facility with the highest marginal cost of production. The average value of the Avoided Cost estimates is 2.58¢ per kWh, and its standard deviation is 0.34¢ per kWh.

V. CONCLUSIONS

The analysis performed on this paper constitutes the first approximation to effectively estimate the current and historical values of the avoided cost of the Puerto Rico Electric Power Authority, using the actual Power Purchasing Agreements and privileged operational and compensational data from the two private cogeneration companies currently operating in Puerto Rico. The results from the analysis can provide a benchmark for entrepreneurs and companies interested in engaging on short and long term contractual energy cogeneration agreements with the Puerto Rico Electric Power Authority. It should be noted that the methodology proposed for the development of such estimates is not limited to Puerto Rico, and is readily transferable to other countries and jurisdictions. Additionally, the results may provide the foundation for carbon-trading operations in the prospects of the future establishment of clean electric energy cogeneration methods from renewable resources.

VI. ACKNOWLEDGMENT

The authors gratefully acknowledge the former Comptroller of Puerto Rico, Mr. Manuel Díaz Saldaña, whom made available for this academic research the privileged compensational data of the two private cogeneration companies currently operating in Puerto Rico.

VII. REFERENCES

Periodicals:

[1] Christensen and Greene, (1976). "Economies of Scale in U.S. Electric Power Generation". The Journal of Political Economy, Vol. 84, No. 4, Part 1, pp. 655-676.

[2] Consumer Price Index for All Urban Consumers: All Items, Index 1982-84=100; U.S. Department of Labor: Bureau of Labor Statistics.

[3] Evans, David and Heckman, James (1984), "A Test of Subadditivity of the Cost Function with an Application to the Bell System," American Economic Review, 74 (4,September), 615-623.

[4] Índice de Precios al Consumidor, Todas las Familias, Total (1984 = 100), Banco de Datos: Unidad de Investigaciones Económicas de la Universidad de Puerto Rico.

[5] L. Guey-Lee. (1999, Mar.). Renewable Electricity Purchases: History and Recent Developments. *Renewable Energy 1998: Issues and Trends*. Energy Information Administration, U.S. Department of Energy.

[6] Statistical Abstract of the United States: 2000, Section 25, *Construction and Housing*, p. 710; U.S. Census Bureau.

[7] "Total Steam Production Plant (Table E, Line No. 6)" de la publicación "Handy-Whitman Index of Public Utility Construction Costs".

[8] 92 Stat. 3117; 16 U.S.C. "Public Utilities Regulatory Policy Act of 1978".

Books:

[9] Cao-Alvira and Cao-García, (2009). "Tariffs and Economic consequences of the Government of Puerto Rico experience from the purchasing power agreements for electric generation and energy capacity from privately-owned qualified cogeneration facilities". *Proceedings of the 8th Latin-American Congress on Electricity Generation and Transmission at Ubatuba, Brazil in October, 2009. ISBN 978-85-61065-01-0.*

[10] *Costing Energy Resource Options: An Avoided Cost Handbook for Electric Utilities*, Tellus Institute, 1995.

[11] "Cost Effectiveness," in *Energy Efficiency Policy Manual*, California Public Utilities Commission, 2001.

[12] Greene, William H. (2008). "Econometric Analysis". Sixth Edition. Upper Saddle River, New Jersey: Pearson Prentice Hall, pp. 167-169.

[13] Mas-Colell, Whinston, and Green, (1995). "Microeconomic Theory", Oxford University Press, Oxford.

[14] Salanie, (2000). "The Microeconomics of Market Failures", The MIT Press, London.

Technical Reports:

[15] F. Graves, P. Hanser, and G. Basheda, "PURPA: Making the sequel better than the Original," Edison Electric Institute, Washington D.C., Dec. 2006.

[16] Energy and Environmental Economics, Inc. (2004, Oct.). "Methodology and Forecast of Long-Term Avoided Costs for the Evaluation of California Energy Efficiency Programs". California Public Utilities Commission, San Francisco, CA.

[17] "PREPA Estimated Avoided Costs" (various years). Autoridad de Energía Eléctrica de Puerto Rico

Standards:

[18] *Frequently Asked Questions: Renewable Energy Request for Project Proposals Release #2*, Renewable Hawaii, 1995. [Online]. Available: http://www.heco.com/portal/site/renewablehawaii.