[Cedeno 6(6): June 2019]
DOI- 10.5281/zenodo.3262358

ISSN 2348 – 8034
Impact Factor- 5.070

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

OPTIMIZATION MODEL TO MINIMIZE BUDGET SUBSIDIES CONSIDERING UNCERTAINTY IN ELECTRICITY DEMAND

Enrique B. Cedeno
School of Management, New York Institute of Technology, Nanjing, China

ABSTRACT

Real-time variations in electricity demand affect the balance between subsidies and contributions. In cases in which subsidies are greater than contributions, additional funds are provided by the government using budget subsidies. Energy policy and planning decisions should include uncertainty in electricity demand to avoid the risk of suboptimal decisions that result in inefficient resource allocation. This research formulates an optimization model to minimize average budget subsidy over a set of random demand scenarios. Results over one hundred random demand values for each residential group indicate for the case study presented here based in the Colombian system it is very unlikely that the cross-subsidy system can operate without requiring a budget subsidy even for small fluctuations in electricity demand subject to bounds on subsidy and contribution factors prevailing during the study period.

Keywords: *electricity tariffs; cross-subsidy; budget subsidy; demand uncertainty; optimization model; Colombia.*

I. INTRODUCTION

Uncertainty in electricity demand should be included in optimization models designed to formulate energy policies to avoid the risk of suboptimal decisions. Demand for electricity varies depending on several aspects such as time of the day, day of the week and season [1-9]. However, macro-level optimization models applied to the electricity sector [1-13] often include simplifications to facilitate problem-solving. These simplifications could include considering the demand as deterministic and the electricity price as given. A common practice is to consider demand as deterministic instead of as a random variable. Deterministic demand is usually set at a peak level since this generally represents the worst-case scenario [1-9]. Another alternative is to consider average values for these quantities [10-13]. Stochastic random demand can also be considered in the analysis by using demand scenarios generated randomly [7] or by representative future conditions [14]. In the design of a cross-subsidy system for the electricity sector, it is desired that the system would be self-financed only by contributions from electricity customers [10, 12, 13]. In case the demand for electricity changes due to overconsumption from subsidized groups this would affect the balance of the system from the design conditions, then the cross-subsidy system would not be able to generate enough resources to be self-financed. In this case, the government could provide budget subsidies to finance the deficit to achieve social or political goals. This is the case of the electricity sector in Colombia which is used in this research to test the proposed model. Electricity subsidies in Colombia are provided to almost 90% of residential customers, the cross-subsidy system under collects requiring budget subsidies of around 15% for the period from 2005-2007 [10, 12-13].However, the budget system has increased to almost 60% for the year 2012 [15]. Hence the importance of designing optimization models that guide the decision-making process decreasing the risk of making sub-optimal decisions [1-9,12,13]. Then the objective of the present research is to formulate an optimization model to minimize the budget subsidy considering uncertainty in electricity demand. This problem involves the cross-product of decision variables [9]. This problem is characterized as a non-linear programming problem [9]. This is a self-referential problem involving determining the electricity demand and the price, where electricity demand depends on the price which is a function of the subsidy or contribution factor [8, 9,12, 13]. This problem can also be characterized as a bilinear problem [8, 9, 12, 13]. In a bilinear problem, once one variable is specified the problem becomes a linear programming problem in the other variable [8]. This allows for solving the problem in a more efficient way once the size of the subsidized and contributing groups are given or the target levels for subsidy and contribution factors are given [9]. The research presented here extends the models presented in [10] to consider demand uncertainty by using a set of random demand scenarios. The author has proposed and algorithm to solve this non-linear problem [9] which has been used to propose alternatives to improve the performance of the cross-subsidy system for the Colombian electricity sector [12-13]. These alternatives reduce the need for budget subsidies and provide full subsidies to customers in the first income decile [12-13].The most recently available census data (at the moment of this research) for the year 2005 [16] suggests that customers in the first income decile will not be able to pay their electricity bill because it represents almost 100 percent of the average household income[10, 12-13]. Therefore, a limitation of the cross-subsidy sector for the electricity sector in Colombia is that is not able to identify customers that need additional financial support [10, 12-13]. Providing benefits to customers that do not need them, as well as missing the target population are some of the arguments given against subsidies [17-19]. Electricity subsidies in British Columbia,Canada [18]and in China [19] have been reported missing the target population providing benefits to higher income consumers. Another argument made against subsidies is based on possible overconsumption due to subsidized prices [17-19]. In cases in which subsidies are used by the government to promote equity, universal access and national development [20-21]basic services are priced low relative to costs, whereas other services are priced high relative to costs to compensate [22-24]. This pricing creates cross-subsidies. Then, subsidized customers are encouraged to consume more, whereas customers from contributing groups reduce their consumption below the efficient level of consumption [17, 20, 25, 26]. Statistical comparison of the electricity consumption from subsidized groups found significant differences in the electricity consumption indicating possible overconsumption from subsidized groups in the residential electricity sector in Colombia for the period 2003-2012 [11].

Figure 1 presents electricity demand curves for subsidized (S) and contributing (C) groups. The price for the subsidized group (P_s) is set below the cost of supply (CS), whereas the price for the contributors (P_c) is set above the cost of supply. This cross-subsidy pricing causes consumption in the subsidized sector to increase from $Q_S(CS)$ to Q_s and consumption in the subsidizing sector to decrease from $Q_C(CS)$ to Q_C. The balance of subsidies and contributions requires $Q_s * (CS- P_s)$ to be equal to $Q_C * (P_c -CS)$ [20]. The uncertainty in electricity demand is represented in Figure 1 by the bell shape curves with means $\mu_s=Q_s$ and $\mu_c=Q_C$. The electricity demand varies depending on the time of the day, day of the week and season. At any time*t*, the realization of the demand is random according to its probability distribution. Its realized value could fall on either side of the mean demand μ. In planning and policy-making, simplifying assumptions are made regarding demand values. It is very likely that at any time *t*, the realization of the demand differs with respect to its value used during policy design. This variability affects the balance between subsidies and contributions. The optimization model presented here seeks to identify optimal subsidy and contribution factors that minimize the average budget subsidy considering demand uncertainty.

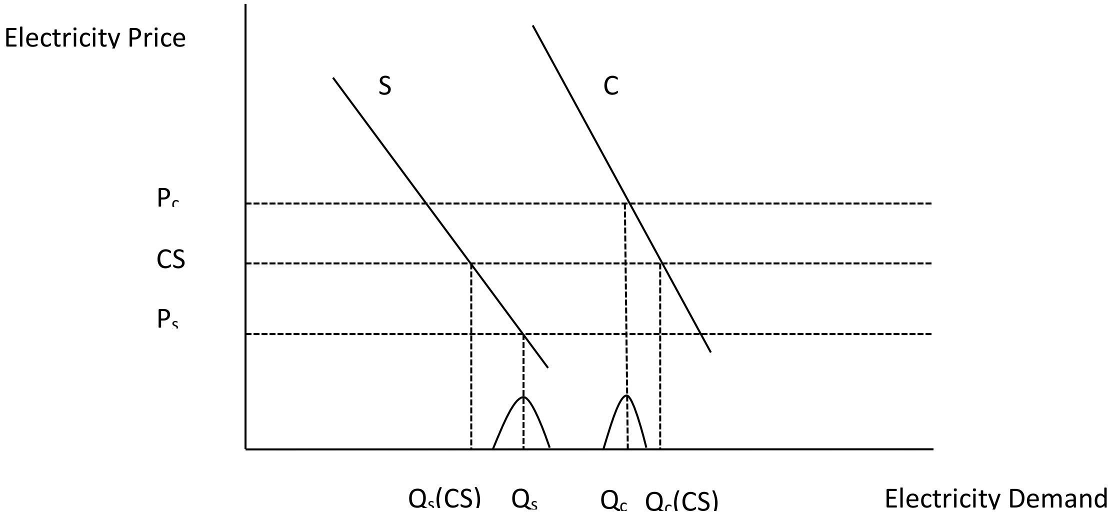

Figure 1. Demand curves for Subsidized and contributor groups.

Cross-subsidies are considered necessaryin public network enterprisesto comply with their social mission [20, 24]. In China, to provide a competitive edge, electricity prices are lower than the cost of supply [17] and cheaper than in developed countries [25]. In Brazil, large industrial customers also benefit from lower tariffs to increase their competitiveness [26]. In Colombia, higher income residential groups contributed a maximum of 60% of their electricity bill towards electricity subsidies at the beginning of the restructuring process in 1994 [27]. Subsidies can be used to promote network development; however, once the network is mature, they can be discontinued [23, 28]. Subsidies are characteristics of network monopolies developed under public ownership [23]. Colombia implemented a cross-subsidy system after the restructuring of its electricity sector in 1994 [10-13, 29]. Subsidies occur when products or services are priced below their marginal costs. Subsidiesalso occur when the government provides a payment to either producers or consumers directly or indirectly to lower the price of the product or to lower production costs [19, 26, 30, 31]. A combination of cross-subsidies and budget subsidies could be implemented in electricity markets in which the government owns and regulates the public network [18, 23]. However, when operation and ownership are separated from regulation, as for instance in the MISO (Midwest Independent System Operator) [7] and PJM (Pennsylvania, New Jersey, and Maryland interconnection) markets in the US, with no political power to access budget subsidies, regulators only have access to cross-subsidies to achieve their social or political goals [23].Subsidies have been used in the telecommunications industry in France and Canada [23, 24]; postal services in the US [23]; the water industry in Scotland [28]; fossil fuels in China, India, Indonesia, Egypt, Thailand, Venezuela, Saudi Arabia, Iran, Iraq and Mexico [17, 25, 32]; natural gas in Ukraine [32] and China [30]; and in the electricity sector in China, Colombia, Brazil, Bolivia, Honduras, Panama, Nicaragua, El Salvador, Mauritania, Jordan, Senegal, Lebanon and Canada [17-19, 32].

II. OPTIMIZATION MODEL

This research extends the work presented in [9] by considering demand as a random variable. Demand scenarios are used to represent uncertainty in electricity demand.The problem presented in [9] is a Mixed Integer Non-linear Programming (MINLP) problem since it involves the product of the decision variables in the objective function.This optimization problem is also a self-referential problem [3, 7-9] involving determining the electricity price, the demand quantity, and the subsistence level. This is in addition to any non-linearities proper to the functions representing the price and the electricity demand. In macro-level decision making some simplifications are made to facilitate problem-solving. Some of these simplifications include considering the problem under deterministic conditions according to which the demand and price are given and set at peak levels or at average values. A more realistic approach is obtained by considering uncertaintyconditions represented by using a set of demand scenarios [7, 14]. This is the approached taken by the research presented in this paper. The constrained optimization model presented in [9] is modified to include a set of demand scenarios generated randomly.

The decision maker in the problem seeks to evaluate the effect of demand uncertainty in the range of optimal subsidy and contribution factors that minimize the average budget subsidy over a set of scenarios. Uncertainty in electricity demand is incorporated into the problem by considering demand as random variables. Any difference from the values used to set budget subsidies in energy policies would cause an unbalance requiring most likely additional funds from the government causing inefficient allocation of resources.The proposed method using demand scenarios has similarities with the method employed by the Midwest Independent System Operator (MISO) in the capacity validation study [7, 14]. In this study, decision makers determine expansion plans for three possible future demand scenarios [14]. The decision makers selected all of the transmission lines common to all three scenarios for implementation. In the case presented here, the optimization model finds optimal subsidy and contribution factors for each scenario minimizing the average budget subsidy over all scenarios [7].Random samples from normal distributions are used to generate demand scenarios.

The minimization problem is presented below:

$$Min\ \left(\frac{\sum_i^{n_s}\ Budget\ \ Subsidy_i}{n_s}\right) \tag{1}$$

Where:

$$Budget\ \ Subsidy_i = Subsidy_i - Contributions_i \tag{2}$$

$$P_{S_{i,j,l}} = CS_{S_{i,j,l}}(1-\alpha_{S_{i,j,l}}) \tag{3}$$

$$Subsidy_i = \sum_{l} \sum_{j=1}^{m} U_{S_{i,j,l}} Q_{S_{i,j,l}} \left(CS_{S_{i,j,l}} - P_{S_{i,j,l}}\right) = \sum_{l} \sum_{j=1}^{m} U_{S_{i,j,l}} Q_{S_{i,j,l}} CS_{S_{i,j,l}} \alpha_{S_{i,j,l}} \tag{4}$$

$$P_{C_{i,k,l}} = CS_{C_{i,k,l}} \left(1 + \beta_{C_{i,k,l}}\right) \tag{5}$$

$$Contributions_i = \sum_{l} \sum_{k=1}^{n} U_{C_{i,k,l}} Q_{C_{i,k,l}} \left(P_{C_{i,k,l}} - CS_{C_{i,k,l}}\right) = \sum_{l} \sum_{k=1}^{n} U_{C_{i,k,l}} Q_{C_{i,k,l}} CS_{C_{i,k,l}} \beta_{C_{i,k,l}} \tag{6}$$

Subject to

$$0 \le LB_{S_{i,j,l}} \le \alpha_{S_{i,j,l}} \le UB_{S_{i,j,l}} \le 1 \tag{7}$$

$$\alpha_{S_{i,j,l}} \ge \alpha_{S_{i,j+1,l}} \tag{8}$$

$$0 \le LB_{C_{i,k,l}} \le \beta_{C_{i,k,l}} \le UB_{C_{i,k,l}} \tag{9}$$

$$\beta_{C_{i,k+1,l}} \ge \beta_{C_{i,k,l}} \tag{10}$$

Notation:

$\alpha_{S_{i,j,l}}$: Subsidy factor for scenario *i* for subsidized group *j* in region *l*.
$\beta_{C_{i,k,l}}$: Contribution factor for scenario *i* for subsidizing group *k* in region *l*.
$C_{k,l}$: Contributor group *k* in region *l*.
$CS_{S_{i,j,l}}$: Cost of supply for scenario *i* for subsidized group *j* in region *l* per Kwh.
$CS_{C_{i,k,l}}$: Cost of supply for scenario *i* for subsidizing group *k* in region *l* per Kwh.
LB : Lower bound.
n_s : number of scenarios
$P_{S_{i,j,l}}$: Electricity price for scenario *i* for subsidized group *j* in region *l* per Kwh.
$P_{C_{i,k,l}}$: Electricity price for scenario *i* for subsidizing group *k* in region *l* per Kwh.
$Q_{S_{i,j,l}}$: Average consumption for scenario *i* per customer in subsidized group *j* in region *l*.
$Q_{C_{i,k,l}}$:Average consumption for scenario *i* per customer in subsidizing group *k* in region *l*.
$S_{j,l}$: Subsidized group *j* in region *l*.
UB : Upper bound
$U_{S_{j,l}}$: Customers in subsidized group *j* in region *l*.
$U_{C_{k,l}}$: Customers in subsidizing group *k* in region *l*.

The objective function (1) minimizes the average budget subsidy over a set of demand scenarios. The budget subsidy (2) is defined as the difference between subsidies (4) and contributions (6). Subsidy factors are included in (3); whereas contribution factors are included in (5).

Establishing bounds on restrictions (7) – (10) requires consensus among different stakeholders including politicians, energy planners, and various consumer groups. These groups may have conflicting objectives.Subsidized groups seek maximization of subsidy factors; whereascontributing groups seek minimization of contributing factors and government seeks an overall reduction of budget subsidy. It is worth mentioning that the proposed model can be applied to other public services to design a cross-subsidy mechanism for a system consisting of *m* subsidized categories and *n* contributing categories havingdifferent costs of supply. In order to simplify the problem for the case study presented in the following sections, it is considered that the size of the subsidized and contributing sectors are given, as well as the subsistence and base level [9]. Then, the optimization problem reduces to find the subsidy (3) and contribution factors (5). This is a linear programming (LP) problem resulting from the bilinear nature of the problem presented in (1) [8, 9]. Then, the solution to this problem is easily attainable by using current optimization software.

III. CHARACTERISTICS OF THE CROSS-SUBSIDY SYSTEM IN COLOMBIA.

The electric sector in Colombia has been considered of academic interest [29] due to the positive results experienced after its deregulation in 1994 related to the quality of service, openness and market and regulatory design. The energy crisis of 1992 motivated the restructuring of the electricity sector in Colombia. During this year hydrological generation capacity was reduced due to an extremely dry season resulting in a long period of load rationing to prevent blackouts. This crisis also had political consequences, transforming politicians and energy planners into risk avoiders favoring over capacity [29, 31]. As a result of the restructuring process in 1994 [33, 34], Colombia implemented a policy of cross-subsidies to promote national development,universal access and social equity.The cross-subsidy system under-collects and requires budget subsidies from the Colombian government of almost 15 percent of the total subsidy amount. However, the budget subsidy was nearly 60 percent for the year 2012 [15]. Then, it is important to monitor the behavior of the system to propose alternatives to improve its performance [9-13].

Unlike unbundled deregulated markets in the US, the Colombian electric system is partially unbundled [29]. Companies are allowed to participate in generation and distribution provided they act independently and do not discriminate against other companies [29]. There is also mixed ownership of electricity assets between the government and private sectors. This mixed ownership allows Colombia to implement a combination of cross-subsidies and budget subsidies.The system is financed by contributions from higher income residential customers, industrial and commercial sectors. The government provides budget subsidies to finance any deficit. Electricity in Colombia was provided at a subsidy to 95 percent of residential customers [9-13].

Residential tariffs for electricity in Colombia should be set according to the same residential classification employed in the provision of residential public water service outlined in CREG resolution 012-93 [35]. This system is based on a residential classification of homes to identify the target population in neighborhoods for the purpose of tariff assignment [36]. Based on the residential classification of homes, there are six residential groups from 1 to 6 in increasing order of financial wealth. Groups 1 to 3 are considered low-income groups and are the beneficiaries of the subsidies. Group 4 is considered neither a contributor nor a subsidized sector; it should pay solely for the cost of the service. Groups 5 and 6 are considered higher income groups. These groups contribute to the subsidies in addition to the contributions made by the industrial and commercial sectors.Residential electricity tariffs are defined in resolutions CREG 80-95 [37], CREG 09-96[38] and CREG 78-97 [39], whereas non-residential electricity tariffs are defined in resolution CREG 79-97 [40].

Based on the rules for the sector a simplified general expression to compute tariffs is provided below [9, 11-13]:

$$T(t)_{ijk} = (1+\rho_{ik}(t))\ C_{jk}(t) \tag{11}$$

Where:

$T(t)_{ijk}$: tariff for customer type *i* at voltage level *j* provided by company *k* at time *t*.

$\rho_{ik}(t)$: subsidy or contribution factor for customer type *i* at time *t* provided by company *k*.

$C_{jk}(t)$: cost of supply at voltage level *j* provided by company *k* at time *t*.

The above equation has similarities with (3) and (5) presented in the previous section.These equations are used to determine subsidy and contribution factors in the research presented here.

Data for the Colombian electricity sector [10-13, 41] indicates that during the study period residential group 1 represents 24 percent of residential customers; whereas groups 2, 3 and 4 represent 40 percent, 25 percent, and 6 percent respectively. Approximately 95 percent of residential customers received subsidies from the system during the three-year study period.

Average electricity prices for subsidized and contributing groups are presented in table 1. Values are given in $/kWh at constant US$ for the year 2007. Despite the rules in the design of the system, the average electricity price for group 6 is lower than the average electricity price for group 5. This requires additional research beyond the scope of the present paper. Table 1 also reports the average electricity consumption in kWh per month for all the groups considered in this research. Average electricity consumption for subsidized group 1 is greater than average electricity consumption for group 2 indicating some overconsumption from group 1 [11].

Table 1.Average electricity price and Average electricity consumption for 2005-2007 [41].

Average	G1	G2	G3	G4	G5	G6	Industrial	Commercial	Others
Electricity Price ($/Kwh)	0.11	0.13	0.16	0.17	0.20	0.19	0.11	0.15	0.13
Electricity Consumption (kWh per month)	147.02	138.2	171.11	214.45	271.98	405.32	16133.34	970.39	2767.64

The cross-subsidy system given the average prices listed above and the underlying subsidy and contribution factors reported elsewhere [10-13] is not able to collect enough funds to provide subsidies to 95% of residential customers. The budget subsidy from the government represents on average approximately 15 percent of the total subsidy amount after discounting all contributions [10-13].

IV. TEST RESULTS

The proposed model presented in this research is applied to 100 demand values generated randomly from normal distributions considering demand variability for each group represented as standard deviation set at 10 percent of the mean demand. Demand values are generated using the function random variate from the normal distribution in Mathematica version 10, setting the seed as 19.The electric sector considered to generate the results presented in the next section is based on the Colombia electric sector as described in the previous section [9-13]. The justification to propose alternative allocation methods for cross-subsidies in Colombia is that the current allocation method does not correlate with the household income [36, 42]. Then, the system is limited in its ability to provide additional support to customers under extreme poverty.

In the case presented here, there are four subsidized residential groups financed by contributions from two higher income residential groups, industrial and commercial customers, as well as other large customers. The mean values are obtained from average electricity prices and average electricity consumption per subscriber, as presented in Table 1. The standard deviation is set at 10 percent of corresponding mean values. The cost of supply for residential customers is set as the average electricity price for customers in group 4. This value corresponds to 0.17 $/Kwh. The average cost of supply for industrial, commercial and other sectors is estimated from equation (5) using the average following values 0.0912560, 0.1209873 and 0.1278521 $/Kwh, respectively [9-13].

Table 2 reports the optimal values obtained from the model presented in this research considering demand variability. The average budget subsidy for each sample case is almost 15 percent. This is coincidentally similar to the average budget subsidy reported for the study period in the previous section.There are only two cases in which budget subsidies are not required. These result in a 2 percent reduction in the probability of requiring budget subsidies when the standard deviation of the demand is set at 10 percent. This probability is very high for the case presented here, which considersa conservative variation in demand. The associated probability of generating enough funds to cover consumption from customers in the first subsidized group is zero.It is assumed that customers in group 1 represent customers in the first income decile [9-13]. It is desired to provide full subsidy to these customers since for them electricity bill could represent 90% of household income [9-13, 42].

Table2. Optimal solution range considering 100 samples at 10 percent demand variance.

	10 percent standard deviation demand
Average Budget subsidy	14.50 percent
Range Budget Subsidy	0 – 28.89 percent
P(Requiring Budget Subsidy)	98 percent
P(Covering 1st subsidized group)	0
α_{S_1}	0.4
α_{S_2}	0.3
α_{S_3}	0.08
$Range\ \ \beta_{c_5}$	0.15-0.20
β_{c_6}	0.2
$\beta_{c_{Industrial}}$	0.2
$\beta_{c_{Commercial}}$	0.2
$\beta_{c_{Others}}$	0.05
P_{S_1}	0.102
P_{S_2}	0.119
P_{S_3}	0.1564
$Range\ \ P_{c_5}$	0.1955-0.204
P_{c_6}	0.204
$P_{c_{Industrial}}$	0.1095
$P_{c_{Commercial}}$	0.1452
$P_{c_{Others}}$	0.1342
Demand Range	19124.74- 28844.16 MWh

In terms of the range of optimal values for subsidy and contribution factors presented in table 8, the subsidy factors for all of the groups in all of the cases are set at the lower bounds, whereas the contributing factors are set at the upper bounds for all groups in all cases except one in which the contribution factor for group 5 is set at the lower bound. The philosophy behind the solution is to give the minimum subsidy and collect the maximum contribution. This is also due to the fact that this bilinear program reduces to a linear program under the assumptions used in the case presented here. Then, all the properties of linear programming hold in this case.The price range provides limited information in this case because the bounds imposed on the subsidy and contribution factors by the current regulations described earlier in the paper do not give flexibility in terms of setting different prices for each scenario. Prices for customers in group 5 vary in one sample from 0.1955 to 0.204 $/MWh. The total demand considered in this case varies from 19124.74 up to 28844.16 MWh. This analysis assumes variation in demand for each group is random from a normal distribution, a limitation of the analysis is the assumption that this variation is homogenous for all groups. Results indicate the variation of the budget subsidy is affected by the distribution of the changes in the subsidized groups and the contributing groups. Another underlying assumption is that electricity demand is mostly price-inelastic. These limitations can be overcome by estimating demand variability and elasticity per group from historical demand data for each demand group in each region. However, access to this data is currently not available. Additional demand scenarios could be generated to represent these two cases, but that would constitute a research study on its own beyond the scope of the analysis presented here.

V. CONCLUSION

Real-time variations in electricity demand affect the balance between subsidies and contributions. In cases in which subsidies are greater than contributions, additional funds are provided by the government using budget subsidies.

Energy policy and planning decisions need to include uncertainty in electricity demand to avoid the risk of suboptimal decisions that result in inefficient resource allocation. Colombia implemented a policy of cross-subsidies to promote national development, universal access, and social equity after restructuring its electricity sector in 1994.However, the system under-collects and requires budget subsidies from the Colombian government of almost 15 percent of the total subsidy amount. However, the budget subsidy was nearly 60 percent for the year 2012 [14], which highlights the importance of designing an efficient cross-subsidy system that considers demand uncertainty.

This research presents an optimization model to evaluate the effect of demand uncertainty over the minimum average budget subsidy for the Colombian electricity system over a set of demand scenarios. Demand uncertainty is included in the model by considering electricity demand as a random variable. The optimization model and its restrictions are designed based on the rules and regulations prevailing in the sector at the time of this research. The optimal results over a set of 100 random demand scenarios at a 10% mean demand variation given the prevailing bounds on subsidy and contribution factors indicate that the probability of requiring a budget subsidy is almost one. The average budget subsidy for these samples is almost 15 percent. Coincidentally for the samples used in this research, this value matches the average budget subsidy during the study period. The maximum budget subsidy for the test cases is 29 percent. It can be inferred from the results presented here that it is very unlikely that the Colombian system can provide subsidies to 95 percent of its residential customers without requiring budget subsidies given the existing bounds established for subsidy and contribution factors during the time of this research. The research presented here shows that demand uncertainty can be included in the design of a cross-subsidy system using demand scenarios and minimizing the average budget subsidy over these scenarios. However, stakeholders in the problem need to join efforts to define relevant scenarios for each demand group and acceptable bounds on the subsidy and contribution factors that are in alignment with the social goals set for the system by the Colombian government.

REFERENCES

1. *Bustamante-Cedeño, E, and S Arora. 2007. Allocation of Transmission Charges for Real Power Transactions using Markov Chains. Generation, Transmission & Distribution IET 1: 655.*
2. *Bustamante-Cedeño, E, and S Arora. 2008. Sensitivity of generation reserve requirements in deregulated power systems. Electric Power Systems Research 78: 1946–1952. doi:10.1016/j.epsr.2008.03.025.*
3. *Cedeño, Enrique B., and Sant Arora. 2013. Integrated transmission and generation planning model in a deregulated environment. Frontiers in Energy 7: 182–190. doi:10.1007/s11708-013-0256-8.*
4. *Cedeno, E. B. & Arora, S. Sensitivity of generation reserve requirements in deregulated power systems. Electric Power Systems Research, 2008, 78(11), 1946-1952.*
5. *Cedeno, E. B. & Arora, S. Cost impact of dynamically managing generation reserves, International Journal of Electrical Power & Energy Systems, Volume 51, October 2013, Pages 292-297.*
6. *Cedeno, E. B. Security of Supply and Generation Reserve Management Delegation under Extremely High Load Curtailment Cost, Appl. Mech. Mater., vol. 799–800, pp. 1257–1262.*
7. *Cedeno, E. B. & Arora, S. Stochastic and Minimum Regret formulations for Transmission Network Expansion Planning under Uncertainties. Journal of the Operational Research Society, (JORS). 2008. Pages: 1-10.*
8. *Cedeno, E. B. & Arora, S. Convexification method for bilinear transmission expansion problem. International Transactions on Electrical Energy Systems. (2013). https://doi.org/10.1002/etep.1721*
9. *Cedeno, E. B. Optimization Model to Minimize Electricity Budget Subsidies. International Journal of Engineering Technology Research & Management.2019. 3 (6) 1-11*
10. *Cedeno, E. B. Cross-subsidies for the Electric Sector in Colombia: are they enough to help poor families? Poverty and Social Protection Conference, Bangkok, Thailand, pp. 38–51. (2016).*
11. *Cedeno, E. B. ANOVA Study of Efficient Management and Allocation of Residential Electricity Subsidies in Colombia. The International Journal of Management. 2018, 7(4), 1-10.*
12. *Cedeno, E. B. Self-financed income-based cross-subsidy allocation for the Electricity sector in Colombia. Global Journal of Engineering Science and Researches, 2019, 6 (3) 273-283.doi: 10.5281/zenodo.2627976 http://www.gjesr.com/Issues%20PDF/Archive-2019/March-2019/32.pdf.*
13. *Cedeno, E.B. From Policy to Implementation: Evaluating Alternative Allocation Systems for Electricity Subsidies in Colombia. American International Journal of Business Management. 2019, 2 (4) 133-141.*

14. *The Minnesota Transmission Owners. 2009. Capacity Validation Study.*
15. *Ministerio de Minas y Energía. 2012. Fondo de Solidaridad para subsidios y redistribución de ingresos.*
16. *Departamento Administrativo Nacional de Estadisticas. (2006). Reporte Pobreza y Condiciones de Vida. Retrieved July 1, 2015, from http://www.dane.gov.co/index.php/estadisticas-por-tema/pobreza-y-condiciones*
17. *Lin, Boqiang, and Zhujun Jiang. 2011. Estimates of energy subsidies in China and impact of energy subsidy reform. Energy Economics 33. Elsevier B.V.: 273–283. doi:10.1016/j.eneco.2010.07.005.*
18. *Pineau, Pierre-Olivier. 2008. Electricity Subsidies in Low-Cost Jurisdictions: The Case of British Columbia. Canadian Public Policy / Analyse de Politiques 34: 379.*
19. *Sun, Chuanwang, and Boqiang Lin. 2013. Reforming residential electricity tariff in China: Block tariffs pricing approach. Energy Policy 60: 741–752. doi:10.1016/j.enpol.2013.05.023.*
20. *Chattopadhyay, Pradip. 2007. Testing the viability of cross-subsidy using time-variant price elasticities of industrial demand for electricity: Indian experience. Energy Policy 35: 487–496. doi:10.1016/j.enpol.2005.12.020.*
21. *Faulhaber, Gerald R. 1975. Cross-Subsidization: Pricing in Public Enterprises. The American Economic Review 65: 966–977.*
22. *Heald, David. 1996. Contrasting approaches to the "problem" of cross-subsidy. Management Accounting Research 7: 53–72. doi:10.1006/mare.1996.0003.*
23. *Heald, David. 1997. Public policy towards cross-subsidy. Annals of Public and Cooperative Economics 68: 591–623.*
24. *Palmer, Karen. 1992. A test for cross-subsidies in local telephone rates: do business customers subsidize residential customers? RAND Journal of Economics 23: 415–431.*
25. *Liu, Wei, and Hong Li. 2011. Improving energy consumption structure: A comprehensive assessment of fossil energy subsidies reform in China. Energy Policy 39. Elsevier: 4134–4143. doi:10.1016/j.enpol.2011.04.013.*
26. *Voll, Sarah Potts, Carlos Pabon-Agudelo, and Michael B. Rosenzweig. 2003. Alternatives for the Elimination of Cross-Subsidies: The Case of Brazil. The Electricity Journal 16: 66–71. doi:10.1016/S1040-6190(03)00046-0.*
27. *Comisión de Regulación de Energía y Gas (CREG). 1996. CREG 09-96.*
28. *Sawkins, John W., and Scott Reid. 2007. The measurement and regulation of cross-subsidy. The case of the Scottish water industry. Utilities Policy 15: 36–48. doi:10.1016/j.jup.2006.07.001.*
29. *Larsen, Erik R, Isaac Dyner, Leonardo Bedoya V, and Carlos Jaime Franco. 2004. Lessons from deregulation in Colombia: successes, failures and the way ahead. Energy Policy 32: 1767.*
30. *Wang, Ting, and Boqiang Lin. 2014. China's natural gas consumption and subsidies-From a sector perspective. Energy Policy 65. Elsevier: 541–551. doi:10.1016/j.enpol.2013.10.065.*
31. *Barrera Rey, F, and A García Morales. 2010. Desempeño del mercado eléctrico colombiano en épocas de niño: lecciones del 2009-10. Alcogen.*
32. *Plante, Michael. 2014. The long-run macroeconomic impacts of fuel subsidies. Journal of Development Economics 107. Elsevier B.V.: 129–143. doi:10.1016/j.jdeveco.2013.11.008.*
33. *Congreso República de Colombia. 1994. Ley 142.*
34. *Congreso República de Colombia. 1994. Ley 143.*
35. *Comisión de Regulación de Energía y Gas (CREG). 1993. CREG 012-93.*
36. *Uribe-Mallarino, Consuelo. 2008. Estratificación social en Bogotá : de la política pública a la dinámica de la segregación social. Universitas Humanística no.65: 139–171.*
37. *Comisión de Regulación de Energía y Gas (CREG). 1995. CREG 80-95.*
38. *Comisión de Regulación de Energía y Gas (CREG). (1996) CREG 09-96.*
39. *Comisión de Regulación de Energía y G (CREG). 1997. CREG 78-97.*
40. *Comisión de Regulación de Energía y Gas (CREG). 1997. CREG 79-97.*
41. *Sistema Unico de Información (SUI). 2014.*
42. *Rosero, L. M. (2004). Estratificación socioeconómica como instrumento de focalización. Economía Y Desarrollo, 3(1), 53.*