Price Elasticity of Demand

1 Introduction

East Kentucky Power Cooperative, Inc. ("EKPC") filed an Integrated Resource Plan ("IRP") with the Kentucky Public Service Commission ("KPSC") on April 23. 2012[1]. The KPSC Staff filed a report titled "Staff Report on the 2012 Integrated Resource Plan of East Kentucky Power Cooperative, Inc. ", on September 2013. In its report, Staff recommended that "EKPC should discuss and report separately the impact on demand and energy forecasts of any projected increases in the price of electricity to its ultimate customers in its next IRP. The price elasticity of the demand for electricity should be fully examined and discussed, and a sensitivity analysis should be performed."

2 Study Objective

EKPC engaged GDS Associates, Inc. ("GDS") to conduct an independent study to estimate price elasticity of demand from primary source data to allow EKPC forecasters to verify and refine the elasticity assumptions that have been assumed for previous planning analyses, and to provide a basis for elasticity assumptions used in future load forecasts. Additionally, in efforts to provide support for EKPC's analysis, the study entailed conducting secondary research to identify price elasticity study results conducted by other electric utilities and research firms. In response to the recommendation made by Staff, this report presents the estimated impact of potential increases in the price of electricity to EKPC's ultimate customers. Additionally, results of the study provide the input necessary to conduct sensitivity analysis in EKPC's next load forecast and IRP.

3 Methodology

Econometric modeling was used to perform the price elasticity analysis. Multiple model specifications were investigated to help provide a reasonable range of elasticity estimates. Models were developed at the aggregate EKPC level by customer class and at the member distribution cooperative level by class. All models were analyzed using data on an annual and monthly basis. GDS developed the methodology, conducted the analysis, and reviewed the methodology and results with EKPC staff prior to publishing this report.

3.1 Data

A database of the components necessary to build econometric models was developed by EKPC and provided to GDS. This section describes the data and sources used for the analysis.

3.1.1 Utility Billing History

Monthly number of customers, kWh sales, and revenues by revenue class (residential, commercial, industrial, street lighting, and public authorities) were compiled for each member cooperative for January 2000 through September 2014.

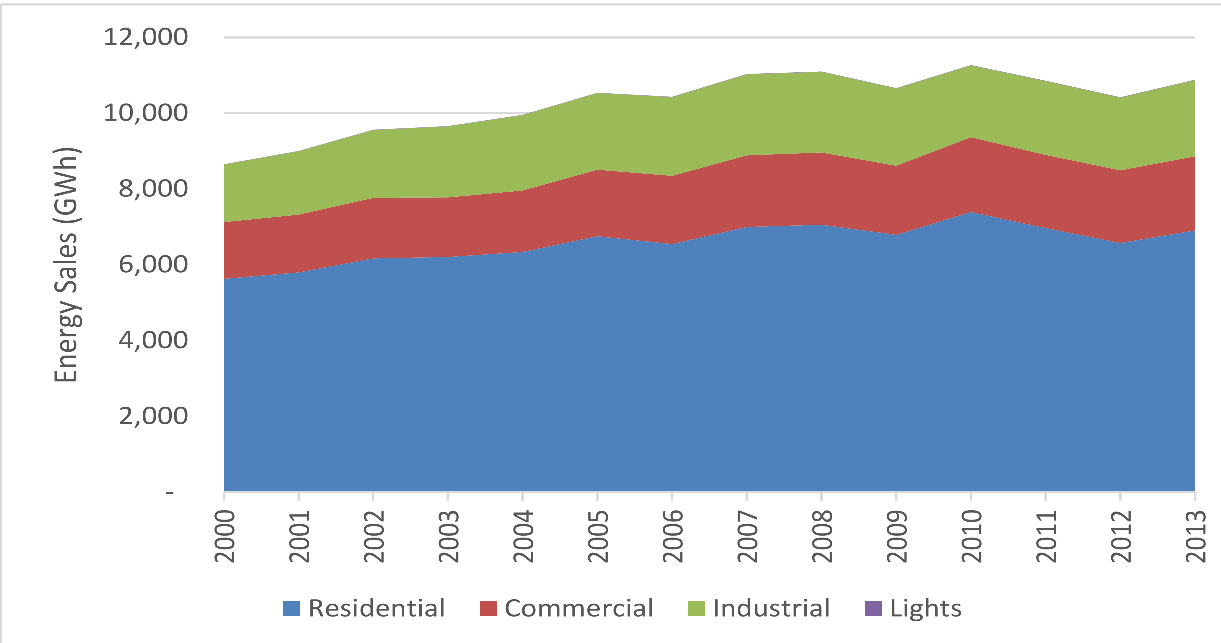
The residential class represents 93% of the total number of customers served by EKPC's member distribution cooperatives. In 2013, the class represented 58% of total energy sales, totaling 6,900 GWh. Residential energy sales have grown by an average compound rate of 1.6% per year from 2000 through 2013.

[1] KPSC Case No. 2012-00149

The commercial class, including public authority accounts, represented 7% of EKPC's customers and 18% of energy sales in 2013. In terms of both number of customers and energy sales, the class grew faster than the residential class from 2000 through 2013. Energy sales averaged 2.1% per year in compound growth.

The industrial class consists of less than 150 total accounts, but represented 25% of total energy sales in 2013. Growth in the industrial class has been healthy, averaging 2.2% per year in energy sales growth.

Figure 2.1 – Energy Sales by Class (2000-2013)



3.1.2 Price of Electricity

Nominal price of electricity was computed using the utility billing history. Annual average revenue per kWh was used to represent nominal price each year. The Purchase Consumption Expenditure ("PCE") deflator, provided by Woods & Poole Economics, Inc., was used to compute real price of electricity. The annual real price of electricity was used to represent price in every month for econometric models developed using monthly data.

Table 2.1 – Purchase Consumption Expenditure Deflator (2009=100)

Year	PCE	Year	PCE
2000	83.1	2008	100.1
2001	84.7	2009	100.0
2002	85.9	2010	101.7
2003	87.6	2011	104.1
2004	89.7	2012	106.0
2005	92.3	2013	107.3
2006	94.7	2014	109.4
2007	97.1		

Real residential price has risen by an average of 7% per year from 2000 through 2013. Commercial and industrial prices have risen a little more modestly at 5% per year.

Figure 2.2 – Residential Price (EKPC Total)

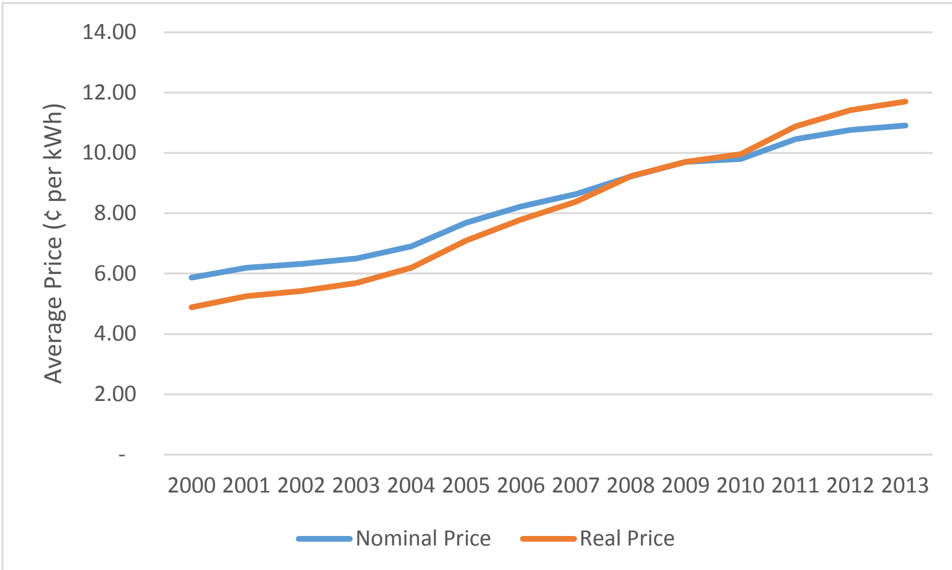
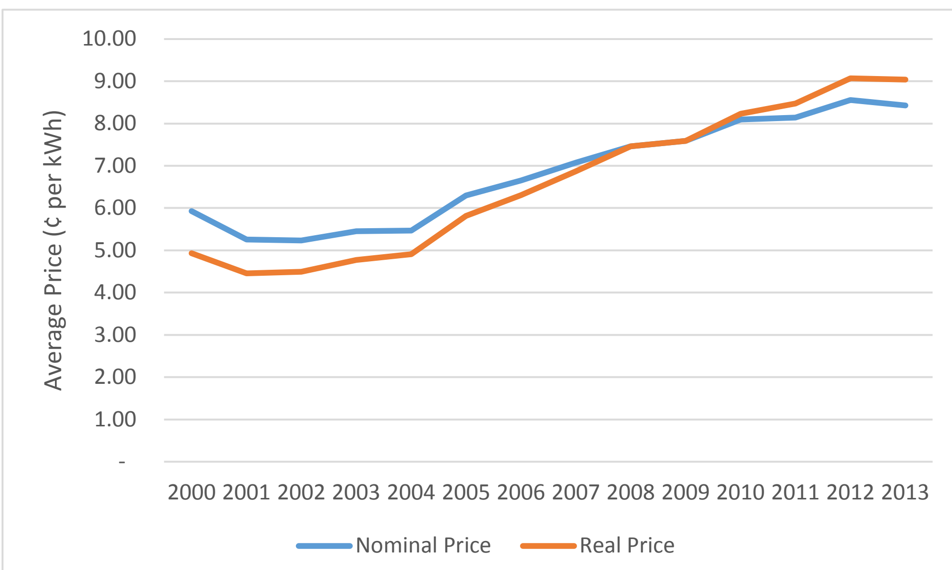


Figure 2.3 – Commercial and Industrial Price (EKPC Total)



3.1.3 Weather Data

Monthly heating degree days ("HDD") and cooling degree days ("CDD") were obtained from the National Oceanic and Atmospheric Association ("NOAA"). Seven weather stations are used to represent local climatological conditions for EKPC's members (see Table 2.2). Due to the fact that reported kWh sales are often based on billing cycle readings and weather data are perfect calendar months, models were tested using actual month weather data, one month lag of weather data, and an average of the current and prior month.

Table 2.2 – Weather Station Assignment

Weather Station	EKPC Member Cooperatives Assigned to Station
Lexington, KY	Blue Grass Energy Cooperative, Clark Energy Cooperative, Inter-County Energy Cooperative
Bowling Green, KY	Farmers RECC, Taylor County RECC
Covington, KY	Fleming-Mason Energy Cooperative, Owen Electric Cooperative
Huntington, WV	Grayson RECC
Jackson, KY	Big Sandy RECC, Cumberland Valley Electric, Jackson Energy Cooperative, Licking Valley RECC
Louisville, KY	Nolin RECC, Salt River Electric Cooperative, Shelby Energy Cooperative
Somerset, KY	South Kentucky RECC

For the EKCP aggregate analyses, weighted average HDD and CDD were computed using class sales assigned to each weather station in each month as the weighting factors.

3.1.4 Economic Data

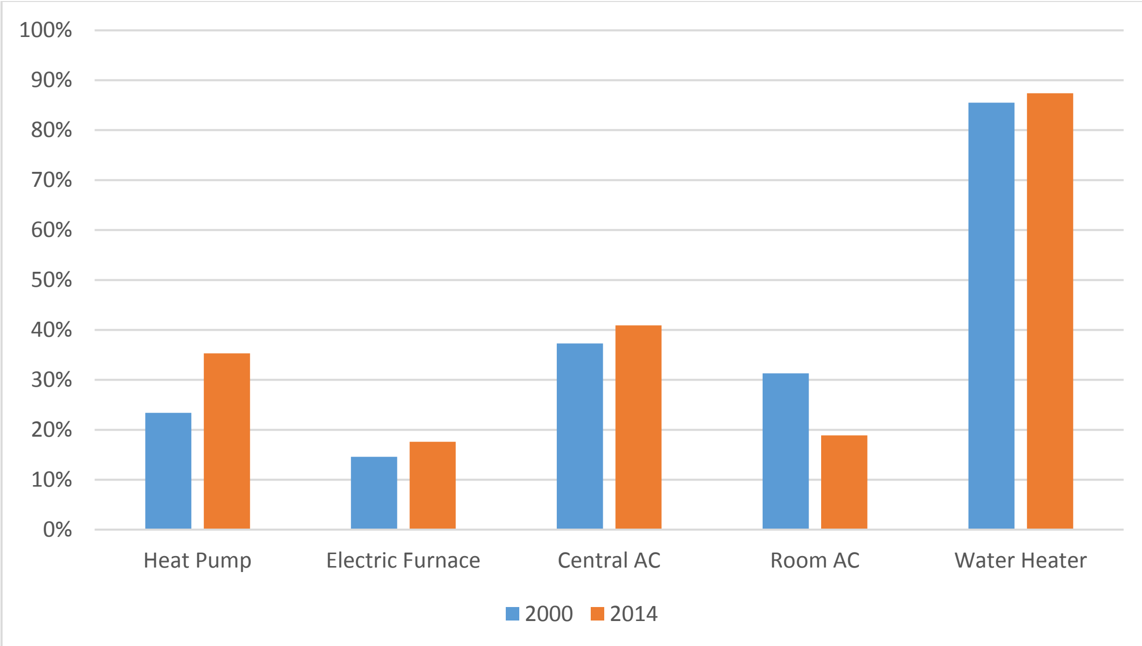
Economic time series data for each member cooperative's service territory was collected from IHS Global Insight[2]. Global Insight draws data from the US Census Bureau, the Bureau of Labor Statistics, and the Bureau of Economic Analysis to develop historical economic time series. For this study, population, real total personal income, and employment were included in the analysis database.

3.1.5 Residential End-Use Appliance Data

Residential electric appliance saturation data was provided to GDS by EKPC staff. The most recent survey was completed in 2013, and surveys have been conducted every two to three years since 1981. EKPC staff interpolated market share information for the intervening years. Appliance efficiency trends over time for major end-use appliances (HVAC equipment and water heaters) were obtained from the Energy Information Administration's ("EIA") Annual Energy Outlook. Appliance saturations are specific to the member service territories. Appliance efficiencies are assumed to be consistent for the entire EKPC territory.

[2] Economic Outlook, March 2014

Figure 2.4 – Residential Electric End-Use Saturations (EKPC Total)



3.2 Econometric Modeling

Several econometric model specifications were designed and tested to evaluate price elasticity of demand. Furthermore, models were developed for the entire EKPC territory in aggregate and for each individual member distribution cooperative. The following sections describe the model designs for the residential and commercial classes. Resultant elasticity estimates produced by these models are provided in Section 3.

3.2.1 Residential Models

Three separate model specifications were tested for the residential price elasticity estimate, one using monthly data and two using annual data. Equations 2.1 through 2.3 show the models tested for aggregate EKPC residential usage. Equations 2.1 and 2.2 were tested for individual member cooperatives.

Equation 2.1

$$AvgUse_{y,m} = \beta_0 + \beta_1 RealPrice_y + \beta_2 PCAPInc_{y,m} + \beta_3 wHDD_{y,m} + \beta_4 wCDD_{y,m} + \varepsilon_{y,m}$$

Equation 2.2

$$AvgUse_y = \beta_0 + \beta_1 RealPrice_y + \beta_2 PCAPInc_y + \beta_3 wHDD_y + \beta_4 wCDD_y + \varepsilon_y$$

Equation 2.3

$$Ln(AvgUse_{y)} = \beta_0 + \beta_1 Ln(RealPrice_y) + \beta_2 Ln(PCAPInc_y) + \beta_3 Ln(wHDD_y) + \beta_4 Ln(wCDD_y) + \varepsilon_y$$

Where:

β_0, β_1, β_2, β_3, and β_4	Regression coefficients
y	Index for the year
m	Index for the month
AvgUse	Residential average usage (kWh per customer)
RealPrice	Real price of electricity
PCAPInc	Per capita income
wHDD	Weighted heating degree days (see further explanation below)
wCDD	Weighted cooling degree days (see further explanation below)
Ln	Natural logarithm
ε	Error term

For some of the individual member models, per capita income had a negative coefficient or had a coefficient with a p-value well in excess of 0.20. A negative coefficient for per capita income is theoretically incorrect, indicating average household energy consumption declines as income increases. In such instances, per capita income was removed from the models.

GDS also tested for first order autocorrelation in the residuals using the Durbin-Watson statistic. In models in which autocorrelation was evident, a first order autoregressive parameter was included in the model to correct for the correlation. This correction helps produce unbiased and more efficient estimators of the coefficients relative to a model with correlated residuals and no autoregressive parameter.

3.2.1.1 Weighted HDD and CDD

For the residential models, HDD and CDD were weighted to take electric appliance market share and efficiency into account. In theory, average usage will be more sensitive to weather as weather-sensitive electric appliances are added to the home (HVAC and water heaters). Likewise, as those appliances become more efficient, average usage will become less sensitive to weather. Therefore, a weighting scheme is developed for the HDD and CDD that effectively multiplies the weather variables by market share (direct relationship) and divides by an index for the change in efficiency over time (indirect relationship). For example, the weights for HDD in January 2000 and January 2014 are shown in table 2.3.

Table 2.3 – Example Development of HDD weights

Line No.	Item	Formula	January 2000	January 2014
[1]	Heat Pump Saturation		0.234	0.351
[2]	Heat Pump Efficiency (HSPF)		6.830	7.550
[3]	Efficiency Index (Sep 2014=1.00)		0.896	0.991
[4]	Heat Pump Weight	[1]÷[3]	0.261	0.354
[5]	Electric Furnace Saturation		0.146	0.175
[6]	Furnace Efficiency		3.410	3.410
[7]	Efficiency Index (Sep 2014=1.00)		1.000	1.000
[8]	Heat Pump Weight	[5]÷[7]	0.146	0.175
[9]	Weight for HDD	[4]+[8]	0.407	0.529

3.2.2 Small Commercial Models – EKPC Aggregate

Three separate model specifications were tested for the aggregate EKPC small commercial price elasticity estimate, one using monthly data and two using annual data. Equations 2.4 through 2.6 show the models tested.

Equation 2.4

$$AvgUse_{y,m} = \beta_0 + \beta_1 RealPrice_y + \beta_2 Emp_{y,m} + \beta_3 HDD_{y,m} + \beta_4 CDD_{y,m} + \varepsilon_{y,m}$$

Equation 2.5

$$AvgUse_y = \beta_0 + \beta_1 RealPrice_y + \beta_2 Emp_y + \beta_3 HDD_y + \beta_4 CDD_y + \varepsilon_y$$

Equation 2.6

$$Ln(AvgUse_{y)} = \beta_0 + \beta_1 Ln(RealPrice_y) + \beta_2 Ln(Emp_y) + \beta_3 Ln(HDD_y) + \beta_4 Ln(CDD_y) + \varepsilon_y$$

Where:

β_0, β_1, β_2, β_3, and β_4	Regression coefficients
y	Index for the year
m	Index for the month
AvgUse	Residential average usage (kWh per customer)
RealPrice	Real price of electricity
Emp	Employment
HDD	Billing cycle heating degree days
CDD	Billing cycle cooling degree days
Ln	Natural logarithm
ε	Error term

3.2.3 Industrial Models – EKPC Aggregate

Three separate model specifications were tested for the industrial price elasticity estimate for aggregate EKPC industrial sales, one using monthly data and two using annual data. Equations 2.7 through 2.9 show the models tested.

Equation 2.7

$$AvgUse_{y,m} = \beta_0 + \beta_1 RealPrice_y + \beta_2 Emp_{y,m} + \sum_m \beta_{3,m} I_m + \varepsilon_{y,m}$$

Equation 2.8

$$AvgUse_y = \beta_0 + \beta_1 RealPrice_y + \beta_2 Emp_y + \varepsilon_y$$

Equation 2.9

$$Ln(AvgUse_{y)} = \beta_0 + \beta_1 Ln(RealPrice_y) + \beta_2 Ln(Emp_y) + \varepsilon_y$$

Where:

β_0, β_1, β_2, and $\beta_{3,m}$	Regression coefficients
y	Index for the year
m	Index for the month
AvgUse	Residential average usage (kWh per customer)
RealPrice	Real price of electricity
Emp	Employment
I_m	Indicator variable for month m
Ln	Natural logarithm
ε	Error term

3.2.4 Commercial and Industrial Models by Member Cooperative

Econometric models consistent with Equation 2.4 were run for the combined commercial and industrial classes by member cooperative. As will be discussed further in Section 3, however, it was difficult to produce models for some members that provided theoretically sound results for price elasticity.

4 Results and Conclusions

At the EKPC aggregate level, the multiple econometric specifications produced elasticity estimates that were statistically equivalent at 90% confidence. The residential models by member cooperative produced a wider array of results as might be expected, but all provided a theoretically correct negative price elasticity estimate. The same cannot be said for all C&I models at the member cooperative level.

4.1 Residential Elasticity

The measured overall price elasticity of demand is approximately -0.25, indicating that a 1% increase in real prices will result in a 0.25% decrease in residential average usage per household across the entire EKPC system. Individual member results vary from a low of -0.02 to a high of -0.73. The higher variability in elasticity estimates at the member level is more likely a function of the data than a true significant difference in price response across different territories. Data adjustments, alignment of billing cycles with weather, and other anomalies are more likely to impact results at the member-level, whereas aggregate data will help average out some of that noise in the data and provide a truer estimate of overall price sensitivity.

Table 3.1 – Aggregate EKCP Residential Price Elasticity Estimates

Model Specification	Estimated Price Elasticity
Monthly Model (Equation 2.1)	-0.271
Annual Model (Equation 2.2)	-0.247
Annual Log-Log Model (Equation 2.3)	-0.181

None of the elasticity estimates shown in Table 3.1 can be verified as statistically different from the others at 90% confidence. Three separate modeling approaches providing consistent results supports the conclusion that the estimated elasticity is reasonable.

Table 3.2 – Member Cooperative Residential Price Elasticity Estimates

Member	Monthly Model (Equation 2.1) Price Elasticity Estimate	Annual Model (Equation 2.2) Price Elasticity Estimate
Jackson Energy Cooperative	-0.730	-0.298
Salt River Electric Cooperative	-0.023	-0.131
Taylor County RECC	-0.069	-0.488
Inter-County Energy Coop.	-0.172	-0.124
Shelby Energy Cooperative	-0.049	-0.035
Farmers RECC	-0.260	-0.223
Owen Electric Cooperative	-0.239	-0.062
Clark Energy Cooperative	-0.190	-0.187
Nolin RECC	-0.156	-0.116
Fleming-Mason Energy Coop.	-0.201	-0.287
South Kentucky RECC	-0.232	-0.177
Licking Valley RECC	-0.105	-0.076
Cumberland Valley Electric	-0.333	-0.060
Big Sandy RECC	-0.163	-0.194
Grayson RECC	-0.517	-0.240
Blue Grass Energy Cooperative	-0.128	-0.121
Weighted Average*	***-0.233***	***-0.168***

* Weights based on 2013 residential energy sales.

Given that: a) noise in billing data has more impact at the member level, and b) for some member models, per capita income did not have significance in the model, GDS recommends that EKPC use a consistent price elasticity estimate based on the aggregated model results provided in Table 3.1. **It is concluded that an elasticity in the range of -0.20 and -0.30 would be a reasonable assumption based on the results of this analysis**.

4.2 Commercial and Industrial Elasticity

Commercial and industrial price elasticity estimates are lower than residential. The small commercial class has an elasticity of approximately -0.10 and the industrial class is about -0.05. Smaller commercial accounts might be quite price inelastic due to several factors, including having little control over electricity consumption (for instance a convenience store with many freezers and refrigerator cases), being a tenant that does not pay the electric bill, or having electricity generally be a small proportion of the budget. Furthermore, large commercial and industrial accounts are unlikely to alter operations in response to small changes in price, but there is certainly a point where, if price goes too high or margins are too low for a company, they might stop operation altogether or shut down a shift, causing a large response to price at some certain threshold. It is reasonable to assume that, as a class, commercial customers are less sensitive to long-term price changes than are residential customers.

Table 3.3 – Aggregate EKPC Commercial and Industrial Price Elasticity Estimates

Model Specification	Small Commercial Price Elasticity	Industrial Price Elasticity
Monthly Model (Equations 2.4 and 2.7)	-0.149	-0.102
Annual Model (Equation 2.5 and 2.8)	-0.117	-0.034
Annual Log-Log Model (Equation 2.6 and 2.9)	-0.097	-0.030

At the member distribution cooperative level, several of the models were unable to measure a statistically significant (indicating a likelihood of a zero elasticity) or theoretically correct (negative coefficient) price elasticity. Due to some members having very few industrial accounts, the member-level analysis was conducted for the commercial and industrial customers in aggregate. As with the residential elasticity, GDS would recommend use of a system-wide elasticity estimate for EKPC's load forecasting. An elasticity assumption in the range of -0.05 to -0.15 is for all commercial and industrial customers based on this analysis.

Table 3.4 – Member Cooperative C&I Price Elasticity Estimates

Member	Monthly Model (Equation 2.4) Price Elasticity Estimate
Jackson Energy Cooperative	-0.177
Salt River Electric Cooperative	-0.045
Taylor County RECC	-0.090
Inter-County Energy Coop.	-0.396
Shelby Energy Cooperative	n/a[1]
Farmers RECC	-0.221
Owen Electric Cooperative	-0.285
Clark Energy Cooperative	-0.131
Nolin RECC	-0.473
Fleming-Mason Energy Coop.	-0.067
South Kentucky RECC	n/a[1]
Licking Valley RECC	-0.023
Cumberland Valley Electric	n/a[1]
Big Sandy RECC	-0.175
Grayson RECC	-0.384
Blue Grass Energy Cooperative	-0.094

4.3 Secondary Research

Secondary research included a review of publically available information related to current price elasticity estimates being made by others in the industry. **Results of the review are provided below and confirm that the elasticity estimates derived for EKPC are consistent with industry estimates**.

Many utilities filing Integrated Resource Plans ("IRP") with regulatory commissions throughout the country make reference to using price of electricity in their forecasting models. However, many either do not indicate the assumed or resultant price elasticities, or they protect the information under confidentiality arrangements. GDS identified three utilities that included elasticity information publicly in their IRP reports. Delmarva Power and Light reported a residential elasticity of -0.13 in its 2014 IRP. They assumed a price elasticity of demand of -0.04 for commercial and -0.14 for industrial. Ameren Missouri's 2014 IRP states that the residential price elasticity they use is -0.14. They also reference a study conducted a few years prior to the 2014 IRP in which they estimated a residential elasticity of -0.16. Big Rivers Electric Corporation[3] reported a price elasticity of -0.18 for all rural customers combined in their 2014 IRP. KU/LGE reports in its March 2014 IRP that they used elasticity estimates of -0.1 for residential and -0.05 for commercial. These estimates are all reasonably consistent with the results obtained for EKPC.

The National Renewal Energy Laboratory ("NREL") completed an analysis of price elasticity in February 2006.[4] They found national residential elasticity of -0.24 and an elasticity of -0.27 for the East South Central region (of which Kentucky is a part). The estimated nationwide commercial price elasticity was -0.21 and the East South Central estimate was -0.27. Although the commercial elasticity estimates for NREL are higher than the EKPC estimates, they are close enough for practical purposes[5]. NREL also conducted analysis at the state level and determined that the price elasticity coefficient for the Kentucky model was not significantly different than zero for both the residential and commercial classifications.

Finally, GDS examined an analysis conducted by the EIA[6]. The study examined, in part, the impacts on energy consumption of potential policies that would limit energy-related carbon dioxide emissions. More specifically, the impacts of a future fee on CO_2 emissions were analyzed for three carbon-fee cases, \$10, \$20, and \$30 per metric ton of CO_2 in 2020 and rising by 5 percent per year annually thereafter. The EIA study was conducted at the national level and for each Census region. EIA reports that the electricity sector alters investment and operating decisions to reduce CO_2 emissions in response to CO_2 fees, and customers react to resulting higher retail electricity prices by cutting demand. An analysis of the changes in electricity prices and energy consumption for the three carbon-fee cases relative to the EIA reference case was performed, and the elasticity of demand (energy consumption) with respect to price for the residential and commercial sectors combined was -0.21 for the East South Central region.

4.4 Conclusions

Based on the analysis conducted, various model specifications produce stable elasticity estimates for the residential and commercial customer classes. Results at the aggregate EKPC level produce reliable estimates of long-term price elasticity of demand for electricity consumption. The range of values estimated from models at the member cooperative level are somewhat volatile but within a reasonable range of the aggregate estimates. GDS recommends use of the aggregate model results for purposes of analyzing load response to price anywhere in the EKPC territory. Furthermore, the estimates derived in

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[3] GDS prepared Big Rivers' 2014 IRP, including performing the price elasticity analysis. The elasticity assumption was reported in the public version of the IRP.

[4] Bernstein, M.A. and J. Griffin. "Regional Differences in the Price-Elasticity of Demand for Energy." NREL, Subcontractor Report NREL/SR-620-39512. February 2006.

[5] Although the elasticity estimate of -0.1 for EKPC is half as much as the elasticity estimate of -0.2 for NREL's regional model, the estimated load reduction per 1% increase in price is only 0.1% different between the two assumptions.

[6] Energy Information Administration, *Further Sensitivity Analysis of Hypothetical Policies to Limit Energy-Related Carbon Dioxide Emission*, Supplement to the Annual Energy Outlook 2013, July 2013.
http://www.eia.gov/forecasts/aeo/supplement/co2/pdf/aeo2013_supplement.pdf

this analysis are consistent with the price elasticity assumptions used by the US Energy Information Administration for its Annual Energy Outlook forecasting, providing greater confidence in the results obtained herein.

- GDS recommends using a **RESIDENTIAL** price elasticity in the range of **-0.20 TO -0.30** as a reasonable assumption for load forecasting residential price sensitivities.
- GDS recommends using a **COMMERCIAL** price elasticity in the range of **-0.05 TO -0.15** as a reasonable assumption for load forecasting commercial price sensitivities.