Q. **Reference Avalon Capacity Study:**

Please provide any estimates of customer costs arising from power outages by customer class, outage duration, and/or other categorizations that may be available derived from customer surveys, other utilities' published values, or internal or external analysis.

A. Newfoundland and Labrador Hydro ("Hydro") tracks damage claim statistics for customer property damaged by the utility's operations, summarizes the results by root cause and time of the year, and provides the information to the Board of Commissioners of Public Utilities in Section 4 of Hydro's Quarterly Regulatory Report. Hydro has not engaged in capturing statistics on customer production losses due to power interruptions; however, Christensen Associates Energy Consulting has conducted some research on the cost of outages documented in other jurisdictions. The research report is provided as NLH-PUB-074, Attachment 1.

CHRISTENSEN ASSOCIATES ENERGY CONSULTING

BRIEF

THE COST OF POWER OUTAGES TO ELECTRICITY CONSUMERS

prepared by

Nicholas Crowley and Robert Camfield

Christensen Associates Energy Consulting, LLC

Madison, Wisconsin

January 18, 2019

Table of Contents

BRIEF

THE COST OF POWER OUTAGES TO ELECTRICITY CONSUMERS

prepared by

Nicholas Crowley and Robert Camfield

Laurits R. Christensen Associates, LLC

January 18, 2019

INTRODUCTION

This discussion is focused on the service reliability to electricity consumers, generally referred to as *outage costs*. Outage costs—sometimes called *value of lost load* (VOLL)—is the cost incurred by customers as a consequence of an unexpected interruption in power supply.[1] This discussion reviews the conceptual foundation for outage costs and provides a brief survey of historical and contemporary outage cost studies.

OUTAGE COSTS, RESOURCE PLANNING, EFFICIENT PRICING

Across North America, electricity consumers have become accustomed to comparatively high levels of supply reliability. Residential customers rely on electricity for lighting, space conditioning, appliances, access to information, and entertainment. For commercial and industrial customers, blackouts cause commerce and the production of goods and services to grind to a halt. At medical facilities, reliable electricity can be a matter of service continuity provided by life support systems. Indeed, power systems are vital to regional economies. To maintain acceptable levels of reliability within power systems, utilities may make costly investments that provide shared improvements in reliability for electricity consumers.

The worth of reliability to consumers—outage costs—factor into the underlying analysis of resource planning decisions, system operations, and the efficient pricing of electricity services. Outage cost estimates are fundamental to both: resource plans and operations focus on electricity supply, while efficient pricing focuses on electricity demand. In fact, the processes of planning, operations, and pricing are integrated. Expectations of demand response are accounted for in resource plans, and efficient prices are based on near-term resource costs, with *both sides* incorporating measures of reliability costs set in accordance with outage cost estimates.

Discrete selection—and effective operation—of power system facilities can significantly mitigate reliability concerns. Section of facilities is the task of resource planning: identifying facility additions that

[1] Service reliability is the worth of the flow continuity of power supply—that consumers can get electricity when they want it. Described as outage costs, service reliability can be viewed as the value given up, or foregone, by consumers as result of unexpected power outages.

provide reliability benefits which more than offset facility costs. This benefit-cost framework serves as the basis for resource selection, both technology choice and timeframe, and is well understood. While determination of incremental resource costs is fairly straightforward, the worth of improved reliability to consumers arising from incremental facility changes proves to be difficult to measure—precisely because it is generally not directly observable.

Efficient pricing sets marginal prices according to the expected value of reliability, for the period over which prices are effective.[2] Thus, effective marginal cost-based prices for the winter season is set according to estimates of winter-season reliability costs, with prices differentiated according to time of day. Similarly, efficient prices for the day-ahead include estimates of hourly reliability costs for the next day, where hourly reliability costs vary from one day to the next—in short, dynamic pricing.[3]

This all boils down to the core issue: the worth to consumers of power supply not served. Essentially, what is the value foregone by consumers as a consequence to unexpected power outages? Outage costs serve as a basis of resource planning and effective electricity pricing and is the subject of the immediate discussion.[4]

OUTAGE COST METHDOLOGY

The value of electricity foregone by consumers as a consequence of power interruptions has no clearly discernable market value.[5] However, the value and worth of reliability to consumers can be estimated, and several methods of inference are available. Researchers Thomas Schroder and Wilhelm Kuckshinrichs at the Institute of Energy and Climate Research classify two overarching categories of measurement, “direct” and “indirect”, each with its own advantages and disadvantages. Within the realm of direct and indirect methods, a variety of technical approaches have been used to estimate consumer outage costs, broadly cast into two categories including *proxy methods*, and *survey methods* of two types: *stated preference* and *revealed preference*. Each methodology is discussed below.

PROXY METHODS are based on observed and estimated data that reflect regional economies. Proxy methods are a form of indirect measurement. Indirect measurement relies on statistical data and

[2] Note that marginal cost-based prices incorporate both energy and reliability cost elements, where reliability costs may be set according to the likelihood of power outage and outage cost estimates, or surrogate proxies based on capacity costs.

[3] Supply-side costs may be used as proxies for customer outage costs providing that supply-side costs provide a reasonable approximation of consumer outage costs.

[4] Outage Costs and Value of Lost Load are alternatively referred to as *Shortage Costs, Damage Costs, Value of Customer Reliability*, *Cost of Unserved Energy*, and *Cost of Power Interruption*.

[5] That is to say, outage experience and costs are not tradable goods, *per se*, where prices are directly observable. However, a secondary market of curtailable services seems conceptually possible: Markets where participants in curtailable service options could trade, through electronically organized markets, the provision of power interruptions made available to electric utilities (interruptible tariff options) and independent service providers (contracts for compensating damages).

macroeconomic simulation to obtain outage valuation estimates. The primary indirect means of evaluating lost load is via macroeconomic analysis. This approach estimates VOLL by estimating the value of loss of production (for non-residential customers) and/or the value loss of leisure time (for residential customers). The basic theory underlying indirect methods of measurement suggests that forgone production or residential leisure time is associated with a monetary value that can be measured using aggregated data published by statistical bureaus for geographic regions.

These regional data can include, for example, estimates of the economic output of goods and services, wages and salaries, and the level of employment. Within the industrial sector, the costs of alternative power supply such as backup generation facilities can be used to infer outage costs. Estimates of outage within the residential sector can be inferred by determining, for the services provided by electricity-using household appliance and equipment, the market prices and costs of the service provided,[6] if such services were obtained outside the home. The intensity of electricity consumption is differentiated within class categories, and it is thus important to gather and map the economic characteristics of the relevant region. Once the region is identified, outage cost estimates are measured as the ratio of electricity costs to the defined output metric. As an example, outage costs ($/MWh) are equal to, for the summer period (3rd quarter), the electricity consumption of the region over the summer months divided by gross state product measure of output for the quarter. In the case of wage and salaries, the estimated outage costs reflect, arguably, the marginal value of leisure time, as neoclassical economic theory suggests that households and consumers will be employed (hours per week) up to the point where the incremental net wage rate approximates the marginal value of foregone leisure time, stated on an hourly basis.

Publicly available data makes proxy methods such as this inexpensive and relatively easy to implement. However, researchers must rely on potentially oversimplified assumptions about the relationship between electricity and production (or leisure time). In addition, macroeconomic data and models are typically operationalized in terms of commercial transactions (wages, hours worked, sales revenues) rather than economic value, captured as economic value, measured as consumer surplus. Proxy methods have substantial limitations beyond this, as noted in the formal literature:

> *The major disadvantages of proxies…is that they do not differentiate outage costs by outage characteristics or provide information on the distribution of outage costs…they at best reflect average outage cost conditions for the average customer. The influence of duration, frequency, timing, particle outages and warming time is unknown.*[7]

For this reason, proxy methods are appropriate to the degree that more substantive methods, discussed below, are not available.

---

[6] As an example, the outage costs attending the electricity consumption associated with home use clothes washer and dryer would be set according to the all-in costs of using a laundry mat, where such costs include transportation costs and transport time.

[7] Reference *Customer Demand For Service Reliability In the Electric Power Industry: A Synthesis of the Outage Cost Literature*, by Douglas Caves, Joseph Herriges, and Robert Windle, bulletin of Economic Research 42:2, 1990.

SURVEY METHODS include two general approaches: *Stated Preference* and *Revealed Preference* methods. The application of stated preference methods involves survey instruments to gather data regarding the preferences of electricity consumers regarding service reliability. The surveys are in the form of a questionnaire where survey participants provide written or electronic responses to highly structured questions.

The survey questions can assume one of two types of inquiry, *Ex Post* and *Ex Ante*. Ex post surveys are conducted following power outage events, while ex ante surveys are conducted prior outage events, though the responses are conditioned by the historical experience of survey participants with respect to outage events. In the case of ex post surveys, the inquiry focuses on how customers responded to outage events, and what power outages cost them. For example, an ex post residential survey questionnaire might inquire about how consumers altered day-to-day activities regarding the use of appliances, or the adjustment to thermostat settings as a consequence to, say, a 4-hour power outage during the depths of winter. Ex post power outage surveys of industrial customers may inquire about production and revenue impacts, or how lost production may have been rescheduled to evening or weekend timeframes and involve overtime pay.[8] In the case of the commercial (or industrial) sectors, power outage events may cause customers to install costly backup power supply facilities.[9]

Ex ante survey methods explore consumer expectations of outages. These ex ante surveys, referred to as *Contingent Valuation* instruments, explore the worth of service reliability through a set of *what-if* questions, presented as scenarios. The questions can assume a *Willingness to Pay* or *Willingness to Accept* structure. In the case of Willingness to Pay (WTP) structure, survey participants are asked how much they would be willing to pay to avoid power outage events, presented as scenarios. Outage scenarios are typically specified in terms of duration, frequency, time of day, season, and notice. Participants are asked to *value* a set of scenarios, perhaps as many as sixteen different scenarios. As an example, an outage scenario might be specified as four hours duration, two events during early evenings of the cold winter season, with one-hour notice. Another scenario might be specified as four outage events of one-hour duration during the mid-afternoon period of summer weekend days. Willingness to Accept (WTA) surveys are the other side of the coin: electricity consumers are asked how much they are *willingness-to-accept* compensation for reductions in reliability where, as with WTP, reductions in reliability are specified as sets of scenarios.

[8] Some might quibble with characterizing this commercial and industrial approach as a stated preference method. This argument is based on the fact that businesses give a self-report on what they would actually experience during an outage. Thus, the method might be better classified as self-report of revealed preference data. Since data collected does not reflect observations of actual behavior, we prefer to classify it as a stated preference method.

[9] Note that the annual costs of backup power supply, including carrying charges on capital and operating expenses, can serve as the basis to estimate outage costs. That is, the expectation of electricity unserved induces customers to install backup facilities, where customers are willing to investment in such facilities in order to mitigate or avoid power outages.

Revealed preference methods use observations of actual behavior to make inferences about the value of the outage. For example, by observing purchase of back-up equipment one might be able to make inferences about the value of outages. Likewise, if consumers of electricity were allowed to select a preferred combination of price and expected outages from their electricity supplier—a menu of service options—observations of service choices would allow inferences about the value of service, and hence outages. Observation of how power users choose among interruptible and/or curtailable rates could form the basis for inferences about outage costs. However, interruptible service is offered only to small numbers of customers and, frequently, interruptible service applies only to a portion of the customer's electric service. Finally, inferences about the value of power can be obtained through the analysis of customer load responses to dynamic pricing including hourly real-time pricing. Again, the analogy is not perfect in that, when faced with changes in hourly real time prices, consumers have the flexibility to adjust their use of electricity to the optimal level given the price signal whereas, in contrast, power outages reduce the level of consumption to zero.

Economists may often attach a higher level of perceived validity to inferences based on revealed preference data. The reason is that preferences guide behaviors. Therefore, observations of behavior provide inferences on underlying preferences. Stated preference data, on the other hand, is thought to be potentially subject to a number of biases. For example, if respondents to a stated preference survey believe that their responses will affect the quality, quantity, or price of the good being studied, this may induce the respondents to systematically misstate their preferences. The general concern is that since real money is not "on the line" in stated preference surveys, respondents will tend to overstate their preferences. Thus, it is often expected that values inferred from stated behavior data are likely to exceed values inferred from revealed preference methods. Furthermore, because of concerns about the adequacy of proxy measures and the difficulty of obtaining revealed preference data, studies of outage costs often employ stated preference methods.

While the reliance on stated preference methods raises the question of possible bias, the empirical evidence across many studies suggests that, on average, the magnitude of this bias may not be large. Moreover, empirical studies do not necessarily demonstrate that bias and cost overstatement attend stated preference studies. Studies comparing revealed reference and stated preference values found that on average stated preference values were slightly lower than revealed preference values (Carson et al. 1989). Furthermore, some studies of the reliability of stated preference values suggest that much of the potential overstatement of values is associated with respondents who appear to be less certain of their responses to the stated preference question. For a variety of reasons, when asked if they would be willing to pay a certain amount for a good, those who have a high degree of uncertainty tend to say they would pay the amount. Thus, by adjusting for levels of uncertainty, stated preference values can be brought into line with revealed preference values. These results suggest that well designed stated preference studies will produce results consistent with results derived from revealed preference studies.

This consideration is important in the context of outage cost studies. Because North American power systems generally exhibit high degrees of reliability, the market experience for developing revealed preference studies is limited. For example, some revealed preference studies make inferences about the value of reliability using observations on investments in back-up services. Yet, if service is highly reliable, consumers of electricity may have little incentive to invest in back-up services, in view of limited outage experience.

In summary, each of the several methodologies for ascertaining outage cost estimates faces unique advantages and drawbacks. Hydro is advised to drawn upon multiple studies to guide its deliberation of the service value harbored by the end-use customers that it serves. Alternative, Hydro may wish to consider commissioning an in-depth study of the preferences of its customers. The study should employ survey methods and use stated preferences, where survey responses are assessed using econometric analysis.

REVIEW OF HISTORICAL STUDIES

This section presents historical studies of outage costs in order to contextualize the contemporary studies presented in the following section. In particular, the values presented herein focus on the surveys of studies reported by Woo and Pupp (1992), by Doug Caves et al. (1989), and Michael Doane et al. (1993). The tables below contain data from these surveys, adjusted to 2018 dollars *Personal Consumption Expenditures* price index (PCE), published by the Bureau of Economic Analysis.

The first set of tables summarize the findings of Woo and Pupp (1992), of City Polytechnic of Hong Kong and Analysis Group, Inc., respectively. Woo and Pupp assembled outage cost estimates from eight studies of residential outage costs, six studies of industrial outage costs, and three studies of commercial outage costs. These estimates were then transformed to represent outage cost per interruption, outage cost per hour of interruption and outage cost per kWh of unserved energy.

Table 1 summarizes the findings of a Canadian study by Wacker, Wojczynaki, and Billinton (1983) on a winter evening, as reported in Woo and Pupp (1992).

Table 1: Residential Outage Cost Estimates obtained by Wacker, Wojczynaki, and Billinton, as Reported in Woo and Pupp (2018 USD)

	Frequency	Duration	Notice	$/Interruption	$/Hr Unserved
Direct Costs					
	Monthly	1	0	2.78	2.78
	Monthly	4	0	27.96	6.99
	Weekly	4	0	43.25	10.81
Willingness to Pay					
	Monthly	4	0	12.47	3.12
	Weekly	4	0	18.98	4.74
	Daily	1	0	19.00	19.00
	Monthly	4	0	25.92	6.47

Table 2 summarizes the findings of a study conducted by Fisher (1986) in Massachusetts, also reported by Woo and Pupp (1992). The table contains lost load valuations by industrial customers on a summer afternoon.

(reference the following page)

Table 2: Industrial Outage Costs obtained by Fisher (1986), as Reported in Woo and Pupp (2018 USD)

Industry	Duration	Notice	$/Interruption	$/Hr Unserved	$/kWh Unserved
Machinery	0.5	0	10,989	21,975	45.47
	1	0	21,661	21,661	43.28
	2	0	29,298	14,647	30.74
	4	0	39,026	9,757	35.84
Electronic & Electrical Machinery	0.5	0	1,232	2,465	22.61
	1	0	2,617	2,617	17.36
	2	0	5,073	2,535	16.26
	4	0	916	2,290	15.86
Measuring Analysis & Control Instruments	0.5	0	9,666	19,329	50.73
	1	0	18,041	18,041	36.37
	2	0	51,303	25,651	48.65
	4	0	71,303	17,824	34.19
Other Manufacturing	0.5	0	17,277	34,557	36.93
	1	0	25,451	25,451	30.04
	2	0	42,989	21,475	28.93
	4	0	71,303	17,824	25.64

Table 3 displays data from the same study, summarizing the findings from commercial customers on a summer afternoon, broken down by subsector.

Table 3: Commercial Outage Costs as Reported in Woo and Pupp (2018 USD)

Industry	Duration	Notice	$/Interruption	$/Hr Unserved	$/kWh Unserved
Wholesale	0.5	0	4,020	8,042	13.23
	1	0	11,824	11,820	27.01
	2	0	23,941	11,973	31.03
	4	0	48,566	12,142	37.21
Retail	0.5	0	558	1,114	29.22
	1	0	1,479	1,479	31.98
	2	0	2,315	1,157	24.95
	4	0	4,606	1,153	19.47
Finance, Insurance, & Real Estate	0.5	0	12,462	24,927	50.73
	1	0	17,700	17,700	30.30
	2	0	29,501	14,752	32.24
	4	0	52,944	13,236	38.32
Services	0.5	0	17,277	34,557	16.54
	1	0	25,451	25,451	16.54
	2	0	42,951	21,475	17.51
	4	0	71,303	17,824	16.83

In a review of outage costs for EPRI, Caves et al. (1989) provide estimates of outage costs on a per kWh unserved basis for the residential, industrial and commercial sectors (Tables 4 – 5). In this review Caves et al. find that the commercial sector tends to have the highest outage costs on a per kWh unserved basis, followed by industrial customers. Residential customers and government and institutional organizations tend to have the lowest outage costs. Caves et al. also explored the impact of duration on outage costs. While they find that outage costs tend to increase with duration, the outage cost per hour of outage tends to decrease.

Table 4: Commercial Outage Costs as Reported in Caves, Herriges, Windle (2018 USD)

Study	Method	Subsector	Dollars/Unserved kWh
Billinton et al. (1982)	Direct Cost	Retail	38.85 - 41.85
Billinton et al. (1982)	Direct Cost	Retail food	23.51 - 40
Billinton et al. (1982)	Direct Cost	Retail trade	28.57 - 71.18
Billinton et al. (1982)	Direct Cost	Retail service	10.31 - 24.78
Ontario Hydro (1981)	Direct Cost	Retail	22.8 - 37.32
Ontario Hydro (1981)	Direct Cost	Office Buildings	44.62 - 110.07
Ontario Hydro (1981)	Direct Cost	Government	3.16 - 5.58
Ontario Hydro (1981)	Direct Cost	Large Farms	858.41 - 1964.48

Table 5: Industrial Outage Costs as Reported in Caves Herriges, Windle (2018 USD)

Study	Method	Timing	Dollars/Unserved kWh
Billinton et al. (1982)	Direct Cost	Winter 10a.m.	15.93 - 37.43
Billinton et al. (1982)	Direct Cost	Winter 10a.m.	9.91 - 35.96
Ontario Hydro (1980)	Direct Cost	n/a	19.64 - 46.12
Ontario Hydro (1980)	Direct Cost	n/a	12.36 - 44.81

The data from a study by Michael J. Doane (**Table 6**) comes from a survey of 2,200 residential customers from the Pacific Gas and Electric Company service area, in California. The survey described ten outage scenarios and asked customers to evaluate the direct economic cost of each outage based on their willingness to each scenario. Specifically, respondents were asked to identify the actions they normally take to mitigate the effect of an outage (eg, using candles, eating out) and to use these actions to help guide their assessment of the outage cost.

Table 6: Industrial Outage Costs by Subsector as Reported in Doane (2018 USD)

Scenario	Duration (hours)	Mean
Winter Evening	1	20.46
Winter Evening	4	37.90
Winter Morning	4	22.99
Winter Morning	12	77.18
Summer Afternoon	1	6.97
Summer Afternoon	4	25.87
Summer Afternoon	12	72.50
Momentary Outage	-	3.16
Summer Afternoon (w/ advanced notice)	1	5.31
Summer Afternoon (voluntary)	5	4.82

REVIEW OF CONTEMPORARY STUDIES

The value of lost load findings presented in this section reflect findings from the past decade. In general, the studies show that despite technological changes in the global economy, the value of lost load has remained relatively constant over several decades.

In 2009, the United States Department of Energy commissioned a report from the Ernest Orlando Lawrence Berkeley National Laboratory on the value of reliability for utility customers in the United States. The study aggregates 28 largely confidential studies that use a direct cost approach, in which surveyed customers report the economic losses they would incur as a result of electric interruptions. The table below summarizes their findings on a dollar per kilowatt-hour basis for residential customers, and on a megawatt-hour basis for non-residential customers.

Table 7: Outage Costs as Reported by the United States Department of Energy (2018 USD)

	Duration			
	30 minutes	1 hour	4 hours	8 hours
Medium and Large C&I	$35.93	$23.28	$16.92	$13.42
Small C&I	$99.64	$66.81	$55.04	$48.68
Residential	$1.51	$0.90	$0.44	$0.30

The study cites a number of limitations that likely effect the results they report:

> *[C]ertain very important variables in the data are confounded among the studies we examined. In particular, region of the country and year of the study are correlated in such a way that it is impossible to separate the effects of these two variables on customer interruption costs. Thus, for example, it is unclear whether the higher interruption cost values for the southwest are purely the result of the hot summer climate in that region or whether those costs are higher in part because of the particular economic and market conditions that prevailed during the year when the study for that region was done. There is also some correlation between regions and scenario characteristics.*

Perhaps the most critical shortcoming of this evaluation is that they were unable to acquire data from the Northeast/Mid-Atlantic region. This makes the findings of the report potentially less relevant to NLH than it might otherwise, as regional and climatic conditions in, say, the American Southwest may give rise to different commercial, industrial, and residential demands.

A 2013 Energy Reliability Council of Texas (ERCOT) study by the London Economics International, LLC shares this regional problem. However, their use of a macroeconomic approach provides a valuable methodological contrast to the DOE study. The findings presented here suggest that the macroeconomic approach may bias the VOLL downward, as the calculated values are much smaller than values obtained from other conventional methodologies. The report focuses on non-residential customers using two different methods. Method One, based on GDP statistics for Metropolitan Statistical Areas (MSAs), scales down Texas GDP data to the ERCOT region using a ratio of GDP as follows. Method two scales GDP using county-level personal income (PI).[10]

Table 8: VOLL Calculated for ERCOT, using a Macroeconomic Approach (2018 USD)

	Method 1 (MSA Ratio)	Method 2 (PI Ratio)
ERCOT Commercial GDP (current million USD)	$908,733	$793,121
ERCOT Commercial Load (MWh)	111,647	111,647
ERCOT Commercial Estimated VOLL ($/kWh)	$8.14	$7.10
ERCTO Industrial GDP (current million USD)	$384,385	$335,482
ERCOT Industrial Load (MWh)	76,052	76,052
ERCOT Industrial Estimated VOLL ($/kWh)	$5.05	$4.41

Each method divides GDP by load to arrive at a value of lost load on a dollar per megawatt hour basis. The results suggest a range of $4.03/kWh to $4.62/kWh for industrial customers, and $6.49/kWh to $7.44/kWh for commercial customers in the ERCOT region.

A 2010 report for the Midcontinent Independent System Operator (MISO) draws upon publicly available data and previously published reports estimating outage costs in the American Midwest. This report relies on direct cost estimates from surveys submitted by commercial and industrial customers. Notice the significant contrast from the direct cost findings here in comparison to the macroeconomic findings of the ERCOT study above.

Table 9: VOLL Calculated for MISO, using Direct Cost Estimates (2018 USD)

Category	Subsector	$/kW	$/Event
Large Commercial and Industrial	Agriculture	31.81	10,663.70
	Mining	99.33	33,651.22
	Construction	31.81	10,663.70
	Manufacturing	53.92	18,140.76
	Transportation	31.81	10,663.70
	Wholesale/Retail	31.81	10,663.70
	Finance/Real Estate	31.81	10,663.70
	Services	19.93	6,717.15
	Public Administration	31.81	10,663.70
Small Commercial and Industrial	Agriculture	63.43	1,315.13
	Mining	63.43	1,315.13
	Construction	51.32	1,064.24
	Manufacturing	45.88	952.94
	Transportation	37.54	779.34
	Wholesale/Retail	63.43	1,315.13
	Finance/Real Estate	45.66	948.27
	Services	19.54	405.85
	Public Administration	42.73	887.10

[10] Method 1: $GDP_{ERCOT} = GDP_{Texas} * (\sum MSA\text{-} GDP_{ERCOT}/\sum MSA\text{-} GDP_{Texas})$;
Method 2: $GDP_{ERCOT} = GDP_{Texas} * (\sum County\text{-} PI_{ERCOT}/\sum County\text{-} PI_{Texas})$

A more recent study prepared by Cambridge Economic Policy Associates (2018) uses two methods: (1) the macroeconomic technique of developing a production function to estimate an indirect VOLL and (2) a willingness-to-pay survey of 892 residential and non-residential consumers throughout Europe. The study segments non-residential customers into a number of categories, with VOLL estimates for each category ranging from €0 to €130 ($147). The industry sector with the highest valuation of reliability is found to be Construction, with a median VOLL of €17.76 ($20.30), while many other industries have a VOLL of less than €1. The study groups together residential customers by region in order to capture the large different weather patterns found across the various corners of Europe. Northern Europe which has a median value of lost load for residential customers of €5.41 ($6.15).

CONCLUDING COMMENTS

The several studies discussed in this brief report employ different methods and draw on the electricity market experience of different regions and timeframes. The studies referenced above suggest that outage cost estimates vary according to sector, timeframe, notice, and historical outage experience. A few general observations are as follows:

- Industrial and commercial sectors appear to have higher outage costs than residential consumers;
- Immediate, unanticipated interruptions are more costly than anticipated power outages; outage costs decline with longer notice time, though not monotonically;
- Outage costs tend to decline as the duration of outages increases;
- Outage costs rise as regional incomes increase, other factors held constant;
- Higher outage frequency tends to reduce outage costs because of behavioral adaptation;
- Arguably, outage cost estimates across sectors should be weighted according to sector composition, region of service territory, and the timeframe where outage events are most likely—for Hydro, winter peak loads.

Across the various studies, residential VOLL appears to assume comparative modest levels, with commercial and industrial outage cost estimates somewhat higher. Study results for residential consumers vary from less than one dollar to values approaching ten dollars, stated on a $/kWh basis. Residential consumers do not produce economic output (goods, services) per se; instead, derive value and worth from leisure time, carried out as household services, unlike the direct production of goods and services by the private and public sectors of regional economies. Commercial and industrial customers require electricity for business purposes and may have significant set up time associated with the restoration of power supply, which translates to a higher VOLL.

REFERENCES

Allan, Ron and Roy Billinton, 1993. "Power System Reliability and Its Assessment, Part 3 Distribution Systems and Economic Considerations", *Power Engineering Journal,* pp. 185-192.

Ashraf, J. and Farhan Sabih 1993. "Estimates of Outage Costs of Electricity in Pakistan,"*Journal of Energy and Development"*, 2(18), pp. 283-91.

Caves, Douglas W., J. A. Herriges, and R. J. Windle, 1990, "Customer Demand for Service Reliability in the Electric Power Industry: A Synthesis of the Outage Costs Literature", *Bulletin of Economic Research*, Vol. 42 No 2, pp 89-119;

Caves, Douglas W., J. A. Herriges, and R. J. Windle, 1989, "Customer Demand for Service Reliability: A Synthesis of the Outage Costs Literature", Electric Power Research Institute, Research Project 2801-1, pp.2-13 to 2-27.

Caves, Douglas W., Joseph A. Herriges, and Robert J. Windle, 1992, "The Cost of Electric Power Interruptions in the Industrial Sector: Estimates Derived from Interruptible Service Programs,"*Land Economics"*, 68(1): 49-61.

Chi-Keung Woo and Roger L. Pupp "Costs of Service Disruptions of Electricity Consumers," *Energy*, Volume 17, No. 2, pp. 109-126, 1992.

Centolella, Paul, "Estimates of the Value of Uninterrupted Service for The Mid-West Independent System Operator," 2010.

"Estimating the Value of Lost Load," prepared for the Electric Reliability Council of Texas, Inc. by London Economics International, LLC. June 17, 2013.

Hartman, Raymond S., Michael J. Doane, and Chi-Keung Woo, 1990, "Status Quo Bias in the Measurement of Value of Service," *Resources and Energy*, 12(2), pp. 197-214.

Michael J. Doane, Raymond S. Hartman, and Chi-Keung Woo, "Households Perceived Value of Service Reliability: An Analysis of Contingent Valuation," *The Energy Journal*, Volume 9, Special Issue on Electric Reliability, 1988.

Sanghvi, A. P., 1990, "Cost-Benefit Analysis of Power System Reliability: Determination of Interruption Costs," *EPRI Report EL-6791,* Volume 1-3.

Schroder, Thomas, and Kuckshinrichs, Wilhelm, "Value of Lost Load: An Efficient Economic Indicator for Power Supply Security? A Literature Review," *Frontiers in Energy,* December 2015.

Subramaniam, R.K., Gary Wacker, and Roy Billinton 1993. "Understanding Commercial Losses Resulting from Electric Service Interruptions," *IEEE Transactions on Industry Applications,* Vol. 29, No. 1, pp. 233-237.

Subramaniam, R.K., Roy Billinton, and Gary Wacker, 1993. "Understanding Industrial Losses Resulting from Electric Service Interruptions," *IEEE Transactions on Industry Applications,* Vol. 29, No. 1, pp. 238-244.

Sullivan, Michael J. *et al.*, 1996, "Interruption Costs, Customer Satisfaction and Expectations for Service Reliability," *IEEE Transactions on Power Systems*, Vol 11, No. 2, pp. 989-995.

"The Economic Ramifications of Resource Adequacy." White Paper for EISPC and NARUC by Astrape Consulting. January 2013.

Tishler, Asher, 1993. "Optimal Production with Uncertain Interruptions in the Supply of Electricity: Estimation of Electricity Outage Costs," *European Economic Review*, 37(6), pp. 1259-74.

Tollefson, G., *et al*., 1993, "A Canadian Customer Survey to Assess Power System Reliability Worth," *IEEE Transactions on Power Systems,* Vol. 9, No. 1. pp. 443-450.

Woo, C. K., and Roger Pupp, "Costs of Service Disruptions to Electricity Consumers," *Energy*, Vol 17, No 2, pp 109-126.