Estimating the Value of Lost Load

Briefing paper prepared for the Electric Reliability Council of Texas, Inc. by London Economics International LLC

June 17th, 2013

London Economics International LLC ("LEI") was retained by the Electric Reliability Council of Texas, Inc. ("ERCOT") to determine a value of lost load ("VOLL"), in aggregate and by customer class, as it relates specifically to rotating outages caused by insufficient operating reserves in the ERCOT region. As an initial step in the engagement, LEI undertook two tasks to lay the foundation for developing a robust approach to estimate VOLL in ERCOT: a literature review and a macroeconomic analysis. LEI has prepared this report on the work completed to date (i.e., the literature review and macroeconomic analysis) in response to a request made by the Public Utility Commission of Texas ("PUCT") during its Open Meeting on June 6, 2013.

In the literature review, LEI reviewed prior VOLL studies, identified estimated VOLLs for other jurisdictions (both in the US and abroad), and distilled best practices in survey design and other empirical techniques for estimating VOLL. LEI found a wide range of VOLL estimates across jurisdictions and even within a single jurisdiction across customers. LEI concluded that the estimates of VOLL for other regions would be misleading proxies for an ERCOT VOLL due to the limited comparability of these regions to ERCOT. Nevertheless, the literature review provided a valuable foundation for determining the type of survey techniques that should be used if in the future ERCOT requests a survey of affected customers in the ERCOT region.

LEI also used macroeconomic analysis to provide indicative estimates of foregone economic value when electricity service is disrupted in Texas using assumptions such as state gross domestic product and average rates paid by electricity customers in Texas. The macroeconomic analysis, by its nature, does not specifically look at the types of interruptions that customers are likely to experience as a result of resource inadequacy (e.g., rotating load shed events of relatively short durations occurring at the distribution level). Therefore, the macroeconomic analysis may not be sufficient to estimate a VOLL for the purposes identified by ERCOT. In addition, a macroeconomic approach has a number of other commonly acknowledged shortcomings. That is, this approach assumes a linear relationship between interruption duration and costs, tends to underestimate VOLL in the short-run, does not account for indirect and induced effects of outages, and presents "average" VOLLs as it cannot account for either the timing or duration of an outage. Nevertheless, the macroeconomic analysis provides a useful benchmark for any future customer survey-based findings.

Given the sensitivity of VOLL to a variety of specific factors such as customer's consumption profile, a region's macroeconomic and climatic attributes, as well as the types of outages experienced/examined, this report does not – and cannot – provide a single VOLL estimate for the ERCOT region at this time for purposes of establishing the economic impact of rotating outages at the distribution level due to inadequate operating reserves. Arriving at an accurate VOLL estimate for ERCOT will require a comprehensive customer survey process. The economic literature review and the macroeconomic analysis could be useful, however, as indicators or points of reference on the general magnitude of the VOLL.

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1 Executive Summary

London Economics International LLC ("LEI") was engaged by the Electric Reliability Council of Texas, Inc. ("ERCOT") to determine a value of lost load ("VOLL"), in aggregate and by customer class, as it relates specifically to rotating outages caused by insufficient operating reserves in the ERCOT region. In order to do so, LEI first undertook research on the concept of value of lost load – what it is and how it is measured from a theoretical and practical standpoint.

VOLL is the value that represents a customer's willingness to pay for reliable electricity service. It is generally measured in dollars per unit of power (e.g., megawatt hour, "MWh"). Accurately estimating VOLL for a given region and a specific type of outage (as requested by ERCOT in this project) is a challenging undertaking as VOLL depends on multiple factors such as the type of customer affected, regional economic conditions and demographics, time and duration of outage, and other specific traits of an outage. As a result, while analysis of available macroeconomic data such as gross domestic product ("GDP") and electric consumption can be used to arrive at a rough indication of 'average' VOLL for a region, an accurate estimate of VOLL for the purposes requested by ERCOT requires surveying of end-use customers in the region to determine their willingness to pay to avoid a specific type of outage, and the economic impact that type of outage has on customers.

This paper presents the results of the first steps in the foundational work that LEI performed over the course of the last few months in the project to estimate VOLL for ERCOT. There are two parts to this report: a literature review and a macroeconomic analysis.

In Section 2 of this paper, in order to further set context, LEI discusses in detail academic studies from the perspective of economic foundations, strengths and weaknesses, and issues related to survey design and processing more generally.

In the literature review (Section 3), LEI examines academic and empirical studies that presented different methods for measuring VOLL and resulting VOLL estimates. LEI reviews specific jurisdictional studies both in the US and abroad, discussing the methodology used to estimate VOLL and the region's comparability with ERCOT, and therefore the relevance of the jurisdiction's VOLL estimates to ERCOT. As will be discussed, the comparability of these regions to ERCOT is generally weak. Furthermore, the estimates for the most comparable regions contain data going back to 1989. It should be noted that customers' views on outages and costs of electricity service, as well as electric consumption patterns, have changed since then. Therefore, the estimates of VOLL from these other empirical studies should not be used as proxies for an ERCOT VOLL during rotating outages at the distribution level to address shortfall in operating reserves.

In Section 4, LEI analyzes available macroeconomic data to produce *simplified, high-level* VOLL estimates for the residential, commercial and industrial customer classes for the ERCOT region. These estimates show considerable variation by customer class. The macroeconomic analysis does not specifically look at the types of interruptions that customers are likely to experience as a result of resource inadequacy (e.g., rotating load shed events of relatively short durations). Moreover, the macroeconomic analysis cannot focus on the specific customers predominantly affected by such outage events. In ERCOT, the rotating outage events at the distribution level primarily impact residential and small commercial customers, and have a limited impact on large industrial customers taking service directly at the transmission network levels. Therefore, the VOLL estimates derived through macroeconomic analysis should not be considered as accurate VOLL estimates during rotating outage events in the ERCOT region. Nevertheless, the estimates may provide a useful benchmark for any future customer survey-based findings.

This report does not – and cannot – provide a single VOLL estimate for the ERCOT region, and specifically for the type of outage event identified by ERCOT. Arriving at an accurate VOLL estimate for the purposes identified by ERCOT will require a comprehensive customer survey process. The various VOLL estimates in the literature review and the estimated 'average' VOLL from the macroeconomic analysis may be used as points of reference, and should not be interpreted as the VOLL, or an indication of the VOLL, for the ERCOT region.

The information contained within this report may be useful for discussions related to resource adequacy for both policymakers and stakeholders including system operators, utilities and retail customers. LEI has identified patterns in VOLL estimates from the jurisdictional studies across different customer classes as well as across different geographies. Furthermore, the jurisdictional studies provide best practices and lessons learned related to estimating VOLL, including survey design and processing, which may be useful should further work be undertaken to estimate VOLL in ERCOT.

The work described in this report represents the first part of the overall planned VOLL study. LEI understands that ERCOT is providing this report to stakeholders in order to inform ongoing resource adequacy discussions. Should ERCOT decide to conduct a customer survey to estimate an ERCOT-specific VOLL in the future, the best practices and lessons learned may assist ERCOT in the survey design and process, while the VOLL estimates from other regions reported here may be useful as independent benchmarks for VOLL estimates derived from such a customer survey process. As part of the work completed to date, LEI has also created an initial survey design assessment and created a roadmap for survey implementation. More specifically, LEI has developed a list of potential survey questions for each customer class in ERCOT, derived from our literature review and macroeconomic analysis. LEI has also had initial discussions with ERCOT staff and retail electric providers ("REPs") regarding developing a sample pool of customers to be surveyed. Furthermore, LEI has researched and assessed available survey tools that could be used to deliver a web-based survey. LEI would be available to complete the survey and the study at a future date if desired by ERCOT.

2 What is VOLL?

VOLL is a useful and important measure in electricity markets. It represents customers' willingness to pay for electricity service (or avoid curtailment). In electricity markets, VOLL is usually measured in dollars per MWh. VOLL valuations can be marginal – the marginal value of the next unit of unserved power – or average – the average value of the unserved power. Marginal values of VOLL are often calculated for peak periods (or "worst case") when customers will place the highest value on electricity. Average VOLLs are averaged over a certain period (e.g., one year) and are not differentiated over time. Average VOLLs tend to be lower than marginal VOLLs at peak times, as they average out the value customers place on electricity over, say a year, and therefore include periods during which customers place a low value on electricity (i.e., when customers are not at home or when businesses are closed). Average VOLLs are commonly used to inform transmission and generation investment, where it may be more appropriate to estimate customers' willingness to pay over longer periods of time.

It is important to also recognize that VOLLs will vary depending on the type of outage considered. Generally, there are three broad classes of outages that can occur on an electricity grid: (1) large-scale, long-term outages in which power is interrupted across a wide area for days or possibly even weeks due to a catastrophic event that causes a system-wide blackout and requires system restart and in some cases, extensive infrastructure repairs (e.g., Hurricane Sandy or the Northeast Blackout in the summer of 2003); (2) more localized outages in which electricity service is unavailable for hours at a time (e.g., as a result of distribution service event or a more localized weather event, like a tornado); and (3) targeted, short-duration outages of select customers over more discrete timeframes (e.g., rotating outages that would be instituted by ERCOT at the distribution level in order to prevent a system-wide blackout). Long duration, system-wide outages will likely have the highest VOLL as the indirect and induced costs of the outage increase over time (loss of wages, loss of perishable goods, etc.). This study was directed specifically at VOLL as it relates to targeted, short-duration outages due to insufficient operating reserves.

VOLL can be used in a variety of ways, both on the planning side of the market and on the operations side. In planning, VOLL can be used to study the cost-benefit of investment in generation and transmission and distribution relative to customers' maximum willingness to pay, as briefly discussed above. For example, the New Zealand Electricity Authority recently conducted a VOLL study to gauge the willingness to pay for transmission infrastructure (see Section 0). On the operations side, VOLL can be used to inform resource adequacy rules and scarcity pricing algorithms. For example, the Midwest Independent Transmission System Operator ("MISO") conducted a study to estimate VOLL to inform its resource adequacy plans when it launched its real-time energy market in 2005 (see Section 0), while Australia uses VOLL to inform its market price cap.[1]

[1] Australian Energy Market Commission. *Final Report Reliability Standard and Settings Review.* April 30, 2010.

3 Literature Review

3.1 Overview

As the first step in the VOLL study, LEI performed a thorough review of empirical studies conducted to establish VOLL in other jurisdictions and determined their applicability to ERCOT. LEI also reviewed academic and theoretical papers related to methodological approaches to establish VOLL and its various applications in electricity markets (i.e., in planning and operations). In addition, LEI reviewed studies to establish VOLL in other sectors (e.g., natural gas). While the estimated VOLL values are not directly applicable to ERCOT, the methodology approach used in other sectors confirms best practices observed in electricity market VOLL literature. A key conclusion from this literature review is that surveys provide more accurate estimates of VOLL than macroeconomic analysis. VOLL estimates will vary based on the length of outage, as well as by customer type, as each customer class has different opportunity costs as they relate to power outages. This variation is most effectively elicited through targeted survey questions.

The studies that estimate VOLL by jurisdiction provide a range of estimates, often disaggregated to sector or customer class. The applicability of these estimates is determined by considering both the methodology used to arrive at the estimate and the similarities between the studied geographic region/market and ERCOT. Although LEI has identified a number of studies with robust methodologies and moderate relevance to ERCOT, no single study has been suggested as an appropriate surrogate for setting the VOLL in ERCOT. VOLL estimates are extremely sensitive to a number of factors, including assumptions used in survey analysis, time and duration of outage, time of advanced notification of outage, customer profile, industry sector and many other factors. As such, the estimates provided by other studies should be considered points of reference only; that is, relative benchmarks against which to compare potential future survey results for ERCOT.

VOLL estimates (in aggregate and by customer class) presented by other studies surveyed by LEI in the literature review typically cover other jurisdictions (although there is one study from 2009 that covers the Southwest US, including Texas). Most studies relied on survey data to estimate VOLL, while a few relied solely on macroeconomic analysis to calculate VOLL. The range of VOLL estimates is shown in Figure 1. Each study's applicability to ERCOT, which weighs comparability more highly than methodology, is also shown.

There are several interesting trends in VOLLs that have emerged from the literature review. Average VOLLs for a developed, industrial economy range from approximately $9,000/MWh to $45,000/MWh. Looking on a more disaggregated level, residential customers generally have a lower VOLL ($0/MWh - $17,976/MWh) than commercial and industrial ("C/I") customers (whose VOLLs range from about $3,000/MWH to $53,907/MWh). Other trends include:

1. in general, residential customers are expected to have the lowest VOLLs, while small C/I customers have the highest VOLLs. Small C/I customers are more labor and capital intensive than residential customers and are less likely to prepare for operational risks such as outages by using interruptible contracts and back-up

generation as hedges against outages than large C/I customers, leading to generally higher VOLLs.

2. C/I VOLLs range widely, but the service sector generally is expected to have the lowest VOLLs, while manufacturing and mining have the highest VOLLs.

Figure 1. Summary of VOLLs by jurisdiction

Region/Market	Methodology	System-wide VOLL	Residential	Non-Residential		Applicability to ERCOT
				Large C/I	*Small C/I*	
US - Southwest	Analysis of past survey results		$0	$8,774	$35,417	High
US - MISO	Analysis of past survey results/ Macroeconomic analysis		$1,735	$29,299	$42,256	Moderate
				Commercial	*Industrial*	
Austria	Survey		$1,544			Low
New Zealand	Survey	$41,269	$11,341	$77,687	$30,874	Low
Australia - Victoria	Survey	$44,438	$4,142	$28,622	$10,457	Moderate
Australia	Analysis of past survey results	$45,708				Low
Republic of Ireland (2010)	Macroeconomic analysis	$9,538	$17,976	$10,272	$3,302	Low
Republic of Ireland (2007)	Macroeconomic analysis	$16,265				Low
US - Northeast	Macroeconomic analysis	$9,283-$13,925				Low

**All values in 2012 US dollars/MWh*

ERCOT has currently suspended plans to conduct a survey of end-use customers to estimate VOLL. Nevertheless, the studies reviewed in this section of the report will provide useful context for resource adequacy discussions and, should ERCOT decide to conduct a customer survey in the future, the best practices and lessons learned from these studies may assist ERCOT in the survey design and implementation. Furthermore, our review of VOLL literature has yielded a range of VOLL estimates that may be useful as independent benchmarks for the estimated VOLL that may be derived in the future using survey techniques.

3.1.1 Organization of the Literature Review

There is a great deal of literature related to the topic of VOLL, ranging from theoretical papers to empirical studies in which VOLL is estimated for specific jurisdictions. In this report, we review a variety of studies, both theoretical and empirical, which cover many jurisdictions in the US and abroad, and a variety of sectors (please see Section 11 for a complete list of works reviewed).

In the sections that follow, we begin with a discussion of the methodologies used to estimate VOLL, including sampling approach, survey design, and survey delivery method. After reviewing the strengths and weaknesses of the different methodologies and survey designs, we then review in detail empirical studies that employed some of these methodologies to estimate VOLL in various regions (and sectors), both in aggregate and by customer class. For empirical studies, we present the estimated VOLL(s), and discuss the methodology used to estimate VOLL, as well as assess the region's comparability to ERCOT. After discussing the jurisdictional studies in detail, LEI distills observations of VOLL trends, and summarizes best practices and lessons learned that may be used to inform future work by ERCOT.

3.2 Methodological Approaches to Estimating VOLL

There are four key methodologies used for estimating VOLL in the field of economics: (1) revealed preference survey; (2) stated choice survey; (3) macroeconomic analysis; and (4) case study analysis (see Figure 2). For each methodology, a detailed explanation of the approach is provided, followed by a discussion of its theoretical and practical strengths and weaknesses. Irrespective of methodology chosen, VOLL is highly variable depending on: (1) sector or customer type; (2) timing of outage; (3) duration of outage;[2] and (4) time of advanced notification of outage and preparation.[3] The detailed review of the jurisdiction studies that follows confirms that the VOLL estimates vary substantially due to these factors.

Figure 2. VOLL Estimation Methodologies

Approach	Description	Strength	Weakness
Revealed preference (market behavior)	Use of surveys to determine expenditures customers incur to ensure reliable generation (i.e., back-up generators and interruptible contracts) to estimate VOLL	▪Uses actual customer data that is generally reliable	▪Only relevant if customers actually invest in back-up generation ▪Limited consideration of duration and/or timing of outages ▪Difficult for residential customers to quantify expenses
Stated choice (contingent valuation and conjoint analysis)	Use of surveys and interviews to infer a customer's willingness-to-pay, willingness-to-accept and trade-off preferences	▪More directly incorporates customer preferences ▪Includes some indirect costs ▪Considers duration and/or timing of outages	▪Experiment and survey design is time-consuming and effort intensive ▪Need to manage for potential biases ▪Residential customers may give unreliable answers due to lack of experience
Macroeconomic (production function)	Uses macroeconomic data and other observable expenditures to estimate VOLL (e.g. GDP/electric consumption)	▪Few variables ▪Easy to obtain data ▪GDP reasonable proxy for business VOLL	▪Does not consider linkages between sectors, productive activities ▪Proxies for cost of residential outages may be arbitrary or bias
Case Study	Examines actual outages to determine VOLL	▪Uses actual, generally reliable data	▪Costly to gather data ▪Available case studies may not be representative of other outages/jurisdictions

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[2] For example, large industrial costs may be insensitive to duration of outage after power supply is interrupted and operations cease. Furthermore, the duration of the outage will not change the fact that it can take a significant amount of time after power supply is returned to restore operations. This is true, but to a lesser extent, for small industrial and commercial consumers.

[3] Adriaan van der Welle, Bob van der Zwaan. *An Overview of Selected Studies on the Value of Lost Load (VOLL)*. Working Paper. November 15, 2007. Page 10.

3.2.1 Revealed Preference

The revealed preference survey method involves asking respondents to estimate the costs they incur from outages at different times of the day, month, and year, and for different outage durations. As the name implies, the objective of this survey approach is to ask questions that will reveal consumers' preferences and appetite for paying to avoid an outage through the use of back-up equipment or interruptible contracts (discussed below).

Examples of revealed preference survey questions include:

- Does your business have any back-up generation equipment to maintain operations in the event of a power failure? *Answer choices: Yes/No/Don't know*

- Please select which type of back-up generation equipment and provide the approximate number of hours that the back-up equipment can carry the load served: *Answer choices: Standby generator/uninterruptible power supply/battery system/other*

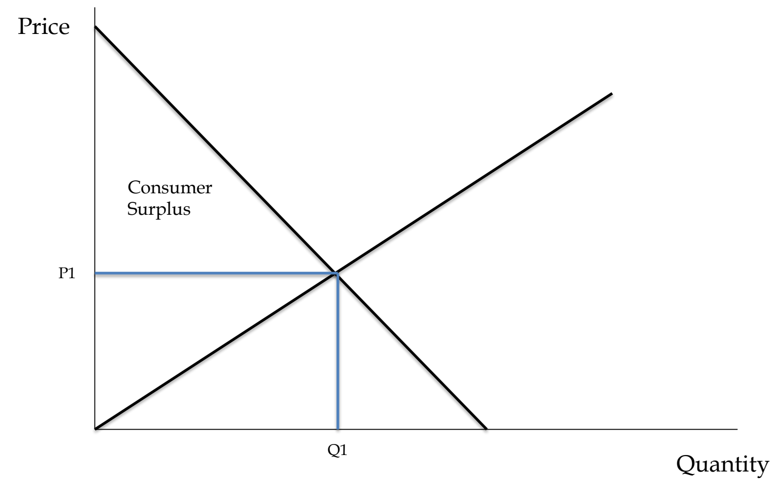
3.2.1.1 Economic foundation

Two economic theories underpin the revealed preference survey approach. The first theory relates to the costs of back-up generation. In principle, a customer can mitigate the effects of an outage through preventative measures (e.g., installing back-up power equipment). If a customer is willing to make an investment, the cost of that investment will implicitly represent the customer's maximum willingness to pay. Alternatively, one can also look at the concept of interruptible contracts to consider the maximum willingness to pay. Such contracts have been used by the agricultural and industrial sectors. Interruptible contracts allow the utility to interrupt service, but in return, the contract will also compensate customers in the event of outage. If a consumer is rational and logical, the expected loss under the interruptible contract should be priced consistent with the marginal costs of back-up generation (self-supply).[4]

The second theory relates to consumer surplus loss. Generally speaking, consumers value their electricity at more than its price; the difference is consumer surplus. During an outage, consumers do not receive this surplus; the savings they make on their power bills are smaller than the amount of value they lose. Consumer surplus is an economic concept that indicates the level of consumer satisfaction. It is measured by the difference between what the consumer is willing to pay and the market price. As shown in Figure 3, for a given market price (e.g., P1), some consumers are willing to pay more than that market price and the consumer surplus measurement seeks to capture that difference.

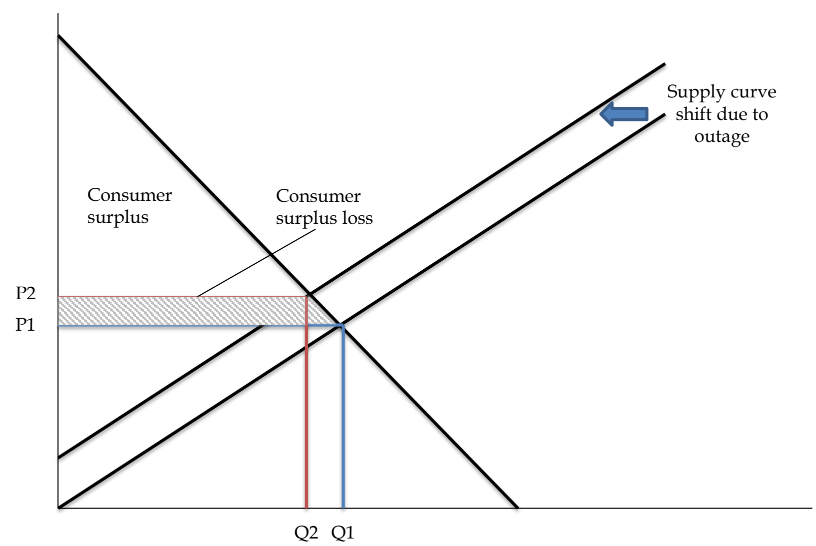
[4] Adriaan van der Welle, Bob van der Zwaan. *An Overview of Selected Studies on the Value of Lost Load (VOLL)*. Working Paper. November 15, 2007. Page 9.

Figure 3. Illustration of the consumer surplus concept in economics



During an outage, the leftward shift in the supply curve results in a consumer surplus loss. That is, the area of consumer surplus shrinks by the amount equal to the shaded area, as shown in Figure 4. If the demand curve is inelastic,[5] and in theory it is relatively inelastic in many electricity markets, the consumer surplus shrinks even more. This revealed or observable loss, minus bill savings, is equivalent to the cost of the outage.[6]

Figure 4. Illustration of consumer surplus loss due to outage



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[5] Demand is inelastic when the rate of change in quantity demand is slower than the rate of change in price. The resulting slope of an inelastic demand curve is steep.

[6] Sanghvi, A. P. *Economic costs of Electricity supply interruptions: IS and foreign experience*. Energy Economics 4 (3): 180-198.

3.2.1.2 Strengths and weaknesses

A strength of the revealed preferences approach is that the survey data are based on actual customer data and actual customer actions (such as their investment in back-up generation or use of interruptible contracts), which is generally reliable and objective.

However, there are several limitations to the approach. In a highly reliable region, where outages are short and infrequent, the cost of back-up generation may be higher than the benefits of ever using such back-up generation. This situation discourages investment in back-up generation. In this case, back-up generation and interruptible contracts can be weak indicators of the cost of an outage.[7] Also, interruptible contracts may not really be "interrupted" by the utility and therefore the customer's expectation is biased. Furthermore, not all sectors use back-up generation or interruptible contracts. Residential and small business customers most likely do not use interruptible contracts or have back-up generation, and therefore may have a difficult time accurately quantifying their costs in an outage. Residential and small business customers may not use interruptible contracts or have back-up generation due to a perception that costs of interruptible contracts and back-up generation are prohibitively high. However, as the costs of back-up generation have decreased in recent years, this perception may be inaccurate. Therefore, applying a revealed preferences approach to these customer classes would yield inaccurate responses.

Finally, the cost of back-up generation and interruptible contracts depends on the customer's sector. For example, a hospital's cost of outage is greater than the cost of setting up back-up generation. In an event of an outage in a hospital, doctors cannot perform diagnostics or surgery, nurses cannot support patients, laboratory samples that require refrigeration are contaminated and lost, and patients' physical and emotional wellbeing and safety are at immediate risk – all of which will have monetary effects that will last longer than the duration of the outage. Therefore, in this case, using the cost of back-up generation as an indicator for a hospital would lead to an underestimation of VOLL.[8]

In addition, as a practical consideration, survey preparation (i.e., designing questions) and survey implementation (delivery of survey and then collection of survey responses and empirical analysis of such responses) can be time consuming and expensive. If not done properly, a survey may result in incorrect and biased conclusions.

3.2.2 Stated Choice

Stated choice surveys estimate VOLL based on costs that are inferred from choices that consumers say they will make under future, hypothetical outages. There are two practical approaches typically deployed under the stated choice survey method: the contingent valuation method ("CVM") and the conjoint analysis.

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[7] Adriaan van der Welle, Bob van der Zwaan. *An Overview of Selected Studies on the Value of Lost Load (VOLL)*. Working Paper. November 15, 2007. Page 11.

[8] Adriaan van der Welle, Bob van der Zwaan. *An Overview of Selected Studies on the Value of Lost Load (VOLL)*. Working Paper. November 15, 2007. Page 11.

CVM involves asking respondents questions related to the damage suffered from the outage, their willingness-to-pay ("WTP") for decreases in outages, and/or their willingness-to-accept ("WTA") compensation for increases in outages. In a conjoint analysis, respondents are given scenarios (in some studies, scenarios are attached with estimated monetary values), each involving one type of reliability (timing and duration outages) and associated electricity price, and asked to rank and comment on which scenario they prefer, e.g., akin to the "trade-off question." Monetary value thus appears indirectly in both analyses.

Once the surveys are completed by survey respondents, regression analysis is applied, using the respondents' choice as the response variable and timing, frequency and duration of outage and the WTP or WTA as the explanatory variables. The coefficient results of the regression are then used to provide WTP and WTA measures based on the various outage parameters and respondent choices, and are then used to calculate an estimated VOLL.

Sample questions in this form of survey include:[9]

- To the best of your memory, how many outages has your house experienced?
- How long did these outages last, in terms of number of hours?
- In the event of a 4-hour outage at the worst time of next year, what actions would your take? Choices and associated costs might include:
    - Light candles or use torch for 4 hours ($4.00)
    - Buy gas lantern ($10.00)
    - Buy some ice to put into refrigerator ($2.00)
    - Drive to a relative or friend's home and stay with them ($10)
    - Buy portable gas stove for cooking and boiling ($30)
    - Buy back-up battery supply to use computer for up to 30 minutes ($40)
    - Buy portable kerosene or LPG space heater to provide heating for one room ($50)
    - Go to a restaurant for one meal ($50)
    - Do nothing and wait for power to return ($0)

3.2.2.1 Economic foundation

CVM and conjoint analysis are forms of choice modeling. Choice modeling theorists believe that human choices are rational and hence contain patterns that may be modeled. In the stated choice approach, respondents' answers to survey questions may contain patterns between

[9] Examples were drawn from a study which will be reviewed below. CRA International. *Assessment of the Value of Customer Reliability (VCR)*. August 12, 2008.

outage duration and timing and the activities that are engaged in during the outage. These activities have monetary cost, which allows for VOLL estimation.

3.2.2.2 Strengths and weaknesses

There are a few strengths to the stated preference survey approach. It is a bottom-up approach that elicits individual customer preferences, providing a high degree of objectivity. It can be used with customers who have never experienced an outage, whereas the revealed preferences approach is more relevant to customers who are more experienced with outages and can reliably report the costs and impacts of such outages. Also, a stated preference survey obviates the need for customers to report direct costs through the price-to-outage trade-off questions, which survey specialists generally believe enables more accurate reporting of VOLL for residential customers (a customer may not know of their direct costs but can accurately judge the opportunity cost of losing service and therefore state their (monetary) utility for maintaining service continuity). Finally, timing and duration of outages can be directly and implicitly incorporated in the survey and post-survey regression analysis with revealed preferences approach. It is also possible in the CVM to survey reputational damage and other intangibles associated with a particular type of outage event.

However, some critics of survey approaches have noted that certain respondents, especially in the residential sector, may not provide reliable answers to questions about damage, WTP, WTA and price-to-outage trade-offs because they rarely have to make such decisions. To control for inexperience of respondents, surveys should include at the outset a question on whether the respondent has experienced an outage before and if so, to what extent. Responding to such questions rationally is especially challenging for respondents in regions with high reliability and low frequency of outages. Also, residential respondents' valuation of the drop in electricity prices is subjective, and may be misvalued if the respondents treat the trade-off questions with skepticism, leading to biased results.[10] Finally, as with other methodologies, survey preparation (i.e., designing questions) and survey implementation can be time consuming and expensive.

3.2.3 Macroeconomic Analysis (Production Function)

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). For the non-residential sector, VOLL is typically obtained using one of the following methods: (1) the ratio of Gross Domestic Product ("GDP") or Gross Value Added ("GVA") to electricity consumption (in MWh) of non-residential consumers, or (2) the ratio of electricity bills to consumption:[11]

1) VOLL = Annual GDP / Annual Consumption

2) VOLL = Annual Electricity Bill / Annual Consumption

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[10] Michiel de Nooij, Carl Koopmans, Carlijn Bijvoet. *The value of supply security: The costs of power interruptions: Economic iput for damage reduction and investment in networks*. January 10, 2005. Page 280.

[11] LEI used macroeconomic analysis to provide a first cut estimate of VOLL in ERCOT. This work was done under Task 2.

Method (1) is more commonly used for the C&I sector.

For the residential sector, only Method (2) is possible, although there have been proxy methods recently developed that attempt to also consider the potential 'value added' of residential consumers' time.[12] In this relatively new approach, a survey is first prepared in order to investigate intraday activities of residential customers. Activities are then assigned certain monetary values, such as average after-tax wages, and then aggregated to form an indication of VOLL using the aggregate wages to consumption ratio.

3.2.3.1 Economic foundation

GDP is the monetary value of goods and services produced by a country within a certain time period. It is usually calculated on an annual basis (although on a national level, quarterly data are also available). GDP measures private and public consumption, government expenses, private and public investments, and net exports, i.e. exports *minus* imports. GVA is similar to GDP. It is a productivity measure of the difference between the monetary value of outputs, the finished goods and services, and the monetary value of inputs such as labor and raw materials. It is also usually calculated on an annual basis.

In terms of an economic foundation for the aggregate wages to consumption ratio, the underlying theory in the residential sector estimate is to find the equilibrium price at which the value of a marginal hour of leisure is equivalent to the value of a marginal hour of labor.

3.2.3.2 Strengths and weaknesses

The production function approach is useful because it requires only a few variables that are relatively easy to obtain to calculate VOLL, and it is therefore less time-consuming and costly than survey methods.

However, it is also important to recognize the weakness of this approach. There can be data inconsistencies between the numerator (GDP or GVA) and the denominator (consumption) because different agencies typically collect these data. For the non-residential sector, this approach assumes that all sectors' business activities cease simultaneously, and does not always consider real world factors, such as:

1. staggered outages, which can disrupt business and non-business activities as much as if these outages were combined into one continuous outage. If unaccounted for, it can lead to underestimations of VOLL;

2. supply chain linkages between sectors, i.e. the "knock-on" effect of stopping one sector's production on another sector's production, which, if unaccounted for, can again lead to underestimations of VOLL;

3. the possibility of engaging in productive, albeit limited, business activities during outage, for example in an emergency grocery stores in communities experiencing an outage during the daytime can still sell goods that do not require refrigeration and have

[12] Leahy, E., and R.S.J. Tol, 2011, An estimate of the value of lost load for Ireland, Energy Policy, 39(3), pp. 1541-1520.

long shelf lives, e.g. canned food. If unaccounted for this will lead to an overestimation of VOLL; and

4. the possibility of recovered production post-outage to compensate for lost production during outage.[13] If unaccounted for, this will lead to an overestimation of VOLL.[14]

For the residential sector, valuing time is difficult. Some leisure activities require electricity, such as surfing the web, and it is difficult to put a monetary value on such activities when they are done purely for personal enjoyment. The electricity bill approach will not recognize the value of such leisure activities. Other household activities do not require electricity, (e.g., reading a book), so it can be argued that a residential VOLL (for example, using aggregate wages to consumption ratios) may be overestimated. Furthermore, assigning a cost to financially intangible activities such as leisure or sleep can lead to arbitrary and biased VOLL estimates. As mentioned, the underlying theory in the residential sector estimate is to find the equilibrium price at which the value of a marginal hour of leisure equals to the value of a marginal hour of labor. In an unplanned outage, the hour is not marginal but random. In this case, estimating VOLL based the value of a marginal hour may lead to underestimation.[15] Though generally easy to obtain, not all macroeconomic data are available and, in such a case, survey or other outreach methods would be required, increasing study time and expenditure.

Finally, in the various methods for estimating VOLL using production functions, there is no consideration of timing and duration of outages.[16]

3.2.4 Case Study

A case study approach may be used to determine the value of lost load that occurred during blackouts. This option analyzes an actual outage event with predefined parameters, such as outage timing, duration and geographic location. It can be used as a "sanity" check of the results of other approaches.

3.2.4.1 Economic foundation

The theory of the firm provides the economic foundation to the case study approach. The theory of the firm seeks to answer questions regarding the existence (why firms emerge), boundaries (difference between firms defining their respective sectors), organization (structure of the firm, hierarchical versus decentralized governance), and heterogeneity of firm strategy. In the event of an outage, firms behave differently as they face different opportunity costs during an outage. Opportunity costs – the basis of VOLL – are thus conditioned by these several attributes, or

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[13] Whether these factors are considered depends on the study.

[14] Peter Cramton, Jeffrey Lien. *Value of Lost Load*. February 14, 2000.

[15] Michiel de Nooij, Carl Koopmans, Carlijn Bijvoet. *The value of supply security: The costs of power interruptions: Economic input for damage reduction and investment in networks*. January 10, 2005. Page 282.

[16] The new wages approach described in in Section 0 is an exception, as it considers timing and duration of outages by assigning different values to residential activities during different periods of the day.

themes, associated with the theory of firm: its industry (the in-patient hospital care industry provides essential healthcare services to the general public and the opportunity costs of outages causing hospital blackouts will be relatively large; the entertainment industry provides non-essential leisure services to the general public and the opportunity costs of outages causing movie theaters to shut down may be relatively small), the product or service it provides (high costs versus low costs), its sales and cost structure (profitability), and firm strategy in the event of an outage (e.g. insurance strategies such as use of back-up generation, interruptible contracts, hedging contracts, or shifting production to another location/branch of the firm). The case study selects one or more of the above theories and performs research and data analysis based on the underlying theory.

3.2.4.2 Strengths and weaknesses

This approach has the benefit of using actual, and generally reliable, data. Also, because the outage event is not hypothetical, the sample period is set. Therefore, it is easier to identify potential factors (or explanatory variables if conducting statistical analysis) and incorporate them into the VOLL calculation. This saves research time and resources. However, even though the outage is actual and not hypothetical, detailed firm-specific data may not be available and the VOLL is not directly observable. And since it is based on a single event, it is most likely not representative of other types of outages.[17]

A case study may be more expensive to conduct than the other three analyses because data need to be very granular and specific to the outage event, i.e. not aggregated estimates like GDP or GVA.

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[17] Billington, Tollefson and Wacker. *Assessment of electric service reliability worth*. International Journal of Electrical Power & Energy Systems 15 (2): 95-100.

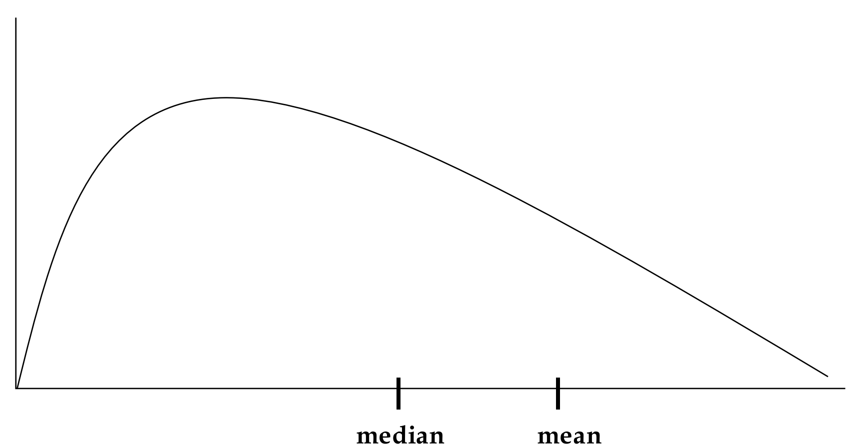
3.3 Jurisdictional Studies

LEI analyzed 10 studies that have established VOLL values for different jurisdictions (and sectors), both within the US and abroad. The goal of this analysis was to identify VOLLs established for other regions, and to evaluate the robustness of the methodology used to estimate VOLL and the comparability of the region to ERCOT. LEI also considered lessons learned and best practices in estimating VOLL.

3.3.1 Reporting of VOLL from jurisdictional studies

The studies that estimate VOLL by jurisdiction provide a range of estimates, often disaggregated to sector or customer class, which may be useful as reference points for ERCOT.[18] The individual survey responses are a combined and reported as a single aggregate point estimate. Although it is common for distribution-based analyses to report the average or mean, with surveys of VOLL, the median is also an important result metric. Survey results tend to be heavily right-skewed (please see Figure 5 below) because in most customer classes, especially commercial and industrial, there are a small number of customers whose interruption costs are significantly higher than other respondents.[19] As such, if a mean value[20] is used for VOLL it is often significantly higher than the median value.[21] Therefore, where possible, the median value is reported when available.

Figure 5. Illustrative example of right-skewed distribution of survey-based VOLL estimates



[18] In presenting the VOLL estimates, LEI has inflated all survey results to 2012 US dollars per megawatt-hour ($/MWh) for ease of comparison.

[19] These high values are plausible, especially for customers operating large and complicated industrial facilities with high energy use.

[20] The mean is the arithmetic average of a set of numbers. The mean is useful for normal distributions, as it can be largely influenced by outliers.

[21] The median of a data set is the middle number when the set is ordered in numerical order. The median is generally used for skewed distributions.

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3.3.2 Evaluating jurisdictional studies

The applicability of the VOLL estimates from the 10 jurisdictional studies to ERCOT is determined by considering both the approach used to arrive at the estimate (methodology) and the similarity between the studied geographical region or market and ERCOT (comparability). As mentioned previously, LEI weighed comparability more highly than methodology in determining each study's applicability to ERCOT. The methodological and comparability metrics are listed in Figure 6.

The methodological metrics evaluate the internal robustness of the study, and are considered in a qualitative manner, ranking the studies according to their relative strengths and weaknesses. For survey-based studies, the metrics consider the underlying survey design, how the survey was implemented and the size of the sample. For example, studies that include a survey with a large sample size that attempted to adjust for biases both in pre-testing and post-survey processing would be considered relatively stronger than a study that relied solely on macroeconomic data. Similarly, studies that considered a variety of timing and duration of outages and that provided VOLLs disaggregated by multiple variables (customer class, sector, etc.) are considered relatively robust.

Figure 6. Methodological and comparability metrics

Methodological Metrics	Comparability Metrics
Survey Design	**Economic/Demographic**
Stated Choice, Revealed Preference? Did design vary by customer class?	Population density (ppl/mile^2)
Survey Delivery Method	GDP per capita (2011 USD$)
Mail, interviews? Did delivery vary by customer class?	Average temperatures (°F)
Adjustment for Bias	Urban : Rural
Was sample data cleaned of outliers? Was sample data representative of region? Was any pilot testing done?	**Electricity Consumption Patterns**
Sample Size	Total annual consumption (MWh)
Sample size, response rate	Peak Demand (MW)
Degree of disaggregation	Customer Mix
By sector, time of day, region, season	Peak Period
Macroeconomic data	**Market Design**
Any consideration of GDP or other macro data?	Wholesale Market?
Timing and duration of outage	Retail Market?
Were a variety considered? During peak periods?	End-Use Customers have Smart Meter?
	Connection with other systems

The comparability metrics compare key features of the geographic region considered against ERCOT, and the various comparability metrics are weighted equally.[22] The comparability metrics fall into three broad categories: (1) economic and demographic; (2) electricity consumption patterns; and (3) market design. Economic and demographic metrics provide an indication of the transmission system design. For example, a highly rural region will likely have a long, linear transmission system that extends across the region with a fairly low customer density. This kind of environment requires a different infrastructure, investment profile and is also likely to have a different consumption profile. We also look at electricity consumption patterns, as indicated by the system size (consumption and peak demand) as well as peak periods and customer mix. The customer mix is an important metric, as VOLLs are often load-weighted, so it is important to understand how each customer class contributes to total system load. Finally, market design metrics consider the underlying market's level of deregulation, and how it is connected with other systems.

We begin by examining the two most applicable studies to ERCOT – the US National Study and the US MISO Study. The remaining studies are grouped by methodology. We then examine the survey based studies, followed by studies using macroeconomic analysis and, finally, we examine a case study. We have also examined studies for other sectors, which can be found in the Appendix on page 65.)

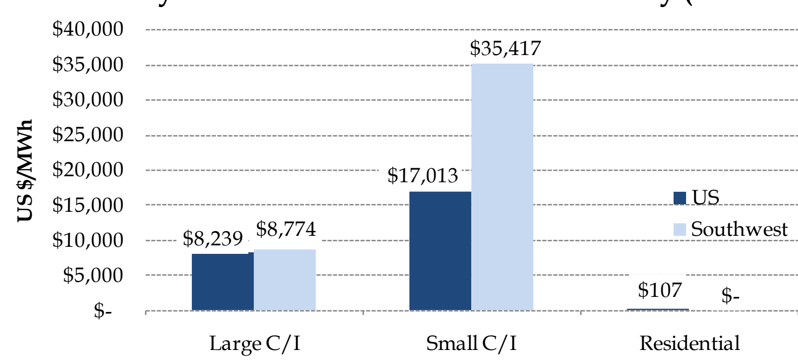
[22] Data for the state of Texas was used where ERCOT data was not available.

3.3.3 United States – National Study

United States – National Study	
Title:	"Estimated Value of Service Reliability for Electric Utility Customers in the US" (2009)
Author(s):	Sullivan, Mercurio, Schellenberg and Berkeley National Laboratory
Methodology:	Meta-database of previous surveys
Sample Data:	Database of 28 surveys conducted by 10 utilities during 1989-2005
Disaggregation:	High. VOLL by customer class, sector, duration, timing and regions
Comparability:	High. Results for Southwest region are a good proxy for ERCOT

In this study, the Berkeley National Laboratory ("Berkeley") presents estimates of VOLLs for the US based on the results of 28 studies conducted by 10 major utilities over a 16-year period (1989-2005).[23] After compiling the results of the studies, Berkeley developed an econometric model that can be used to calculate customer interruption costs by season, time of day, day of the week, geographical regions within the US by customer class. The Southwest region is a good proxy for ERCOT, and represents 13% of datapoints in the database. These datapoints represent the results of a survey conducted by Salt River Project (serving central Arizona) in 2000, which were then extrapolated to cover the entire Southwest region. Texas is generally considered part of the Southwest, and the states in the Southwest US share similar temperatures, peak periods and GDP per capita. Figure 7 shows the estimated VOLL by customer class for both the national level and for the Southwest region. Overall, the Southwest has a higher than average VOLL for all C/I customers based on this National Study. Median values are presented as mean results are heavily right-skewed.

Figure 7. Estimated VOLLs by Customer Class in US National Study (median value, $/MWh)



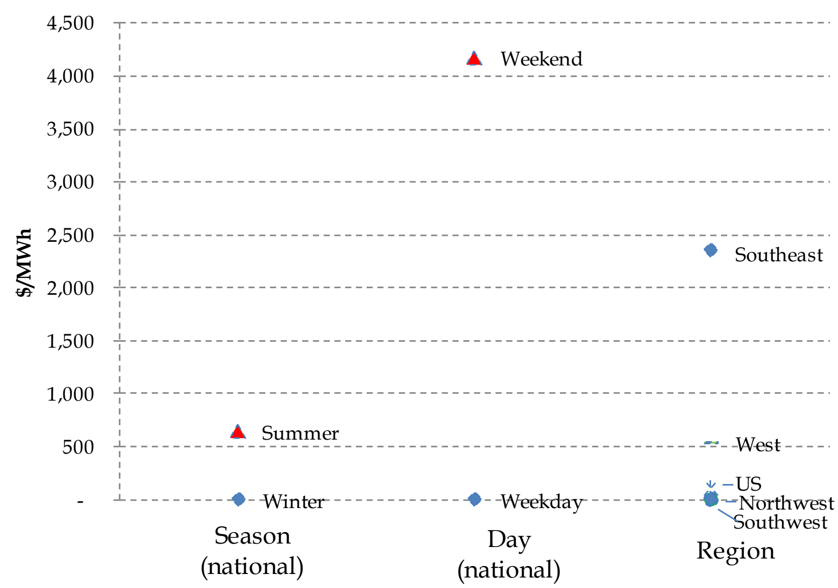
**Large C/I are customers with consumption greater than 50 MWh per annum*

[23] The utilities include Bonneville Power Administration, Duke Energy, Mid America Power, Pacific Gas and Electric Company, Puget Sound Energy, Salt River Project, Southern California Edison, and Southern Company.

The Berkeley study is particularly informative as it provides highly disaggregated results (see Figure 8, Figure 9, Figure 10, and Figure 11). Some general trends in VOLLs can be observed in the results.

- VOLLs are generally higher in the summer than in the winter. This is a reflection of the fact that peak usage occurs during the summer season for the majority of the regions surveyed;[24]
- VOLLs for commercial and industrial customers are higher during weekdays while VOLLs for residential customers are higher on the weekends, reflecting the peak usage periods of the respective customer classes;
- small C/I customers have significant higher VOLLs than large C/I customers in most sectors (see Figure 11);[25]
- residential VOLLs are relatively low, generally falling below $1,000/MWh;
- large C/I VOLLs generally fall between $4,000 - $10,000/MWh; and
- small C/I VOLLs range wider, but do cluster between $20,000 - $40,000/MWh.

Figure 8. Estimated Residential VOLLs in the US National Study (median value, $/MWh)



[24] The database does not contain any results for the Northeast, which is a winter peaking region.

[25] This may be a result of the choice to designate large C/I as those customers whose annual consumption exceeds 50 MWh. However, other studies confirm this general trend – small C/I customers generally have higher VOLLs than large C/I customers.

Figure 9. Estimated VOLL for Small C/I in the US National Study (median value, $/MWh)

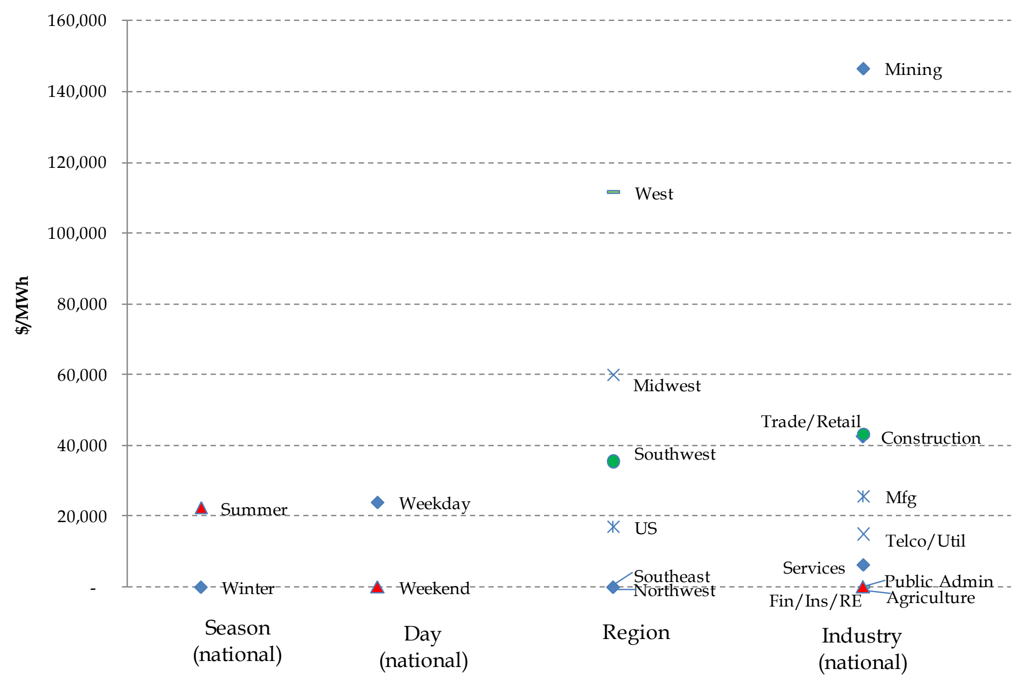


Figure 10. Estimated VOLL for large C/I in the US National Study (median value, $/MWh)

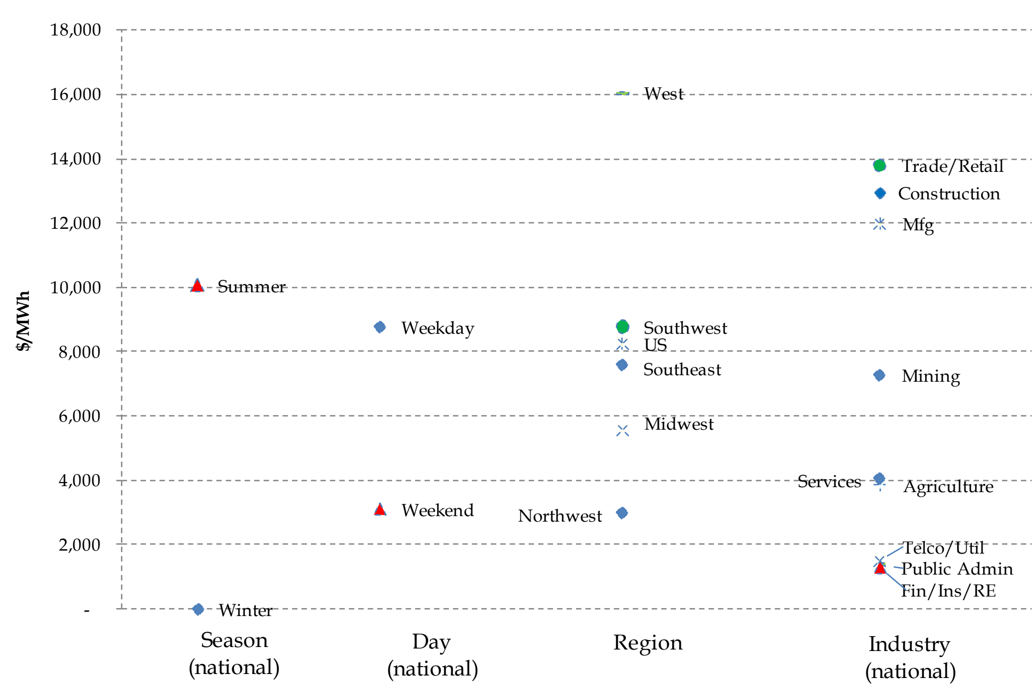
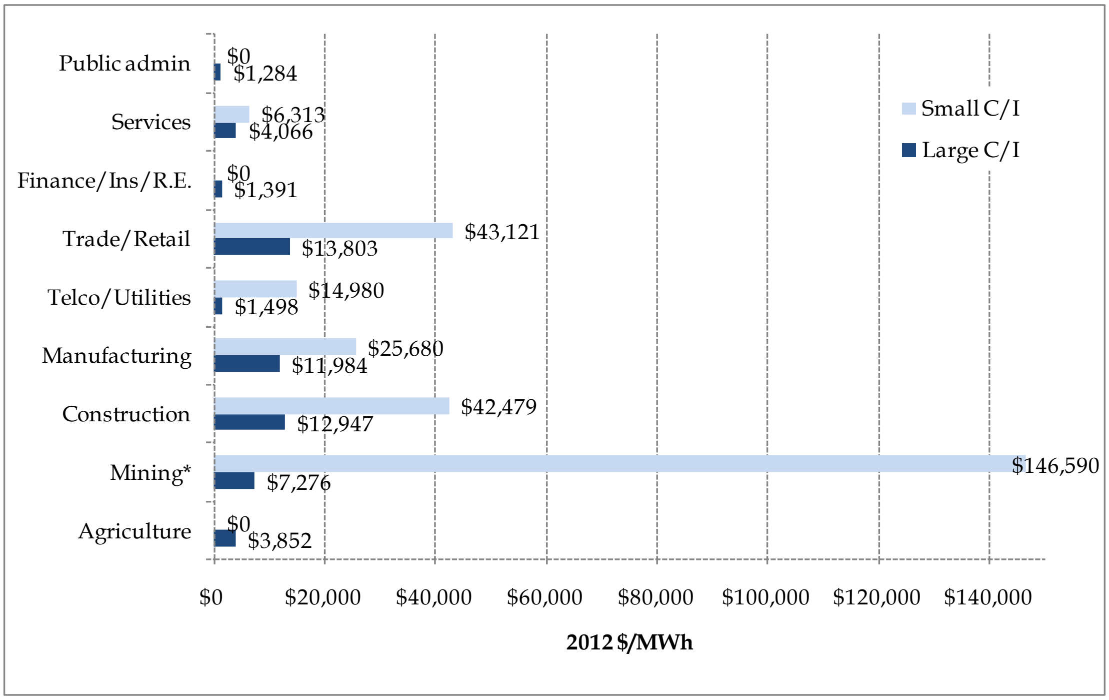


Figure 11. Estimated VOLLs by sector in the US National Study (median value, $/MWh)



**mining includes oil and gas extraction and production*

3.3.3.1 Methodology

The VOLLs depicted in this study are the result of statistical analysis of a meta-database of survey results. The results of 28 studies were compiled into a single database, with common variable definitions and names. Extreme outliers were excluded, eliminating approximately 3% of observations. The benefit of this database is that it provides granular results, disaggregating at the customer class level by season, day, sector, and region. This allows for identification of broader trends in VOLL across many regions in the US and customer class. However, there are also limitations to the database, which combines many surveys done by various entities over many years – not necessarily using exactly same questionnaire. In the database, certain variables are confounded in such a way that it is impossible to separate their effects on interruption costs. That is, it is impossible to separate the region of the country and the year of the study. For example, it's not clear whether the high interruption values for the Southwest are a result of the hot summer climate in the region or the particular economics and market conditions during the year the study was done. Furthermore, given the size of the area covered, normalization of the national results may eliminate regional variations in sectoral and seasonal estimates. Finally, it is important to note that the database relies on surveys going as far back as 1989. Electric consumption patterns have changed since then, as have economic values attached to many products and services throughout the economy.

As the underlying survey results are not available for study, LEI cannot comment on the robustness of the surveys conducted. However, as the studies were reviewed by the national lab, LEI assumes that the underlying surveys are relatively robust and provide useful data.

Figure 12. Methodology for US study

Methodological Metric	Comment
Survey Design	Estimates generated by compiling a meta-database of survey results from 28 surveys conducted by 10 utilities during 1989-2005;
Survey Delivery Method	Varies by underlying survey; residential surveys were primarily mailings
Adjustment for Bias	▪ The database was adjusted for extreme outliers ▪ The size of the database makes it impossible to separate the effects of certain variables (e.g., region and time) ▪ No comment was made about the specific methodological approach of each survey, there is likely some variation in how biases were treated in each survey ▪ Does not cover all of the US (e.g., the Northeast is not included)
Sample Size	Large. Meta-database comprised of 28 studies conducted during 1989-2005. Includes responses of 11,970 firms and 7,693 households
Degree of disaggregation	High. Lists VOLL by customer class and 9 industry sectors as well as by duration of outage, time of outage and region
Macroeconomic data	None
Timing and duration of outage	Considers a variety of times and durations

3.3.3.2 Comparability

At the national level, which is used for sectoral analysis, there is limited comparability to ERCOT as the database covers many regions in the US. However, the Southwest region of the study (representing 13% of datapoints) is highly comparable to ERCOT. Texas is generally considered part of the Southwest, and the state shares similar temperatures, peak periods and GDP per capita with the other states in the region, as summarized in the figure below. Furthermore, the customer mix is nearly identical. Results for the Southwest were reported for customer class, but not by industry, day or season.

Figure 13. Comparability table of the Southwest

Comparability Metric	Southwest	ERCOT
Population density (ppl / sq mile)	56	101
Average temperatures (°F)	Winter: 36 Summer: 73	Winter: 49 Summer: 81
GDP per capita (2011 USD$)	47,727	49,543
Connection with other systems	Yes (CAISO, ERCOT)	Yes, but limited (SPP/Mexico)
Total annual consumption (MWh)	760,064,673 (2011)	335,000,000 (2011)
Peak Demand (MW)	143,724 (2011)	63,379 (2011)
Customer Mix	37% residential 34% commercial 29% industrial	38% residential 34% commercial 28% industrial
Wholesale Market?	No	Yes
Retail Market?	*Variation by state*	Yes
End-Use Customers have Smart Meter	*Variation by state*	Yes
Peak Period	Summer Afternoon	Summer Afternoon

3.3.3.3 Key Takeaways

The VOLL estimates based on the meta-database highlight some important observations:

- statistical analysis shows a significant difference between median and mean VOLL values. Mean values are significantly higher due to the right-skew of the results;

- many residential customers may report a zero cost for one-hour outages. However, residential costs may increase with the duration of the outage. It is important to recognize that zero values may be accurate estimates for residential customers during short outages. As a result, it is important that surveys include questions to determine how sensitive the VOLL estimates are to the duration and timing of the outage; and

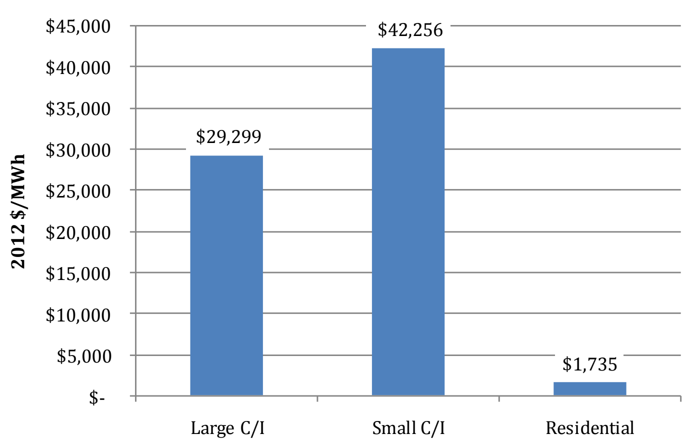
- VOLLs range widely by customer class. However, residential customers appear to have the lowest VOLLs, while small C/I have the highest VOLL values. Small C/I customers are more labor and capital intensive than residential customers and are less likely to prepare for operational risks such as outages by using interruptible contracts and back-up generation as hedges against outages than large C/I customers, leading to generally higher VOLLs. This trend has also been confirmed by other studies discussed later in this section.

3.3.4 United States - MISO

United States - MISO	
Title:	"Estimate of the Value of Uninterrupted Service for MISO" (2006)
Author(s):	Centelella, Science Applications International Corporation ("SAIC")
Methodology:	Meta-database of previous surveys + economic data
Sample Data:	Database of 24 surveys conducted by 8 utilities during 1989-2002
Disaggregation:	High. VOLL by customer class and industry sector
Comparability:	Moderate. Differences are due to MISO's larger footprint (11 states)

In this 2005 study, MISO used multipliers from the Berkeley meta-database (see Section 0) in conjunction with macroeconomic data specific to the Midwest region to calculate VOLL by customer class. The purpose of the VOLL study was to use the VOLL to inform MISO's resource adequacy plan. Specifically, MISO, at the time an energy-only market, used the estimated VOLL to inform and validate its approach to set security interruption prices (the price at which load is curtailed); the prices were not set exactly equal to VOLL as estimated in the study.[26] MISO estimated VOLLs by customer class, which ranged from $1,735/MWh to $42,256/MWh (see Figure 14).

Figure 14. Estimated VOLL in the MISO Study (median value, $/MWh)

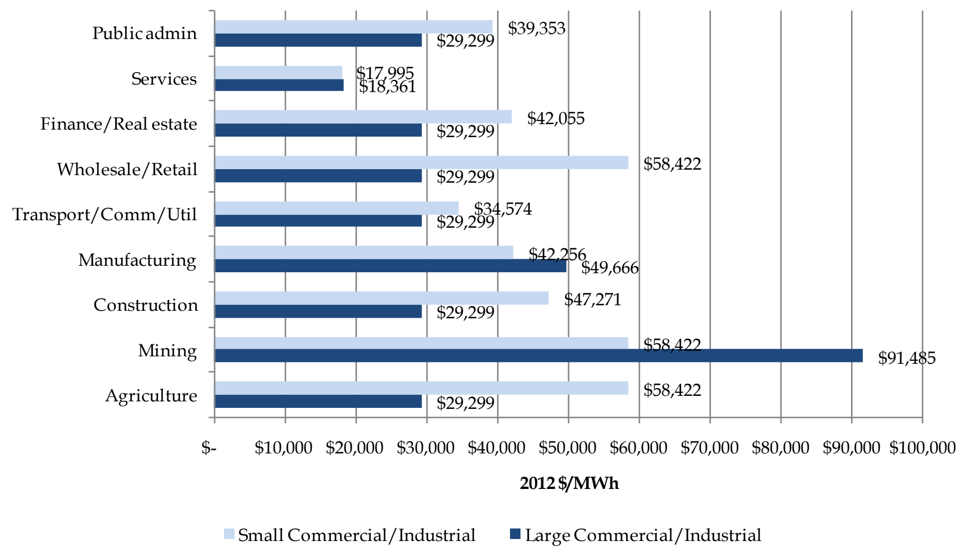


**Large C/I are customers with consumption greater than 1,000 MWh per annum*

[26] MISO currently uses a VOLL of $3,500/MWh for its Operating Reserve and Regulating Reserve demand curves. MISO. *Regulating Reserve Demand Curve – Floor Price – Tariff Sheets*. December 2009.

In addition, MISO provided VOLL estimates by sector for commercial and industrial customers (see Figure 15). According to this study, small C/I customers tended to have higher VOLLs in most sectors, with the exception of mining and manufacturing. The services sector had the lowest VOLLs in both the large and small C/I customer classes.

Figure 15. Estimated VOLLs by sector in the MISO study (median value, $/MWh)



**Mining includes oil and gas extraction and production*

3.3.4.1 Methodology

The MISO study relied on a combination of outputs from the meta-database of survey results from an earlier version of the National database (see Section 0) coupled with detailed macroeconomic inputs. This was seen as a cost-effective way to leverage survey results without incurring additional time or cost, which could be high given the size of MISO's footprint. However, this approach could have been improved through the use of additional surveying in the MISO footprint as surveys from the Midwest region only represent a small portion of the total data points in the national database (8% overall), and there were no direct survey results for the residential sector in the Midwest. The limitations discussed in Section 3.3.3.1 apply here.

Figure 16. Methodology for MISO study

Methodological Metric	Comment
Survey Design	Estimates generated using a statistical model generated from a meta-database developed by Berkeley National Lab (2003 version) in conjunction with publicly available macroeconomic data for the Midwest
Survey Delivery Method	Varies by underlying survey;
Adjustment for Bias	▪ The database was adjusted for biases and MISO presented results as a distribution ▪ Median averages were presented rather than mean values due to large outliers ▪ Study includes list of caveats on results (including weakness of using a meta-database; inability to measure long-term costs; does not consider outage source)
Sample Size	Large. Meta-database comprised of 24 studies conducted by 8 utilities during 1989-2002
Degree of disaggregation	High. Lists VOLL by customer class and 9 industry sectors
Macroeconomic data	Study used as inputs to econometric analysis relevant macroeconomic data (e.g., household income and expenditures, GDP, etc.) taken from Midwest Census region
Timing and duration of outage	1 hour during the summer afternoon (MISO peak)

3.3.4.2 Comparability

MISO is moderately comparable to ERCOT (see Figure 17). The regions have a similar customer mix, GDP per capita and population metrics (density and urbanization). The key differences between ERCOT and MISO are primarily a function of MISO's larger footprint, which covers 11 states. Given its size, MISO has more variability in temperatures, greater overall consumption and greater peak demand, as summarized below. We therefore rate the results from this study as relatively less comparable than the Southwest region survey results from the National Study.

Figure 17. Comparability table of MISO

Comparability Metric	MISO	ERCOT
Population density (ppl / sq mile)	95	101
Average temperatures (°F)	Winter: 23 Summer: 70	Winter: 49 Summer: 81
GDP per capita (2011 USD$)	54,579	49,543
Connection with other systems	Yes, PJM	Yes, but limited (SPP/Mexico)
Total annual consumption (MWh)	594,000,000 (2011)	335,000,000 (2011)
Peak Demand (MW)	104,000 (2011)	63,379 (2011)
Customer Mix	34% residential 32% commercial 34% industrial	38% residential 24% commercial 28% industrial
Urban : Rural	34% urban 66% rural	44% urban 56% rural
Wholesale Market?	Yes	Yes
Retail Market?	Yes, but very limited	Yes
End-Use Customers have Smart Meter	Yes	Yes
Peak Period	Summer Afternoon	Summer Afternoon

3.3.4.3 Key Takeaways

The MISO study reinforces many of the key observations made in the National study done by Berkeley (see Section 3.3.3.3), and may serve as a useful benchmark for ERCOT. In particular, the MISO study demonstrates that:

- residential customers have the lowest VOLL of all customer classes;
- small C/I customers have the largest VOLL of the customer classes; this is an important confirmation as the MISO study defines small C/I over a much broader range than the Berkeley study; and
- the services sector has the lowest VOLL for all commercial and industrial customers.

3.3.5 Austria

Austria	
Title:	"The Value of Supply Security: the Costs of Power Outages to Austrian Households, Firms and the Public Sector"
Author(s):	Johannes Reichl, Michael Schmidthaler, Friedrich Schneider
Methodology:	Robust survey
Sample Data:	Representative, large
Disaggregation:	High, covering every sector of the country with up to 15 sectoral VOLLs
Comparability:	Moderate to low, dissimilarities in population density, peak demand and consumption, similarities in customer mix and peak period

This is a 2012 survey study that employs a combination of Stated Choice and Revealed Preference surveys, macroeconomic data and case study analysis to estimate VOLL for the country of Austria. The purpose of the study is academic, though it claims that its results could potentially be used for "energy political decisions, benefit cost analyses, or the design of regulatory frameworks."[27]

For the non-residential sector, a Revealed Preference survey was conducted. The study assumes that consumers experience exclusively monetary losses and estimates the monetary losses related to the inability to engage in certain activities during the outage. These monetary losses are however deducted by labor and raw material costs and also by the portion of added value which can be recovered later, after the outage ends and when certain activities resume, resulting in net monetary loss. For example, if the monetary loss of a cupcake store is $1,000 and labor and raw material expenses are $500, but after the outage ends, $200 of the monetary the loss is recoverable, then the net monetary loss is $1,000 - $500 - $200 = $300.

For the residential sector, a Stated Choice survey was conducted to gauge willingness-to-pay. Representativeness of sample data was ensured. In the non-residential sector, all nine Austrian provinces and all economic sectors were surveyed, in total 201 non-residential consumers participated in the survey. On the residential side, 894 residential consumers participated in the survey with 704 customers interviewed face-to-face, and 190 responses received from the online survey. In the residential sector, a demographic breakdown of sample data was matched against national data to assess representativeness. The total sample size was therefore 1,095 (201 non-residential and 895 residential). Using the WTP survey approach, the mean VOLL for the residential sector was calculated and is reported in Figure 18.

[27] Reichl et al. *The Value of Supply Security: the Costs of Power Outages to Austrian Households, Firms and the Public Sector.* 2012. Page 4.

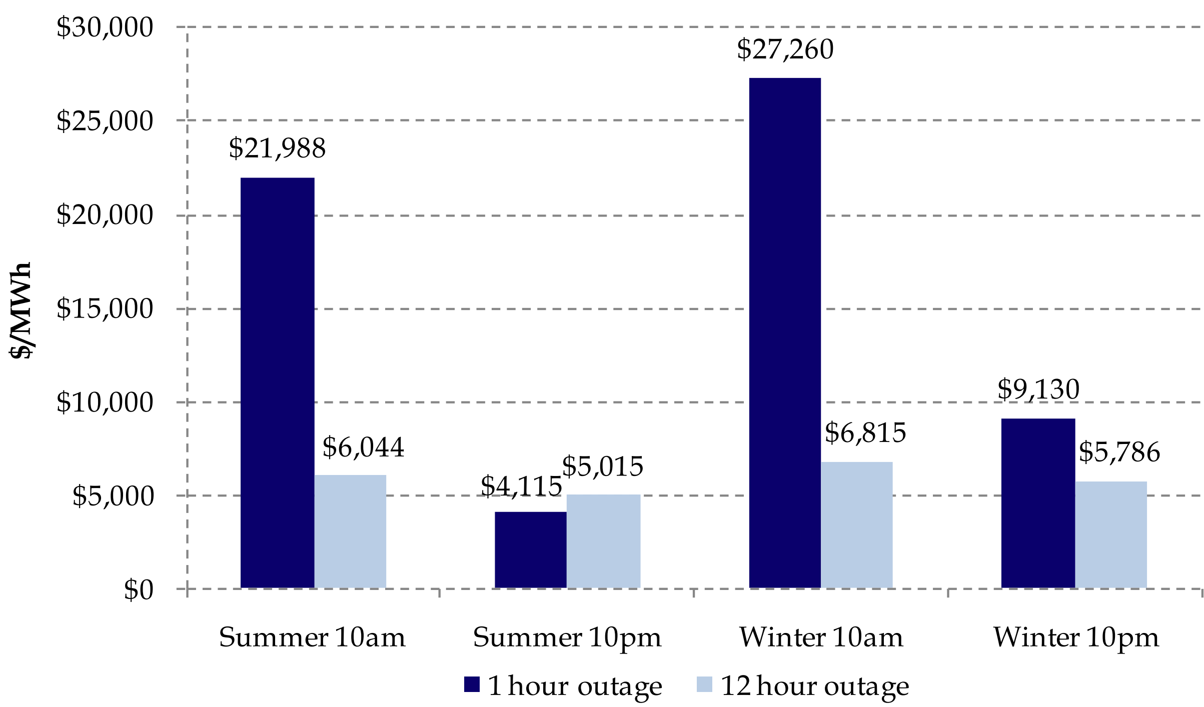
Figure 18. Mean VOLL for residential sector of Austria, classified by length of outage

Total Hours of Outage	1	4	12	24
VOLL ($/MWh)	1,800	4,886	12,730	22,245

All dollars are reported in 2012 USD

The timing and duration of the outage were incorporated in this study. This estimation method was then combined with a proprietary macroeconomic assessment model that simulates a power outage on an arbitrary day in the summer and winter at 10am and 10pm, and estimates the associated VOLLs of 1-hour and 12-hour outages. While activities were not differentiated, the WTP survey included demographic (income, gender) and outage timing and duration factors. Load levels were not differentiated. VOLLs were estimated for outages occurring at different times of year and of varying durations (i.e., 1- and 12-hour durations) for the combined residential and non-residential sectors. Short duration VOLLs were most costly, exhibiting and expected diminishing marginal cost of outage (see Figure 19).

Figure 19. VOLL for combined residential and non-residential sectors



The estimation was finally applied to a case study of 12-hour power outage that occurred on August 16, 2011 to estimate the sectoral loss of electricity (in GWh) and economic loss (€ million). The estimated implied VOLLs by sector are summarized in Figure 20. The sector VOLLs range widely, from a low of $857/MWh in the water supply sector to a high of $54,006/MWh in the construction sector.

Figure 20. Electricity loss, economic loss and implied VOLL during a 12-hour outage on August 16, 2011 (Austria study)

Sector Code	Sector	Electricity not supplied (GWh)	Total loss (mil $)	Implied VOLL ($/MWh)
A	Agriculture, hunting and forestry	1.7	7.6	4,463
B	Mining and quarrying	1	1.5	1,543
C	Manufacturing	34.4	146.6	4,261
D	Electricity, gas, steam and air conditioning supply	13.9	18.1	1,304
E	Water supply; sewerage; waste management and remediation activities	3.3	2.8	857
F	Construction	0.7	37.8	54,006
G	Wholesale and retail trade; repair of motor vehicles and motorcycles	3.6	161.0	44,719
H	Transportation and storage	4.7	35.6	7,578
I	Accommodation and food service activities	0.9	14.1	15,716
J	Information and communication	0.8	15.8	19,770
K	Financial and insurance activities	2.1	26.5	12,614
L	Real-estate activities	0.8	10.4	13,019
M	Professional, scientific and technical activities	1.4	23.0	16,441
N	Administrative and support service activities	1.1	18.4	16,716
OPQ RSTU	Public sector	8.5	58.6	6,898
TOTAL	Non-Residential consumers	78.9	578.2	7,329
TOTAL	Residential consumers	23.4	36.1	1,544
TOTAL*	Non-Residential and Residential consumers	102.3	614.4	6,006

All dollars are reported in 2012 USD

**LEI produced the Total results*

As already mentioned, sample data were generally representative, and this was verified by the authors. Sample sizes are moderately large, ranging from 201 respondents in the non-residential sector to 894 consumers in the residential sector. The level of disaggregation is high in this single-event case study, but low in terms of the mean VOLL and macroeconomic assessment-based VOLL reported. It is notable, as already mentioned above, that the timing and duration of the outage are incorporated in this study to produce mean residential VOLLs and macroeconomic assessment-based VOLLs by outage duration.

3.3.5.1 Comparability

The comparability table below shows that Austria exhibits limited comparability with ERCOT. Austria has a much higher population density and lower temperatures, peak demand and consumption, though it is comparable in terms of GDP per capita, customer mix and urban/rural mix.

Figure 21. Comparability table of Austria

Comparability Metric	Austria	ERCOT
Population density (ppl / sq mile)	264	101
Average temperatures (°F)	Winter: 27-37 Summer: 57-77	Winter: 49 Summer: 81
GDP per capita (2011 USD$)	64,619	49,543
Connection with other systems	Yes	Yes, but limited (SPP/Mexico)
Total annual consumption (MWh)	63,000,000 (2012)	335,000,000 (2011)
Peak Demand (MW)	12,000	63,379 (2011)
Customer Mix	35% residential 35% industrial 30% transport	38% residential 24% commercial 28% industrial
Urban : Rural	67.9% urban 32.1% rural	44% urban 56% rural
Wholesale Market?	Yes	Yes
Retail Market?	Yes	Yes
End-Use Customers have Smart Meter	Yes, there are currently smart meters installed in test regions	Yes
Peak Period	Summer Afternoon	Summer Afternoon

3.3.5.2 Key Takeaways

- Industrial sector (construction and automotive trade) VOLLs were the highest, commercial sector VOLLs are the next highest and agricultural and mining sectors VOLLs are the lowest in the overall non-residential sector;
- residential sector VOLLs are the lowest at $1,544/MWh;
- given moderate to low comparability to ERCOT, these values are not applicable to ERCOT but their relative rankings of VOLLs may be applicable to ERCOT; and
- an attribute of a robust sample process is that the sample data should be representative of the population (and this study tested explicitly for representativeness).

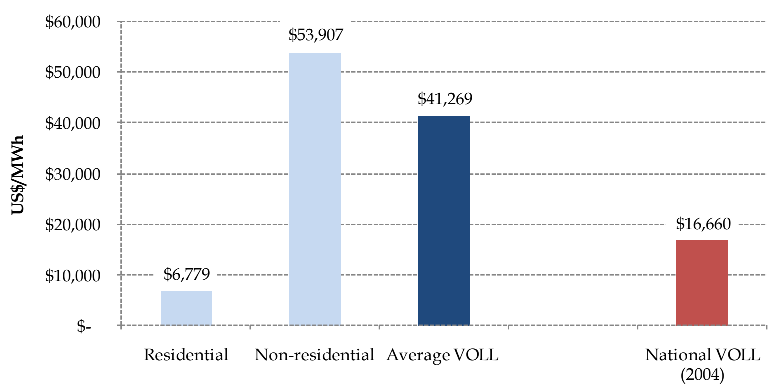
3.3.6 New Zealand

New Zealand	
Title:	"Investigation into VOLL in New Zealand" (2012)
Author(s):	New Zealand Electric Authority
Methodology:	Robust survey
Sample Data:	Representative, large
Disaggregation:	Low
Comparability:	Low

In 2008, the New Zealand Electricity Commission initiated an investigation into the appropriateness of the current VOLL and its application for purposes of transmission investment. The current VOLL of $16,600/MWh was set in 2004. As part of its investigation, the Commission conducted a survey of customers to determine their willingness-to-pay for reliable service. The report disaggregated results by customer class (residential and non-residential) and by customers' connection to the grid (grid connected and non-grid connected).[28]

The survey results, which reported a mean, load-weighted VOLL for an eight-hour outage, show an average VOLL for New Zealand of $41,269/MWh, well above the current VOLL (see Figure 22). Notably, a median value was not reported. The relatively high value estimated is also a function of "worst case" outage conditions – an 8-hour duration outage. LEI understands that further study and stakeholder consultation is currently underway and must be completed before a final recommendation on VOLL is made to the New Zealand Electricity Commission.

Figure 22. Estimated VOLLs in New Zealand (mean value, $/MWh)



**Values reported are load-weighted averages for an eight-hour outage during peak time (i.e., "worst case")*

[28] The separation of grid connected from non-grid connected customers in this study is likely a function of the VOLL's ultimate use – determining levels of transmission investment.

3.3.6.1 Methodology

The New Zealand study used a combination of mail surveys and in-person interviews to determine VOLL for different customer classes. The mail surveys, which were used for residential and small and medium C/I customers, used a stated choice approach. The surveys were mailed to 13,347 customers and 3,215 completed surveys were returned. This 24% response rate is relatively high for mail surveys. For large customers, a direct measurement, or revealed preference, survey was performed through in-person interviews. Once the survey responses (both stated choice and direct measurement) were received, they were analyzed to estimate VOLL. Extreme outliers were excluded.

Figure 23. New Zealand's Methodology Metrics

Methodological Metric	Comment
Survey Design	Stated choice survey for residential and small to medium C/I customers; direct measurement interviews for large C/I customers
Survey Delivery Method	Mail and interviews
Adjustment for Bias	▪ Cognitive and pilot testing was conducted to eliminate biases in the survey ▪ The study is careful to list the weaknesses of its results (valid only for customers that responded, likelihood for large regional variability) ▪ Results are sensitive to organizations studied, duration of outage and method of weighting responses
Sample Size	Large. Surveys were mailed to 13,347 consumers with 3,215 responses received; direct cost interviews conducted for 33 large customers
Degree of disaggregation	Low. Lists VOLL by residential/non-residential and by grid connected/non-grid connected
Macroeconomic data	None
Timing and duration of outage	8 hour outage during winter evening (New Zealand peak)

Overall, LEI found the survey methodology to be robust, and it the considerable attention spent on survey design was noteworthy. The stated choice surveys were subjected to two rounds of cognitive testing to ensure that the survey's questions were understood without assistance. The cognitive test process involved a researcher meeting face-to-face with a respondent and making observations while the respondent completed the questionnaire. Once the questionnaire was completed, the researcher asked the respondent about question clarity and flow, as well as understanding. As a result of this testing, changes were made to the surveys, including a decision to add an additional question on minimum compensation that would be required by the respondent in a worst case power outage. Surveyors noted that while the cognitive test ensured that the stated choice questions were understood, the changes gave rise to challenges in modeling and analyzing the results.

Direct measurement surveys, conducted during in-person interviews, were used to estimate VOLL for large electricity consumers. In total, 33 customers were interviewed, covering a range of sectors in various regions of New Zealand. In most cases, the estimated costs of outages were supported by financial records and records of costs incurred during actual outages.[29] During the

[29] The Chief Financial Officer of the company was often in attendance during the interviews.

interviews, customers were asked to quantify both direct and indirect costs of outages. Indirect costs include insurance, on-site generation, other redundant power supply arrangements, and reputational damage.[30]

3.3.6.2 Comparability

Comparability between New Zealand and ERCOT is low due to a variety of factors (see Figure 24). New Zealand and ERCOT differ in terms of consumption and demand, peak periods, climate and urbanization. The two regions also differ in fundamental economic dimensions such as structure and energy-intensity of the economy, productivity in electric-intensive industries and price levels. There are some similarities in market design and customer mix. However, the New Zealand system is several orders of magnitude smaller than ERCOT. Furthermore, the New Zealand system is essentially composed of two smaller grids (North Island and South Island) connected via a high voltage direct current ("HVDC") link.

Figure 24. New Zealand Comparability to ERCOT

Comparability Metric	New Zealand	ERCOT
Population density (ppl / sq mile)	42	101
Average temperatures (°F)	Winter: 50-59 Summer: 68-86	Winter: 49 Summer: 81
GDP per capita (2011 USD$)	38,563	49,543
Connection with other systems	No	Yes, but limited (SPP/Mexico)
Total annual consumption (MWh)	40,700,000 (2011)	335,000,000 (2011)
Peak Demand (MW)	6,330	63,379
Customer Mix	35% residential 29% commercial 36% industrial	38% residential 34% commercial 28% industrial
Urban : Rural	86% urban 14% rural	44% urban 56% rural
Wholesale Market?	Yes	Yes
Retail Market?	Yes	Yes
End-Use Customers have Smart Meter?	Yes, 42% penetration	Yes
Peak Period	Winter Evening	Summer Afternoon

3.3.6.3 Key Takeaways

In addition to establishing an average VOLL and VOLL by customer class, the New Zealand survey yielded some key observations that are confirmed as well by other survey studies:

- VOLL varies widely across C/I sectors (i.e., agriculture, services, etc.);

[30] Some of these costs (insurance, back-up generation) were included in direct costs. Reputational damage was particularly important to respondents.

- in-person interviews with the larger C/I customers revealed that companies have a wide range of energy risk management practices, and few have invested in alternative energy supplies; and

- relatively short outages can result in significant losses of production (hours or even days) for some companies. Surveys targeted at commercial and industrial customers should include questions to determine the impact of various duration outages on production re-start and opportunity to "make-up" for lost production.

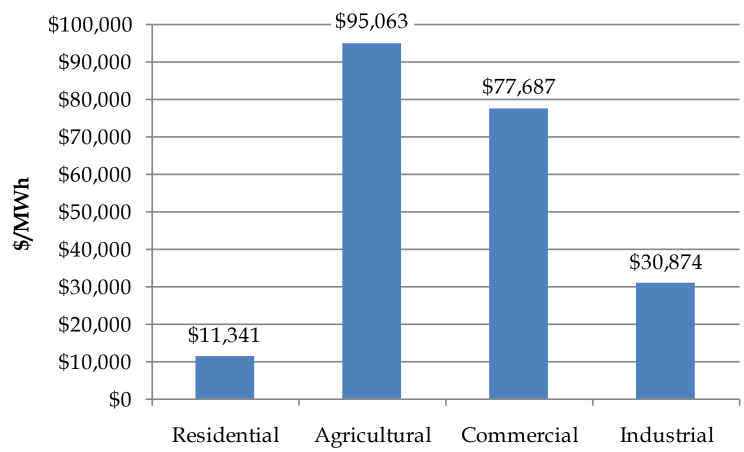
3.3.7 Australia – State of Victoria

Australia – State of Victoria	
Title:	"Assessment of the Value of Customer Reliability (VCR)"
Author(s):	CRA International
Methodology:	Robust survey
Sample Data:	Representative and moderate
Disaggregation:	Moderate, standard sectoral VOLLs
Comparability:	Moderate to low, multiple differences in population density, peak demand, consumption, urban/rural mix, similarity in temperature ranges

3.3.7.1 Methodology

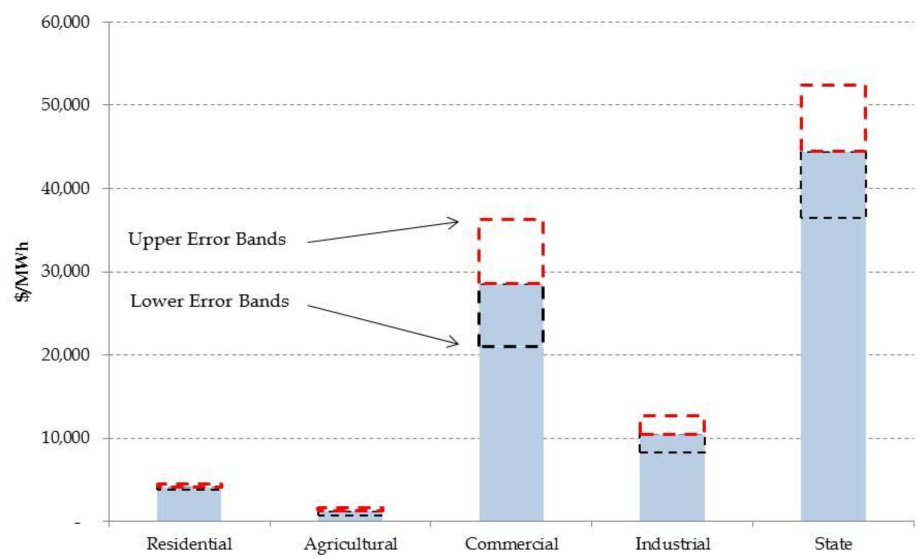
This is a 2008 survey study that employs a combination of stated choice and revealed preference methods to estimate VOLL for the state of Victoria in Australia. The purpose of the study was to assess the market benefits of transmission investment in Victoria. For the non-residential sector, which includes the agricultural, commercial and industrial sectors, revealed preference survey methods were used. For the residential sector, a stated choice survey was conducted to gauge willingness-to-pay. The concept behind this type of survey is known as economic substitution, wherein the respondents select a set of activities that they would engage in to mitigate the outages of various durations. Durations included 20 minutes, 1, 2, 4, 8, and 24 hours. Activities are pre-assigned with associated costs. The surveys also gathered information on respondents' energy consumption, which was used to estimate the value of unserved energy, or "USE". USE is then used to estimate the statistical probability values of sectoral and state level VOLLs. Sector level VOLLs were developed by weighting VOLLs for each duration interval by its associated probability and adding up weighted values. Sector VOLLs from this study are presented in Figure 25.

Figure 25. Sectoral VOLLs in Victoria, Australia



The state level VOLL was calculated by weighting each sector level VOLL by total annual electricity consumption as a proportion of total state consumption and then by adding up weighted values. Mean weighted sector level VOLLs and the mean state level VOLL are reported in the study and summarized below, including weighted error bands reflecting 95% confidence intervals from a distribution of mean VOLLs. Note that the state level VOLL is a simple addition of the weighted sector level VOLLs, but the state level error band is not a simple addition of the constituent error bands.

Figure 26. Weighted sectoral and state level VOLLs with error bands in Victoria, Australia



Questionnaires were mailed, with a cover letter from staff on the transmission system operator's letter head and a self-addressed, stamped return envelope was provided. Follow-up reminder calls were also made to encourage questionnaire completion. The study states that respondents in each sector were representative samples of each sector. Sample data were also cleaned and adjusted for bias. For example, survey responses that indicated VOLL levels that were six standard deviations from the mean for each sector and duration were considered outliers and were thus removed from sample. Sample sizes were moderately large as 2,870 surveys were sent with a target response of 1,200. In the end, 920 surveys were returned, resulting in an actual response rate of 32%. After consideration of completeness, actual usable surveys totaled 821, resulting in a usable rate of 68%. A usable survey is one with answers sufficient enough to be used for analysis. Both percentages are considered high by survey specialists. Large commercial and large industrial consumers' usable rates were low at 8% and 38%, respectively, and the study's authors explain that this was likely due to insufficient time to assess the costs of outages to their business activities. By disaggregating between residential, agricultural, commercial and industrial, this study's level of disaggregation is moderate and standard.

3.3.7.2 Comparability

The comparability table below shows that Victoria exhibits limited comparability with ERCOT. Victoria has lower population density, peak demand, consumption and rural population percentage. Much of these characteristics can be explained by Victoria's land size and coastal population. Peak period and GDP per capita are similar.

Figure 27. Comparability table of Victoria, state in Australia

Comparability Metric	Victoria (in Australia)	ERCOT
Population density (ppl / sq mile)	64	101
Average temperatures (°F)	Winter: 44-59 Summer: 57-79	Winter: 49 Summer: 81
GDP per capita (2011 USD$)	59,378	49,543
Connection with other systems	Yes, within NEM	Yes, but limited (SPP/Mexico)
Total annual consumption (MWh)	56,250,000 (2012)	335,000,000 (2011)
Peak Demand (MW)	9,378 (2012)	63,379 (2011)
Customer Mix	*Data not available*	38% residential 24% commercial 28% industrial
Urban : Rural	93.5% urban 6.5% rural	44% urban 56% rural
Wholesale Market?	Yes	Yes
Retail Market?	Yes	Yes
End-Use Customers have Smart Meter	In process of rolling out to small businesses by end of 2013	Yes
Peak Period	Summer Afternoon	Summer Afternoon

3.3.7.3 Key Takeaways

In this study, we observe that the agricultural VOLLs are the highest. This may be due to the fact that the agricultural sector is less prepared, or less able, to mitigate the full costs of an electricity outage compared to the commercial and industrial sectors. Note, however, that on a weighted basis, weighted agricultural sector VOLL is the lowest. Commercial and then industrial VOLLs are the next highest, with residential VOLL being the lowest of all the VOLLs established in this study. In terms of specific VOLL values, given Victoria's moderate to low comparability to ERCOT, these observations are not directly applicable to ERCOT. However, this survey presented several best practices in survey design and implementation:

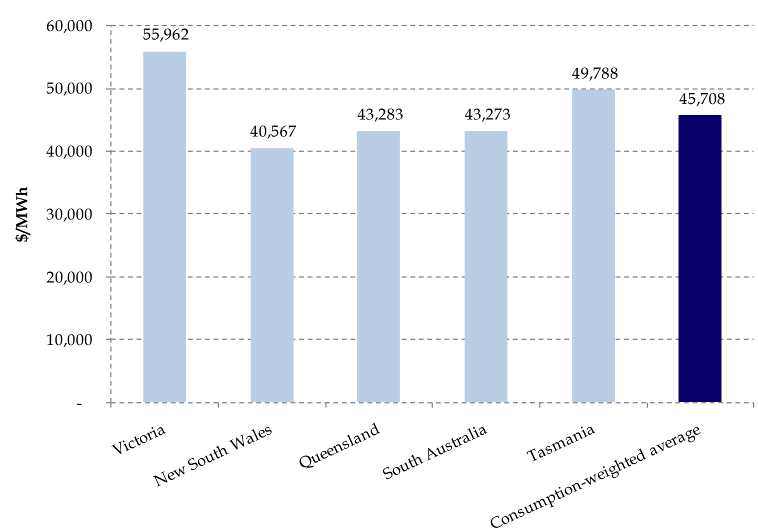
- sample data cleaning, such as the removal of outliers, is likely needed to reduce bias in VOLL estimates;
- reporting both response rate and usability rate is important. If the survey is returned but is largely incomplete, it is unusable and not any more helpful than an unreturned survey.

3.3.8 Australia – National

Australia - National	
Title:	"Valuing Reliability in the National Electricity Market" (2011)
Author(s):	Oakley Greenwood prepared for the Australian Energy Market Operator
Methodology:	Study of a survey study
Sample Data:	Not relevant
Disaggregation:	Low, state and national level VOLLs
Comparability:	Low, due to Australia's large land size, low population density and highly variable demographic and climatic attributes

This national Australia study used the survey data of the Victoria study to derive, through modifications, a national level VOLL estimate for the country of Australia. Victoria state level VOLL results were extrapolated to the other Australian states with the use of sectoral outage probabilities and electricity consumption trends, and then escalated to 2011 levels by multiplying the estimates by annual percentage changes in sectoral productivity indices. These state level VOLLs and state consumption percentages were then used to derive a consumption-weighted average national VOLL estimate. Note that in extrapolating Victoria VOLLs to other states, no consideration was given to demographic differences between states, such as income distribution and income levels, age distribution, urban/rural mix or climatic considerations (and resulting differences in consumption patterns). In the non-residential sector, no adjustment was made with respect to size and type of C/I customers or alternative energy availability.

Figure 28. State level and national VOLL estimates for Australia



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Victoria and Tasmania VOLLs are highest due to relatively higher probabilities of an outage occurring that would last between 1 and 4 hours. Given diminishing marginal cost of outage (over duration of outage), the probabilities concentrated in the lower range of duration of outages carry greater weightings in the extrapolation of VOLL levels to other states.

3.3.8.1 Methodology

Because this national study is based on the survey study for Victoria, LEI's comments on survey design, implementation and sample data, are discussed in Section 0.

3.3.8.2 Comparability

As shown in Figure 29 below, Australia as a whole has very low comparability with ERCOT. Australia has much lower population density, peak demand, rural population percentage and wide variation in temperature given its land size. Economic development on the basis of GDP per capita is somewhat similar.

Figure 29. Comparability table of Australia

Comparability Metric	Australia	ERCOT
Population density (ppl / sq mile)	7.3	101
Average temperatures (°F)	Winter: 33-91 Summer: 51-97 *Variability is huge given Australia's land size*	Winter: 49 Summer: 81
GDP per capita (2011 USD$)	60,979	49,543
Connection with other systems	No	Yes, but limited (SPP/Mexico)
Total annual consumption (MWh)	225,000,000 (2012)	335,000,000 (2011)
Peak Demand (MW)	13,781	63,379
Customer Mix	28% residential 23% commercial 49% industrial	38% residential 24% commercial 28% industrial
Urban : Rural	89% urban 11% rural (2010)	44% urban 56% rural
Wholesale Market?	Yes	Yes
Retail Market?	Yes	Yes
End-Use Customers have Smart Meter	No	Yes
Peak Period	Summer Afternoon	Summer Afternoon

3.3.8.3 Key Takeaways

This national study is useful in demonstrating techniques of extrapolation from one region to another, but it could have been improved by considering more detailed demographic and technical differences among regions, rather than just outage probabilities and electricity consumption.

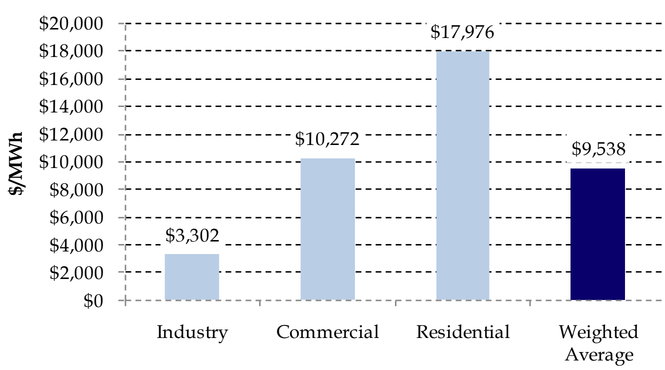
3.3.9 Republic of Ireland (2010)

Republic of Ireland (2010)	
Title:	"An Estimate of the Value of Lost Load for Ireland" (2010)
Author(s):	Leahy and Tol from Trinity College Dublin and Vrijie Universiteit, Amsterdam
Methodology:	Macroeconomic, with some survey data
Sample Data:	Not relevant
Disaggregation:	Moderate, standard sectoral VOLLs
Comparability:	Moderate to low, due to differences in population density, weather, peak demand and period

3.3.9.1 Methodology

This is a 2010 macroeconomic study of VOLL for Ireland, focusing on the Republic of Ireland.[31] The study uses the production function approach, whereby VOLL is calculated as Gross Value Added ("GVA") divided by electricity consumption. For the non-residential sector (i.e., commercial and industrial) annual sectoral GVA and electricity consumption profiles were used. For the residential sector, survey data on intraday, hourly residential activities was used in combination with assumed monetary values representing opportunity costs for various residential activities. For example, a zero opportunity cost was assigned to the consumer who is not at home or is at home and sleeping; opportunity cost of average wage after tax was assigned to the consumer who is at home and working; opportunity cost of half of the average wage after tax was assigned to the consumer who is at home and is neither working nor sleeping.

Figure 30. Estimated sectoral VOLLs for the Republic of Ireland



[31] Only the residential sector of Northern Ireland was reported, and we did not consider this result to be comprehensive enough to warrant reporting here.

The core method of this VOLL study is production function approximations. However, survey data were used in the residential sector. This survey data provided information on the intraday, hourly activities of a typical residential customer. Activities were assigned monetary values, which is the basis for residential VOLL. The degree of disaggregation is moderate. While the timing of the outage was incorporated in the study, the duration was not.

It is important to note that the residential VOLL is much higher than the industry and commercial VOLLs in this study. This may be because in the residential analysis, the monetary values assigned to residential activities may have been set too high, or residential activities from the survey data were outdated. On the other hand, it could be that the GVAs reported for the C/I sectors were outdated or underestimated the true production value lost because it did not account for knock-on effects of a sector losing power. Overall, this highlights one of the dangers of using macroeconomic approach: a high level, top-down approach can lack granularity and hence accuracy when producing VOLL estimates, especially if timing and duration are critical characteristics of the outage being studied.

3.3.9.2 Comparability

The comparability table below shows that the Republic of Ireland exhibits limited comparability with ERCOT. There are dissimilarities in population density, weather, peak demand and peak period.

Figure 31. Comparability table of Republic of Ireland

Comparability Metric	Ireland	ERCOT
Population density (ppl / sq mile)	168	101
Average temperatures (°F)	Winter: 42 Summer: 58	Winter: 49 Summer: 81
GDP per capita (2011 USD$)	48,423	49,543
Connection with other systems	Yes, but limited to Northern Ireland UK	Yes, but limited (SPP/Mexico)
Total annual consumption (MWh)	26,100,000 (2012)	335,000,000 (2011)
Peak Demand (MW)	5,090	63,379
Customer Mix	*To be determined*	38% residential 24% commercial 28% industrial
Urban : Rural	62% urban 38% rural	44% urban 56% rural
Wholesale Market?	Yes	Yes
Retail Market?	Yes, but limited	Yes
End-Use Customers have Smart Meter	No	Yes
Peak Period	Winter Evening	Summer Afternoon

3.3.9.3 Key Takeaways

Overall, the low applicability of this region to ERCOT and the unusual differences between the residential and non-residential VOLLs show that these results are most likely not directly applicable to ERCOT:

- with respect to the non-residential sectors, input data are accessible but simplified because it is annualized, resulting in an output of the VOLL estimate which is also simplified. VOLL estimate should be more granular and sensitive to seasonal or intraday timing and duration of outages;

- with respect to the residential sector, assumptions need to be made with respect to intraday activities and monetary values need to be assigned, and:
    - monetary values can be arbitrary and based on input data that are not granular enough;
    - activities not requiring electricity may represent value *not* lost and if unaccounted for may lead to overestimation of VOLL.

3.3.10 Republic of Ireland (2007)

Ireland (2007)	
Title:	"The Value of Lost Load, the Market Price Cap and the Market Price Floor"
Author(s):	All Island Project
Methodology:	Microeconomic
Sample Data:	Not relevant
Disaggregation:	Low, generic VOLL
Comparability:	Moderate to low, due to differences in population density, weather, peak demand and period. See section 0.

3.3.10.1 Methodology

This is a 2007 non-survey study of VOLL. It applies a "generation security standard" to estimate VOLL for the country of Ireland. The purpose of the study was to estimate a VOLL figure to then estimate load- and generation-based capacity payments.

VOLL is calculated as equal to or less than fixed cost of a peaking plant divided by security standard, D, plus the variable cost of a peaking plant:

$$\text{VOLL} \leq \text{Fixed Cost of Peaker} / D + \text{Variable Cost of Peaker}$$

The security standard, D, is the optimal annual average duration of interruptions to supply and is measured in hours.[32] The VOLL was reported to be between $13,330/MWh and $16,941/MWh in 2012 USD, depending on the assumed costs of a peaker in the study.

Figure 32. Generation security standard VOLL for Ireland 2007-2008

	Nov-Dec 2007	Jan-Sep 2008	Weighted Average
VOLL ($/MWh)	13,330	16,941	16,265

All dollars are reported in 2012 USD

This generation security standard approach is a microeconomic approach. It is a non-survey method for setting a VOLL estimate and does not employ survey and statistical analysis of survey data. There is no survey design, survey delivery method, adjustment for bias or sample size. The degree of disaggregation is low as there is neither regional nor sectoral disaggregation. The study acknowledges that it may be theoretically better to estimate VOLL using survey data and that the use of fixed and variable costs of a peaking plant and security standard is not

[32] The algorithm used to optimize D was not disclosed by the authors.

strictly a measure of VOLL in terms of the marginal value of lost load, instead it is strictly a measure of cost required to reduce load shedding to the optimal annual average duration of interruptions to supply, i.e. security standard, D (which is 8 hours in this study).[33]

3.3.10.2 Comparability

Please see Section 3.3.9.2.

3.3.10.3 Key Takeaways

It should be noted that the estimated VOLL using this proxy method for ensuring reliability with new generation is higher than the VOLL estimated using macroeconomic, production function techniques in the 2010 Republic of Ireland study. VOLL in this study is not strictly a measure of value of lost load from the consumers' perspective, but rather a measure of cost required to reduce load shedding to the optimal annual average duration of interruptions to supply. The security standard algorithm is based on a constrained optimization problem that is required to produce the security standard, D.

[33] James Curtin and Tony Doherty. *The Value of Lost Load, the Market Price Cap and the Market Price Floor.* July 2, 2007. Pages 4-5.

3.3.11 United States – Northeast, and Ontario, Canada

United States – Northeast, and Ontario, Canada	
Title:	"The Economic Cost of the Blackout"
Author(s):	ICF Consulting
Methodology:	Weak form of macroeconomic study of an actual outage event
Sample Data:	Not relevant
Disaggregation:	Low, generic VOLL

This is a 2003 study of the economic costs associated with an actual outage event – the Northeast Blackout, which occurred in the US on August 14, 2003. This was an actual outage and therefore had specific characteristics related to length and duration of outage. The Northeast Blackout was a widespread outage, cascading throughout 8 states in the Northeast and the Midwest of the US and Ontario, Canada. The outage began at approximately 4pm EST and lasted between 5 to 10 hours (depending on the region). The outage led to a temporary loss of more than 61,800 MW of generating capacity and affected more than 50 million people.[34] The study of this outage assumes VOLL as a multiple of retail electricity price, and uses this assumed VOLL level to calculate total economic cost of an outage – that is, VOLL is not an output but an intermediary input in the analysis.[35] The economic cost is then estimated by multiplying the average value of electricity and the magnitude and duration of the blackout. The value of electricity is estimated by the assumed VOLL, a multiple of the average retail electricity price – multiples of 80 and 120 were used. Since retail electricity prices for the event were not available at that time of the study, the average region-wide retail price as of August 2002 was used as a proxy for the retail price of the event (which took place August 2003). An average price was used to smooth out regional variations in retail prices. The average retail price was estimated at $93/MWh.

The study concluded that the total economic costs of this outage event amounted to $7 to $10 billion (in current dollar terms), as summarized in Figure 33.

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[34] NERC. *August 14, 2003, Northeast Blackout Impacts and the Actions and the Energy Policy Act of 2005*. <http://www.nerc.com/docs/docs/blackout/ISPE%20Annual%20Conf%20-%20August%2014%20Blackout%20EPA%20of%202005.pdf>

[35] Case studies' methodology will depend on the purpose of the case study.

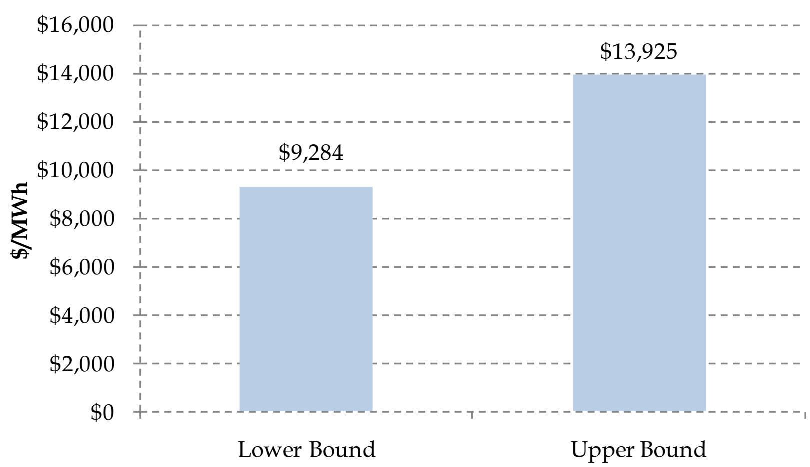
Figure 33. Total Economic Cost of the Northeast Blackout 2003

Approximate Start Time	Approximate End Time	Lost Megawatt	Duration		Cost of Blackout ($ Billion 2003 USD)		Cost of Blackout ($ Billion 2012 USD)	
		MW	Hour	MWh	Lower Bound	Upper Bound	Lower Bound	Upper Bound
8/14 - 4 PM	8/14 - 8 PM	61,800	4	247,200	$ 1.8	$ 2.8	$ 2.2	$ 3.5
8/14 - 8 PM	8/15 - 6 AM	30,900	10	309,000	$ 2.3	$ 3.4	$ 2.9	$ 4.2
8/15 - 6 AM	8/15 - 10 AM	15,450	4	61,800	$ 0.5	$ 0.7	$ 0.6	$ 0.9
8/15 - 10 AM	8/16 - 12 AM	13,200	14	184,800	$ 1.4	$ 2.1	$ 1.7	$ 2.6
8/16 - 12 AM	8/16 - 10 AM	6,600	10	66,000	$ 0.5	$ 0.7	$ 0.6	$ 0.9
8/16 - 10 AM	8/17 - 6 AM	2,000	20	40,000	$ 0.3	$ 0.4	$ 0.4	$ 0.5
8/17 - 6 AM	8/17 - 4 PM	1,000	10	10,000	$ 0.1	$ 0.1	$ 0.1	$ 0.1
Total Economic Cost					$ 6.8	$ 10.3	$ 8.5	$ 12.9

Total is rounded to one decimal point

The lower and upper bound of the assumed VOLL were set equal to 80 to 120 times the retail price of electricity of $93/MWh, which is $7,440/MWh and $11,160/MWh in 2003 USD ($9,284/MWh and $13,925/MWh in 2012 USD), as documented in the figure below.

Figure 34. Lower and upper bound VOLLs assumed in study



This particular macroeconomic study uses quantitative analysis but does not employ survey and statistical analysis of survey data. There is no survey design, survey delivery method, no requirement for the adjustment for bias because there is no sample size. The degree of disaggregation is low as there is neither regional nor sectoral disaggregation. The actual outage event affected 8 US states and Canada and lasted between 5-10 hours overlapping peak and non-peak hours. However, the method applied in this study could not differentiate across geographical regions or account for timing of outage. The use of the average August 2002 retail price to represent the event price also means that it did not represent actual specific prices.

3.3.11.1 Key Takeaways

The 2003 Northeast Blackout Study by ICF is an example of a macroeconomic study estimating total economic loss based on assumed VOLL estimates in conjunction with foregone electricity consumption. A multiple of 80 and 120 times the retail price was used to estimate the lower and upper bounds of VOLL – which equaled $9,284/MWh and $13,925/MWh in 2012 USD respectively; the retail price of $93/MWh was based on the regional and seasonal average retail price for the Northeast.

Both multiples and retail price determinations should be regarded as macroeconomic, high-level estimates of factors used to estimate VOLL. These determinations are highly subjective as well and a change in the multiple will lead to a multiplicative change in the assumed VOLL levels (e.g. a multiple of 160 instead of 80 doubles the VOLL estimate).[36]

This study's VOLL estimates as useful proxies for ERCOT is therefore limited because this method does not examine the relationship between VOLL and the outage event, but rather makes certain assumptions about VOLL parameters and VOLL. Also, the region studied has low comparability with ERCOT, further limiting the usefulness of the study's VOLL estimates.

[36] These multiples were chosen without detailed data analytical justification.

3.4 Lessons learned

In reviewing these 10 jurisdictional studies, we have gained several insights in VOLL estimation and methodology. We have separated these insights into three areas:

1. ***General observations*** about VOLL, including trends in VOLL estimates. These trends may serve as a benchmark against ERCOT-specific survey results, if these are developed in the future.

2. ***Observations related to the methodological approach*** used to estimate VOLL. These include observations about which approaches have been the most successful for each customer class.

3. ***Observations specific to survey design and analysis***. These include best practices for survey questionnaire development and survey processing.

With respect to the item (2) above, across all studies where surveys were conducted, stated choice surveys were used for residential customers while revealed preference surveys were used for large industrial customers. This observed trend is also consistent with theoretical considerations of survey application. In relation to item (3), the survey-based studies also underscore the importance of pre-testing surveys to ensure that questions are properly understood and minimize any challenges respondents may have in completing the survey. This will enhance the "usability" rate and robustness of the responses. Careful post-processing to eliminate biases is also important to providing a well-founded and well-supported estimate of VOLL. Ultimately, the lessons learned from careful study of existing VOLL literature and empirical studies may assist ERCOT in future work on customer surveys of VOLL.

<u>General Observations:</u>

1. **VOLL estimates are highly sensitive to several factors, including customer profile (different customers will have different valuations they put on electricity service),[37] timing and duration of outage, and the weighting of responses.**

    - In general, small C/I tend to have higher VOLLs than large C/I; mining and manufacturing tend to have higher VOLLs than other industry sectors; VOLL is highest for small to medium C/I customers and lowest for residential customers

    - Load-weighted averages are often in the $30,000 - $40,000 per MWh range

    - Residential VOLLs in the US are in the $1,000 – $4,000 range, while VOLLs in international jurisdictions tend to be much higher. This variation may be due to a variety of factors, including different consumption patterns and costs of

[37] In addition, customer class definition can differ both by sector and how they are defined, making comparison across jurisdictional studies more difficult.

electricity in the regions studied, as well as the different methodologies used to estimate VOLL in each study.

2. **VOLLs based on non-survey techniques (e.g., macroeconomic analysis) are highly sensitive to assumptions, which should be tested and further supported by reasonable external evidence (Northeast Blackout, Republic of Ireland).**

   - For example, case studies using a multiple-of-retail price approach to establish VOLL (the Northeast Blackout of 2003 study used multiples of 80 and 120) essentially assume a VOLL, rather than estimate a VOLL**.** If the assumed multiples are modified, this would dramatically change the estimated VOLL.

   - In addition, VOLL studies for the residential sector that look at the value of leisure activity also need to subjectively monetize such activities. For example, the Republic of Ireland study (2010) assumed only three types of opportunity costs (zero, full wage, half wage) for all residential activities during an outage – this metric can likely be improved by accounting for age, income level and intra-regional geographical distributions, as well as further disaggregation of leisure activities.

3. **For distributional estimates of VOLL, reporting of median results may be more reasonable than reporting the mean values, since underlying distributions can be strongly right-skewed (Berkeley, MISO).**

   - This distributional outcome can be mitigated to some degree if sample data, such as costs related to outages, can be cleaned of outliers[38] (Victoria, US National, US MISO).

[38] In order to analyze adjustments for outliers, one must first identify outliers and then consider whether they should be removed or retained as part of the sample. There are two common methods to identify outliers in a data set. The first method is to locate outliers graphically. Using a scatterplot of a response variable (i.e., VOLL) against an explanatory variable (e.g. duration of outage), or a residual plot of residual of a multiple regression model against an explanatory variable, outliers can be located visually. The second method is by using a studentized residual, given by the expression $t_i = \frac{r_i}{StdErr(r_{-i})}$ where r_i is the residual for observation *i* and $StdErr(r_{-i})$ is the standard error of residuals excluding observation *i*. The higher the absolute value of the studentized residual t_i, the more likely that it is an outlier. To decide whether to discard an outlier, formal statistical tests can be applied to determine a cut-off point for t_i, but often in econometric or statistic practice, one should turn to qualitative and contextual considerations as well. First, after identifying an outlier, one should check for data entry errors related to the outlying observation. In surveys, data entry error by the survey designer may be detected and corrected but not if the error is caused by the survey taker. Second, one should check how the fitted model changes if the outlying observation is discarded and question whether the fitted model makes sense logically or intuitively. While the presence of the outlying observation can greatly affect the fitted model, it may also convey significant information that is pertinent to the study's objectives. In summary, outliers can be identified graphically and quantitatively, but the decision to discard them depends on qualitative and contextual considerations.

4. **Studies that have tried to combine the results from multiple surveys into a single database have exhibited a large range in VOLL estimates depending on location and customer class (Berkeley, MISO).**

    - MISO and Berkeley each define large and small C/I differently, which may impact the reported results and therefore make comparability to other jurisdictions more difficult.

5. **Recent VOLL studies often relied on results from past surveys rather than conducting new surveys. This observation is consistent with practical concerns related to the effort and expense of executing a customer survey. However, the costs of conducting a customer survey must be weighed against the need for updated information. Relying on prior surveys means that the updated study is not reflecting the latest information on customer consumption patterns and willingness to pay.**

    - The meta-database used for the US and MISO estimates contain data going back to 1989 – customers' views on outages and costs of operation, as well as electric consumption patterns have changed since then (although these two surveys rank "highest" as their comparability was closest to ERCOT).

    - For example, residential VOLLs may now be higher due to the increased use of electronics in households (home computers, DVDs, etc.). This may impact the relevance of the results for the Southwest, which were based on a survey done in 2000.

    - Residential customers were often contacted by mail; sample sizes in aggregate are in the thousands per region, which indicates that a very small portion of the total population was surveyed.

    - Response rates and usability rates can be low because questionnaires are often time-consuming for respondents – this can discourage the researcher or sponsor from taking the survey approach. On the other hand, careful survey design and pre-testing can assist in refining the survey questionnaire to increase response rates and usability.

    - Statistically robust surveys are time-consuming to design and implement. Nevertheless, they have been implemented by a number of jurisdictions because of the value they can provide to policymakers and regulators.

Observations on Methodology:

6. **VOLL studies using a macroeconomic approach (e.g., production function methods) appear to have estimated C/I VOLLs that are well below other approaches while the residential VOLL is significantly higher (Republic of Ireland, 2010).**

    - The novel approach for estimating residential sector VOLL in the Republic of Ireland (2010) VOLL study appears to be sensitive to the assumptions made, highlighting the shortcomings of relying solely on macroeconomic analysis.

7. **Studies using a combination of stated choice for residential consumers and revealed preference for non-residential consumers appear to be the standard in survey studies of VOLL.**

   - Survey questions need to be carefully designed to not bias responses.

   - If revealed preference surveys are conducted in-person, having the CFO or equivalent in attendance to provide supporting documentation from financial records is useful.

<u>Observations on Survey Design and Analysis</u>

8. **Sample data should be tested for representativeness (Austria).**

9. **Sample data may need to be examined for extreme outliers, and adjustments may need to be made for potential biases (Victoria, MISO, Berkeley).**

10. **Pre-testing survey questionnaires can ensure that questions are well-understood and increase the "usability" rate of responses, but may create challenges in post-processing and modeling of survey responses (Victoria, New Zealand).**

4 Macroeconomic Analysis

Macroeconomic analysis can be used to provide indicative estimates of foregone economic value when electricity service is disrupted. Although such analysis has a number of shortcomings, it can nevertheless provide estimates of VOLL that can serve as useful independent reference points to cross-check customer survey results. To demonstrate the method, LEI used a production function approach to calculate implied VOLL levels for non-residential customers at both the Texas and ERCOT levels using 2011 Gross Domestic Product ("GDP") data. LEI also prepared a preliminary VOLL calculation for residential customers by relying on the direct cost of electricity paid for by retail customers, i.e. average household electricity bills. This approach will understate the VOLL for residential customers because it does not consider the foregone value of leisure activities or other indirect costs.

4.1 Approach and methods

A number of macroeconomic analysis methods have been described in the economic literature for VOLL estimation. A macroeconomic analysis approach estimates VOLL indirectly through the examination of variables related (more or less closely) to the costs of power supply interruptions. These methods are useful as a complement, but not substitute, to more detailed analysis using market behavior observations, surveys, or event case studies. Under macroeconomic analysis methods, the choice of variable will depend on the customer class for which a VOLL estimate is being developed. In addition, depending on the variable used in the analysis, the implied VOLL result may provide an upper or a lower bound to the VOLL estimate range. Commonly referenced macroeconomic analysis methods include:

- **GDP to load:** For estimates of the productive sectors' VOLL, i.e. commercial and industrial ("C/I") customers, a macroeconomic approach ("production function" approach) is often used.[39] Under this approach, the implied VOLL is equal to the ratio of GDP to the quantity of electricity consumed (or load). The approach assumes that average VOLL equals the average cost of lost production, which in turn equals the average foregone value-added per MWh of supply shortage;
- **Wage differential:** For estimates of households' VOLL (i.e., residential customers), a wage-differential approach has been used to relate power interruptions to a value of lost leisure time.[40] The approach assumes that the hourly value of leisure is equal to hourly wage and that the VOLL equals the hourly value of leisure multiplied by a coefficient, which will vary with the importance of power supply for typical household activities at various times of the day; and

[39] The VOLL for residential customers cannot be estimated using this approach as the residential customer class typically consumes its electricity during leisure activities, which do not contribute to GDP. *See:* Leahy & Tol. *An estimate of the value of lost load for Ireland.* ESRI working paper, No. 357. 2010.

[40] This approach relies on underlying survey data in which customers provide information on how their time during the day is spent (i.e., at home during leisure time, at home working, not at home, etc.). No similar information is available for Texas or the ERCOT region, therefore, LEI was unable to estimate VOLL using the wage-differential approach. *See:* Leahy & Tol. *An estimate of the value of lost load for Ireland.* ESRI working paper, No. 357. 2010. *See also:* M. de Nooij et al. *The value of supply security the costs of power interruptions: Economic input for damage reduction and investment in networks.* Energy Economics. July 2006.

- **Bill to consumption:** Generally, the ratio of electricity bills to total power consumption ("bill-to-consumption approach") provides a reasonable lower bound for VOLL estimates of various customer classes.[41] Indeed, if customers are rational, their VOLL has to be ***at least*** equal to the rate they pay for each MWh of supply.

Given the data employed in the above methods, we must recognize a number of shortcomings to macroeconomic analysis methods:

- These approaches provide "averages". That is, the implied VOLL results do not account for either the timing or duration of an outage, as they rely on annualized GDP and wage data. However, interruption costs may vary significantly with duration and with the season of the year, the day of the week, and even time of day.
- Macroeconomic analysis methods assume a linear relationship between interruption duration and total interruption costs, which may well not be the case. For example, C/I customers may incur large costs during the first hours of an outage, but as operations shut down and employees are sent home, the cost curve will flatten out. On the other hand, some sectors may see costs increase after a certain duration threshold as equipment is damaged (e.g., aluminum pot smelters "freeze over") or merchandise is lost (e.g., refrigerated products);
- The production function method tends to underestimate actual VOLL in the short-run as indirect and induced effects (restart costs, damage to equipment, or hazards to the labor force) are not incorporated;
- The bill approach tends to underestimate VOLL in the short-run as it does not account for indirect costs (e.g., spoiled food) and the value of lost leisure time (e.g., missing a favorite TV show);
- The wage-differential method tends to overestimate the VOLL attributed to residential customers, as certain leisure time activities (e.g., outdoors activities) are not necessarily impacted by electric service outages. However, the results from this method are sensitive to the assumptions made and may result in under-estimations in case wage coefficients were understating the importance of power supply for various times of the day; and
- All macroeconomic analysis methods tend to overestimate VOLL in the long-run as improvements in conservation and energy efficiency occur or frequent outages impact consumer behavior and expectations regarding services.

Nevertheless, indicative estimates from a macroeconomic analysis will provide a useful independent reference point to cross-check any potential future survey results.

Macroeconomic analysis methods also have the advantage that they require few and readily available data inputs that are not subject to dispute, such as GDP and metered consumption. Therefore, macroeconomic analysis methods can easily be used to conduct VOLL in different jurisdictions and in different time periods, which can show how VOLL can change across economies and over time.

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[41] Van der Welle & van der Zwaan. *An Overview of Selected Studies on the Value of Lost Load.* ECN. Nov 2007. P.7.

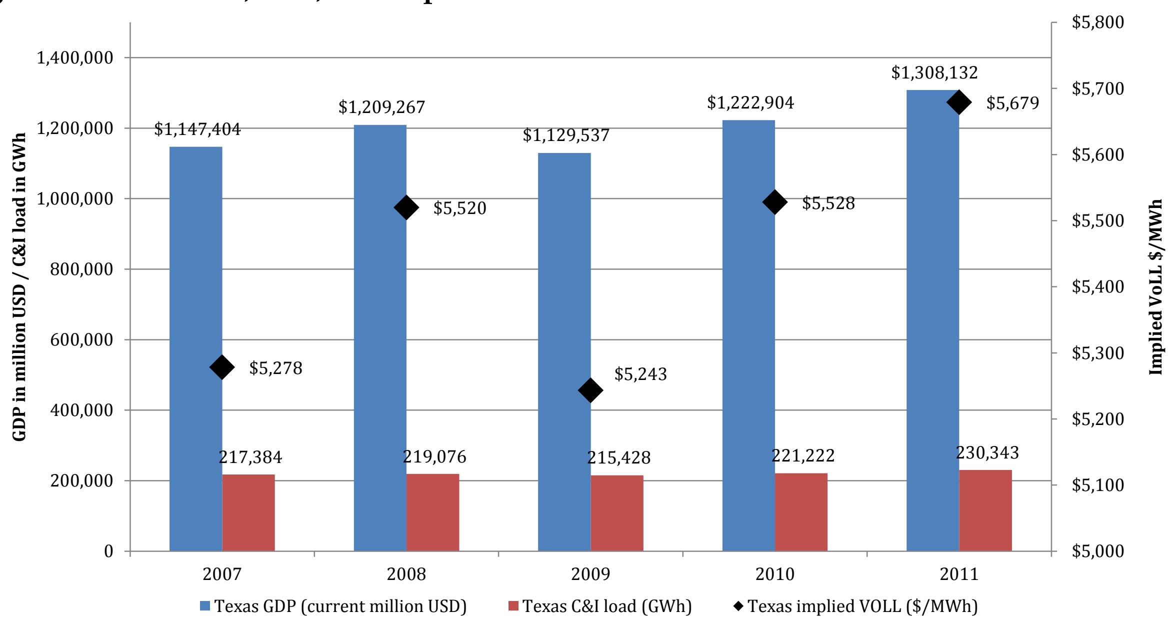
4.2 Application of the production function method

4.2.1 Average non-residential VOLL

Using the production function approach, LEI first estimated the VOLL of non-residential customers for the state of Texas as a whole. GDP and non-residential electricity consumption figures are readily available at the state level. State-level GDP data are available from the US Bureau of Economic Analysis ("BEA").[42] Load data is available from Energy Information Agency's ("EIA") Form EIA-861.[43] GDP is paired with non-residential load to reflect the fact that households' electricity consumption is not typically considered an input into the economic production process. Unlike firms and the government, households do not perform "value added" activities while consuming electricity performing leisurely activities. However, this is a simplification – some individuals work from home (i.e., undertake value added activities). The electric consumption of such individuals during work hours at home contribute to economic output and should ideally be accounted for in the calculation of non-residential VOLL, but data granularity is insufficient to properly estimate this contribution.

As shown in Figure 35 and Figure 36 below, the GDP-to-load ratio method results in an implied VOLL of $5,679/MWh for the state of Texas in 2011. From 2007 to 2011, implied VOLL grew at a compounded annual growth rate ("CAGR") of 1.85%, and notably this growth rate in VOLL is the result of economic activity growing at a faster rate than consumption over this period. The recessionary events of 2009 also affected the measure of VOLL as seen in the 2009 estimate.

Figure 35. Texas GDP, load, and implied VOLL



[42] Data can be found at (GDP by State > All industry totals in current dollars ("USD")) BEA. "Regional Data" page: http://www.bea.gov/iTable/index_regional.cfm

[4343] See Appendix A (Section **Error! Reference source not found.**) for more background information on the load data.

Figure 36. Texas implied VOLL

		2007		2008		2009		2010		2011	CAGR
Texas GDP (current million USD)	$	1,147,404	$	1,209,267	$	1,129,537	$	1,222,904	$	1,308,132	*3.33%*
Texas C&I load (GWh)		217,384		219,076		215,428		221,222		230,343	*1.46%*
Texas implied VoLL ($/MWh)	$	5,278	$	5,520	$	5,243	$	5,528	$	5,679	*1.85%*

Sources: BEA and Form EIA-861.

In order to narrow down the analysis from a statewide macroeconomic VOLL estimate to an ERCOT macroeconomic VOLL, adjustments to both load and economic activity had to be made to represent the narrower geographical region of ERCOT. First, the Texas C/I load was scaled down to reflect ERCOT-only C/I electric load. This was done through cross-checking the list of retailers active in ERCOT, as provided by ERCOT, against Texas electricity sales by retailers, reported under Form EIA-861. The analysis yielded C/I consumption of 187,699 GWh for 2011, as compared to the state-wide C/I figure of 230,343 GWh (ERCOT C/I is approximately 81% of Texas C/I load). Second, Texas GDP was adjusted to filter out non-ERCOT Texas economic output. Precise GDP data are not readily available for the ERCOT footprint. Two different methods were developed to approximate ERCOT-only GDP:

- **Method 1 – MSA Ratio:** Based on 2011 GDP statistics for Metropolitan Statistical Areas ("MSAs") published by the BEA[44,45] Texas GDP was scaled down by the ratio of the aggregated GDP of all ERCOT MSAs over the aggregated GDP of all MSAs in the state of Texas, as represented by the following formula to arrive at an ERCOT-only GDP:[46]

$$\mathbf{GDP_{ERCOT} = GDP_{TEXAS} * (\sum MSA\text{-}GDP_{ERCOT} / \sum MSA\text{-}GDP_{TEXAS})}$$

- **Method 2 – Personal Income Ratio:** Based on 2011 county-level personal income ("PI") data published by the BEA,[47] Texas GDP was scaled down by the ratio of aggregated PI of all ERCOT counties over aggregated PI of all counties in the state of Texas, as represented by the following formula:[48]

$$\mathbf{GDP_{ERCOT} = GDP_{TEXAS} * (\sum County\text{-}PI_{ERCOT} / \sum County\text{-}PI_{TEXAS})}$$

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44 MSAs are geographic entities defined by the Office of Management and Budget (OMB) for use by Federal statistical agencies in collecting, tabulating, and publishing Federal statistics. An MSA contains a core urban area of 50,000 or more population. Each MSA consists of one or more counties and includes the counties containing the core urban area, as well as any adjacent counties that have a high degree of social and economic integration (as measured by commuting to work) with the urban core.

45 BEA. "Regional Data" page: http://www.bea.gov/iTable/index_regional.cfm

46 See Appendix B (Section 8) for a list of Texas MSAs and calculation of the MSA ERCOT-to-Texas ratio.

47 BEA. "Regional Data" page: http://www.bea.gov/iTable/index_regional.cfm

48 See Appendix C (Section 9) for a list of ERCOT counties and calculation of the PI ERCOT-to-Texas ratio.

As shown in Figure 37 below, applying the GDP-to-load ratio method to ERCOT results in a 2011 implied VOLL ranging from $5,645/MWh to $6,468/MWh, depending on the method used to approximate ERCOT GDP.

It is important to note that both of these methods introduce some possibility for measurement error. Method 1 (MSA) assumes that non-MSA GDP is distributed between ERCOT and non-ERCOT areas in proportion to the MSA GDP distribution. That is, the aggregated GDP of all the MSAs in the state of Texas represents 93% of Texas GDP. Method 1 assumes that the remaining 7% of GDP is distributed between ERCOT and the rest of Texas in the same ratio as MSA GDP. Mining output is the primary component of the non-MSA GDP (i.e., the 7%).[49] Therefore, depending whether mining activities are mostly taking place within or outside of ERCOT, Method 1 could lead to an implied ERCOT macroeconomic VOLL that respectively under-represents or over-represents mining-specific VOLL. In reality, mining activities are taking place in both ERCOT and non-ERCOT areas, so it is difficult to pinpoint the potential direction of any bias at the sector level.[50]

Method 2 (PI) assumes that GDP distribution across counties follows PI distribution. That is, we are assuming that individuals live in the same county as their workplace, and that their portion of aggregate Texas PI is proportional to their contribution to total Texas GDP. GDP data are not granular enough to verify that assumption. Therefore, depending on the range of commuting in ERCOT relative to range of commuting in other parts of Texas, Method 2 could lead to an implied ERCOT VOLL that respectively overestimates or underestimates actual ERCOT VOLL.

Similarly, it is also important to note neither Texas nor the ERCOT region is a closed economy. In each case, intermediate and final goods are traded into and out of the region. And, perhaps more importantly, ownership structures span geographical boundaries. So a branch office or site might be located in the region but have its contributions recorded in another state (head office) and vice versa.

Figure 37. 2011 ERCOT-wide implied macroeconomic VOLL

	Method 1 (MSA ratio)	Method 2 (PI Ratio)
ERCOT-wide estimated GDP (current million USD)	$ 1,214,062	$ 1,059,605
ERCOT-wide C/I estimated load (GWh)	187,699	187,699
ERCOT-wide implied VOLL ($/MWh)	$ 6,468	$ 5,645

Sources: BEA, Form EIA-861, and ERCOT

[49] Mining activities represents 9% of Texas GDP with $118,600 million worth of output. Only 16% of this amount was produced within the perimeter of one of Texas MSAs ($19,270 million).

[50] Uranium mining activities are taking place in southern Texas which is part of ERCOT. Coal mining operations are located both within ERCOT (in both the South and North load zones) and outside of ERCOT (mainly in the Northeastern corner of Texas). Shale gas extraction operations are also located both within ERCOT (Barnett and Eagle Ford shale plays) and outside of ERCOT (Haynesville and Barnett-Woodford shale plays). [*See:* Railroad Commission of Texas: http://www.rrc.state.tx.us/programs/mining/index.php. *See also:* EIA maps: http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/maps/maps.htm]

4.2.2 Customer class-specific VOLL

Various industries and customer types differ in their dependency on electricity for production of their goods and services and therefore will face different levels of foregone economic output as a function of electricity consumed. The non-residential VOLL estimates consider commercial and industrial customers in the aggregate and therefore average out these considerations. In fact, prior economic studies have shown that VOLL for the commercial sector generally differs from that of the industrial sector.[51] LEI therefore undertook an analysis that aimed to disaggregate the VOLL estimate for commercial and industrial customers.

Load data for each customer class were sourced from Form EIA-861 filings. According to the reported data, in 2011, commercial and industrial customers represented 34% and 27% - or 128 TWh and 102 TWh - of total state load, respectively. The portion of Texas GDP attributable to each customer class was obtained by segregating Texas GDP along North American Industry Classification System ("NAICS") codes reflecting customer class definitions used in EIA-861, in order to make the numerator and denominator in the VOLL estimates as comparable as possible.[52] Please refer to Appendix D (Section 10) for a detailed breakdown of commercial versus industrial Texas GDP in 2011.

As shown in Figure 38 below, sector-level calculations yield an implied VOLL of $6,979/MWh for commercial customers versus an implied VOLL of $3,706/MWh for industrial customers in Texas based on 2011 GDP figures. It is interesting to note that from 2007 to 2011, the commercial sector implied VOLL grows at a CAGR of approximately 0.3%, while over the same period, the industrial sector implied VOLL grows at a significantly higher CAGR of about 3%. The difference in VOLL CAGR can mainly be explained by different load growth patterns. While the commercial sector saw its load and its economic output grow steadily by 3.8% and 4%, respectively, the industrial sector saw a 1.8% CAGR in economic output and a -1.1% CAGR in load over the period. Therefore, the industrial sector saw its power-productivity rate (ratio of output over MWh consumed) grow which explains the increase in implied VOLL.

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[51] The degree and direction of the difference will depend on the sub-sectors composing each of the commercial and the industrial category examined in the study. [*See:* Van der Welle & van der Zwaan. *An Overview of Selected Studies on the Value of Lost Load.* ECN. Nov 2007. P.7. and LaCommare & Eto. *Cost of Power Interruptions to Electricity Consumers in the United States (U.S.).* Lawrence Berkeley National Laboratory. Environmental Energy Technologies Division. LBNL-58154. February 2006. P.14.]

[52] The Industrial Sector is defined by the EIA as "An energy-consuming sector that consists of all facilities and equipment used for producing, processing, or assembling goods. The industrial sector encompasses the following types of activity manufacturing (NAICS codes 31-33); agriculture, forestry, fishing and hunting (NAICS code 11); mining, including oil and gas extraction (NAICS code 21); and construction (NAICS code 23)." The Commercial Sector is defined by the EIA as "An energy-consuming sector that consists of service-providing facilities and equipment of businesses; Federal, State, and local governments; and other private and public organizations, such as religious, social, or fraternal groups. The commercial sector includes institutional living quarters. It also includes sewage treatment facilities." [EIA Glossary: http://www.eia.gov/tools/glossary/index.cfm]

Figure 38. Texas sector-specific implied VOLL

	2007	2008	2009	2010	2011	CAGR
Texas commercial GDP (current million USD)	$ 763,338	$ 810,134	$ 808,905	$ 853,859	$ 894,748	*4.05%*
Texas commercial load (GWh)	110,563	113,452	118,497	121,467	128,214	*3.77%*
Texas commercial estimated VOLL ($/MWh)	$ 6,904	$ 7,141	$ 6,826	$ 7,030	$ 6,979	*0.27%*
	2007	**2008**	**2009**	**2010**	**2011**	***CAGR***
Texas industrial GDP (current million USD)	$ 352,288	$ 365,054	$ 289,311	$ 336,001	$ 378,469	*1.81%*
Texas industrial load (GWh)	106,820	105,624	96,931	99,754	102,129	*-1.12%*
Texas industrial estimated VOLL ($/MWh)	$ 3,298	$ 3,456	$ 2,985	$ 3,368	$ 3,706	*2.96%*

Note: the continued increase in Texas commercial load observable even through the financial crisis may be explained by the relatively strong performance of the state during those years: household income and Texas foreign-born population grew in 2008 and the state outperformed the rest of the country in terms of employment growth by a full percentage point after it emerged from the recession in mid-2009. Finally, the housing market downturn was milder than elsewhere (the purchase-only home price index, issued by the Federal Housing Finance Agency (FHFA), shows that home values appreciated 4.6% in Texas from the end of 2006 to second quarter 2009 while they fell 10.3% nationwide). On the other hand, industrial load slump in 2009 is explained by lower demand for manufactured goods in the rest of the US as well as foreign markets. [Federal Reserve Bank of Dallas. Southwest Economy Report. Fourth Quarter 2009 and Fourth Quarter 2011.]

Sources: BEA, Form EIA-861

Similarly to the analysis conducted for non-residential VOLL as a whole, commercial and industrial VOLLs were subsequently narrowed down to the ERCOT level, adjusting both load and GDP inputs. Load data were adjusted by cross-checking the list of ERCOT retailers against the Form EIA-861 data. Texas GDP data for the commercial and industrial sectors were then adjusted to filter out non-ERCOT Texas economic output, using both the MSA ERCOT-to-Texas and PI ERCOT-to-Texas ratios developed in Section 4.2.1 above. The same concerns regarding measurement errors introduced by the estimation methods for scaling down to the ERCOT level were present in this analysis.

As shown in Figure 39, sector-level calculations for ERCOT yield an implied VOLL ranging from $6,492 to $7,438/MWh for commercial customers versus implied VOLL ranging from $4,031 to $4,619/MWh for industrial customers, based on 2011 GDP data. The ratio of industrial implied VOLL to commercial implied VOLL was approximately 62%, showing a narrower gap between industrial and commercial implied VOLL at the ERCOT level than at the Texas level.

Figure 39. 2011 ERCOT-wide sector-specific implied macroeconomic VOLL

	Method 1 (MSA ratio)		Method 2 (PI Ratio)	
ERCOT commercial GDP (current million USD)	$	830,405	$	724,758
ERCOT commercial load (GWh)		111,647		111,647
ERCOT commercial estimated VOLL ($/MWh)	$	7,438	$	6,492
	Method 1 (MSA ratio)		**Method 2 (PI Ratio)**	
ERCOT industrial GDP (current million USD)	$	351,253	$	306,565
ERCOT industrial load (GWh)		76,052		76,052
ERCOT industrial estimated VOLL ($/MWh)	$	4,619	$	4,031

Sources: BEA, Form EIA-861, and ERCOT

4.3 Application of the bill-to-consumption method

Application of the bill-to-consumption method provides a lower bound to our estimates of implied VOLL for non-residential sectors as well as a preliminary estimate of residential implied VOLL. Although electric bill data per customer class are not available, the EIA provides data on average retail rates for each customer class.[53] Average retail rates are used in this study as proxies for primary data derived from electric bills.

This method does not reflect the indirect costs or foregone value of leisure time for residential customers experiencing a power outage. This method also does not reflect the foregone value-added creation of commercial and industrial customers for which electricity supply has been interrupted. Therefore, the results presented below only constitute a lower bound to the actual VOLL of the various customer classes examined:

- Based on 2011 average residential retail rate of 11.08 cents/kWh, the residential implied VOLL is $110.80/MWh for 2011;
- Based on 2011 average commercial retail rate of 17.66 cents/kWh, the commercial implied VOLL is $176.60/MWh for 2011; and
- Based on 2011 average industrial retail rate of 12.48 cents/kWh, the industrial implied VOLL is $124.80/MWh for 2011.

[53] EIA. "Electricity Data" page: http://www.eia.gov/electricity/data.cfm#sales

Figure 40. Texas historical average retail rates per customer class

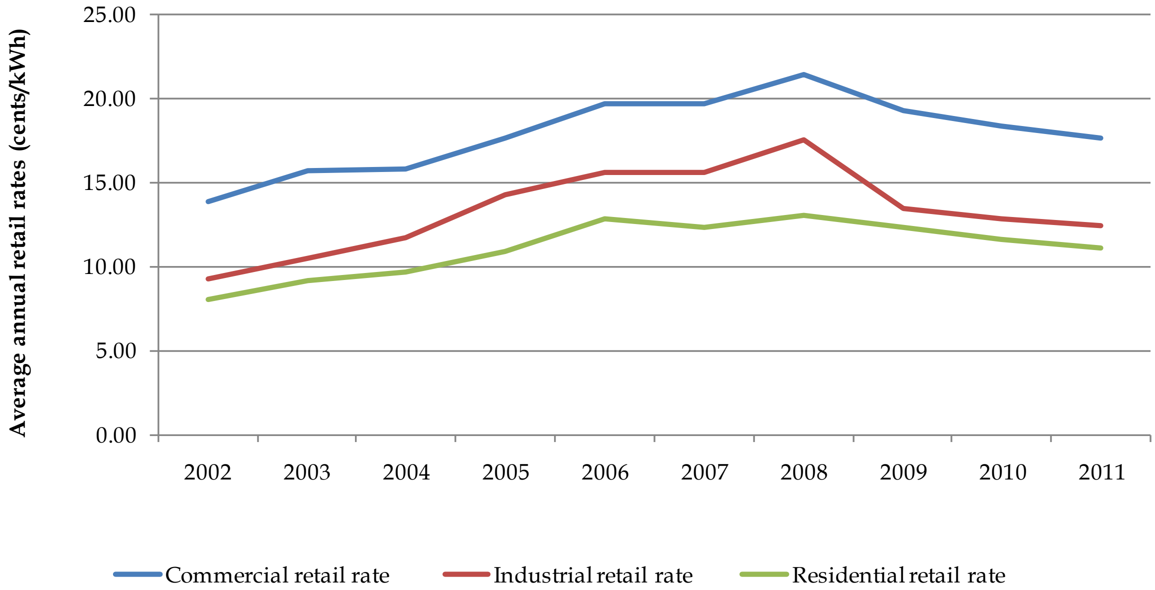

Figure 41. Texas historical average retail rates per customer class (continued)

(cents/kWh)	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Commercial retail rate	13.90	15.68	15.80	17.70	19.70	19.74	21.50	19.32	18.38	17.66
Industrial retail rate	9.32	10.54	11.74	14.28	15.64	15.58	17.58	13.48	12.88	12.48
Residential retail rate	8.05	9.16	9.73	10.93	12.86	12.34	13.04	12.38	11.60	11.08
Total retail rate	13.24	15.00	15.90	18.28	20.68	20.22	21.98	19.72	18.68	18.00

Source: EIA

4.4 Summary of findings

VOLL should present consumers' willingness to pay to avoid a supply interruption. A macroeconomic analysis will be only a rough proxy. Key findings of LEI's indicative macroeconomic analysis include the following:

- based on 2011 GDP figures, the state-wide and ERCOT-wide estimate for VOLL for C/I customers is in the range of $6,000/MWh;
- Texas versus ERCOT estimates for C/I VOLL are generally in the same range;
- commercial customers' VOLL using allocated GDP by sector for 2011 is estimated at $6,979/MWh and appears to be higher than the estimated VOLL of $3,706/MWh for industrial customers;

- using 2011 average retail rates paid by residential consumers across the state, the implied VOLL estimate using the bill-to-consumption approach for residential customers is only $110/MWh; however.

- the VOLL estimates using the bill-to-consumption method will understate significantly the actual VOLL for residential customers.[54]

Figure 42 below provides a summary of the VOLL estimates that the production function and the bill-to-consumption methods yielded using 2011 data.

Figure 42. Summary of 2011 VOLL estimates derived from macroeconomic analysis

<table>
<tr><th></th><th>Residential</th><th>Commercial</th><th>Industrial</th></tr>
<tr><td rowspan="2">Texas estimated VOLL range ($/MWh)</td><td rowspan="2">$110</td><td>$177 - $6,979</td><td>$125 - $3,706</td></tr>
<tr><td colspan="2">$5,679</td></tr>
<tr><td rowspan="2">ERCOT estimated VOLL range ($/MWh)</td><td rowspan="2"></td><td>$6,492</td><td>$4,031</td></tr>
<tr><td colspan="2">$5,645 - $6,468</td></tr>
</table>

[54] The potential bias is demonstrated by comparing the implied VOLL estimates for C/I using GDP indicators with the VOLL estimated based on the bill-to-consumption method.

5 Concluding Remarks

As the initial step in the process to establish a VOLL for the ERCOT region, LEI undertook a literature review and a macroeconomic analysis to lay the foundation for developing a robust approach to estimate VOLL in ERCOT. The review of relevant economic literature and jurisdictional case studies provides observations on trends in VOLL, as well as lessons learned and best practices in estimating VOLL through customer surveys and other techniques. In demonstration of non-survey techniques, e.g. the production function approach, LEI calculated indicative estimates of VOLL for Texas and ERCOT using macroeconomic electric consumption data. However, given the shortcomings of this approach, and ERCOT's focus on VOLL as it relates to rotating outages, these estimates are only useful as benchmarks against which future survey-based results may be checked.

LEI concludes that accurately estimating VOLL for a region is a challenging task that ultimately requires a survey of affected customers. The literature review demonstrates the sensitivity of VOLL to specific regional and outage attributes such as customer profile, economic conditions, climate, and the length and duration of outages. Given the general low comparability of the regions studied to ERCOT and the outdated data of certain studies, the VOLL estimates from the jurisdictional studies should not be used as proxies for an ERCOT VOLL. However, the results of the literature review will nevertheless be useful. Should ERCOT decide to design and administer a survey to determine VOLL in the future, the VOLL estimates from other studies considered robust and relevant to ERCOT may serve as independent benchmarks for cross-checking the survey results. Experience with survey design and implementation reported in the literature may be used to refine ERCOT's survey design and analysis to ensure robust results.

LEI used macroeconomic analysis to calculate implied VOLL for non-residential customers at both the Texas and ERCOT levels using 2011 GDP data. The implied VOLL is an annualized average and likely understates the VOLL during rotating outages as every hour of the year is not "equally" important to non-residential customers (i.e., if an outage occurs at a critical time in production the VOLL would be much higher than the annualized average). LEI also prepared a preliminary VOLL calculation for residential customers by relying on the direct cost of electricity paid for by retail customers (i.e., average household electricity bills). This approach understates the VOLL for residential customers as it does not consider the foregone value of leisure activities or other indirect costs. Not surprisingly then, this method, coupled with the macroeconomic analysis, provided a wide range of potential VOLLs for ERCOT. Given the shortcomings of these approaches, these values should be not considered as accurate estimates of VOLL in ERCOT during rotating outage events. However, like the literature survey outputs, these indicative VOLL estimates provide an independent benchmark for checking future survey results, if a customer survey is undertaken in the future by ERCOT.

Given the work completed to date, LEI cannot recommend a single VOLL estimate for ERCOT. Developing a robust, region-specific estimate of VOLL for the type of outages that ERCOT would like to consider requires a survey of end-use customers. Should ERCOT so desire, LEI would be available to complete the survey and the study at a future date. Completing the survey and study would provide the ERCOT with an accurate estimate of VOLL for the types of outage events which ERCOT is interested in examining.

6 Appendix A: VOLL in the Gas Sector

United Kingdom – Gas Sector (2011)	
Title:	"Estimating Value of Lost Load" (2011)
Author(s):	London Economics
Methodology:	Combined Stated Choice and macroeconomic
Sample Data:	Large, representative
Disaggregation:	Moderate, standard sectoral VOLLs
Comparability:	Not relevant, given fundamental differences in underlying commodity and unit of VOLL measurement

This is a VOLL study of gas users in the United Kingdom, conducted in 2011. This study utilizes a combination of Stated Preference and macroeconomic (production function) approach. It is notable that these same VOLL estimation methodologies are used in another sector, which confirms general applicability.

6.1 Residential and small and medium enterprise

To estimate VOLL for residential, small and medium enterprise ("SME") gas users, the Stated Preference survey is used. Respondents were given scenarios with timing, frequency and duration of outage, as well as WTP and WTA numbers, and were then asked to choose between scenarios.

Figure 43. Sample scenario questions

Alternative A

You lose your gas in the summer

This will happen once every 5 years

It lasts for 1 day

You receive compensation of £5 per day without gas

Alternative B

You lose your gas in the summer

This will happen once every 20 years

It lasts for 1 month

You receive compensation of £30 per day without gas

Please choose between the two alternatives: A, B, or Don't Know

A regression model was applied to response variables of choice against explanatory continuous and dummy variables of timing, frequency and duration of outage and WTP and WTA (continuous variable called monetary value):

$$Choice_i = \alpha + \beta1*duration_i + \beta2*duration_i^2 + \beta3*duration_i*summer_i + \beta4*duration_i^2*summer_i + \beta5*duration_i*frequency_i + \beta6*duration_i^2*frequency_i + \beta7*monetary\ value_i + \beta8*Don't\ know\ dummy + \varepsilon_i$$

Regression results provided quantitative associations between WTP and WTA and the timing, frequency and duration of outages. WTP and WTA were then used to calculate a range of VOLLs broken down by sector and type of outage. Multiple VOLLs reported in terms of pounds per therm, pounds per day and year, under different scenarios.[55]

Samples were adjusted to ensure that they were representative of the United Kingdom. For example, a smaller share of very small companies (0-9 employees) and construction companies used gas rather than electricity, and this had to be adjusted to ensure against overrepresentation by the survey.

For the residential sector, on-line surveys 1,000 respondents and face-to-face surveys of 100 surveys were conducted. The sample was drawn randomly from YouGov's 315,000 of adults in the United Kingdom

For the SME sector, survey was conducted by telephone and mail. 500 SME respondents were drawn from Experian.

The degree of disaggregation is moderate and macroeconomic data were not used for these sectors. Timing and duration of outages, as stated above, were considered and incorporated in the calculation.

6.2 Commercial and industrial

For the commercial and industrial ("C&I"), a variation of the macroeconomic (production function) methodology was applied to estimate VOLL. In theory, the study states that VOLL is the lost gross revenue from the loss of production ability and is estimated by revenues less variable costs and cost of storable non-depreciable inputs. Furthermore, if the customer's production can be compensated post-outage, i.e. can be delayed, then the resultant VOLL estimate may be overestimated.[56] In practice, this study calculates VOLL by dividing GVA by gas used (therms per year), which is the standard production function approach. Data collected were highly disaggregated into 16 sectors:

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[55] Reporting the VOLLs in pound/therms per year would lead to potential translation corruption due to the absence of a single VOLL number per sector or for the whole region leads to arbitrary choices as to how to select and construct such a single value, and fundamental differences between gas and electricity as commodities and the units used.

[56] London Economics. *Estimating Value of Lost Load (VoLL).* July 5, 2011.

VOLL = GVA / GU*100 pence/therm

Where GVA= Gross Value Added

GU = Gas used (therms per year)

There is no survey design, survey delivery or sample data and no requirement to adjust for bias.

6.3 Key Takeaways

The key takeaway from this VOLL for natural gas study is that it confirms the applicability of key survey methodologies reviewed in this report.

However, comparability of the specific VOLL estimates should be avoided between gas and electricity because of the fundamental difference between the commodities, including consumption patterns by customers, relative importance to production, and units of measurement.

7 Appendix B: Load data

Texas load data downloaded from Form EIA-861 data reported by retail service providers:

Year	Residential Sales GWh	Commercial Sales GWh	Industrial Sales GWh	Transportation Sales GWh	Total Sales GWh
2007	124,921	110,563	106,820	67	342,372
2008	127,700	113,452	105,624	69	346,844
2009	129,797	118,497	96,931	71	345,296
2010	137,161	121,467	99,754	74	358,458
2011	145,654	128,214	102,129	68	376,065

ERCOT-wide and zonal load data were based on data reported by ERCOT:

Area	Total Sales GWh
LZ_HOUSTON	89,109
LZ_NORTH	129,211
LZ_SOUTH	91,221
LZ_WEST	24,342
ERCOT	333,883

ERCOT customer class-specific data downloaded from the EIA website, based on Form EIA-861 data reported by retail service providers:

Year	Residential Sales GWh	Commercial Sales GWh	Industrial Sales GWh	Transportation Sales GWh	Total Sales GWh
2011	111,647	76,052	129,533	68	317,300

Note: The discrepancy of 16,582 GWh between the Ventyx Suite and the EIA website databases was deemed low enough to allow for consistent ground for comparison of the results.

8 Appendix C: List of Texas MSAs

Data on MSAs were sourced the BEA website:

MSA name	Load Zone	2011 All industry GDP (current million USD)	
Abilene, TX (MSA)	ERCOT	$	5,608
Austin-Round Rock-San Marcos, TX (MSA)	ERCOT	$	90,913
Brownsville-Harlingen, TX (MSA)	ERCOT	$	8,167
College Station-Bryan, TX (MSA)	ERCOT	$	7,117
Corpus Christi, TX (MSA)	ERCOT	$	20,260
Dallas-Fort Worth-Arlington, TX (MSA)	ERCOT	$	391,350
Houston-Sugar Land-Baytown, TX (MSA)	ERCOT	$	419,696
Killeen-Temple-Fort Hood, TX (MSA)	ERCOT	$	16,262
Laredo, TX (MSA)	ERCOT	$	6,550
McAllen-Edinburg-Mission, TX (MSA)	ERCOT	$	15,379
Midland, TX (MSA)	ERCOT	$	14,729
Odessa, TX (MSA)	ERCOT	$	6,959
San Angelo, TX (MSA)	ERCOT	$	4,065
San Antonio-New Braunfels, TX (MSA)	ERCOT	$	86,386
Sherman-Denison, TX (MSA)	ERCOT	$	3,552
Tyler, TX (MSA)	ERCOT	$	9,306
Victoria, TX (MSA)	ERCOT	$	6,129
Waco, TX (MSA)	ERCOT	$	8,750
Wichita Falls, TX (MSA)	ERCOT	$	5,816
Amarillo, TX (MSA)	Outside ERCOT	$	10,300
Beaumont-Port Arthur, TX (MSA)	Outside ERCOT	$	22,427
El Paso, TX (MSA)	Outside ERCOT	$	28,755
Longview, TX (MSA)	Outside ERCOT	$	10,632
Lubbock, TX (MSA)	Outside ERCOT	$	10,531
Texarkana, TX-Texarkana, AR (MSA)	Outside ERCOT	$	4,679
Sub-total	**ERCOT**	$	1,126,994
Sub-total	**Outside ERCOT**	$	87,324
	Total	$	1,214,318

The MSA ERCOT-to-Texas was calculated as follow:

Area	2011 aggregated GDP (current million USD)	
All-ERCOT MSAs	$	1,126,994
All-Texas MSAs	$	1,214,318
ERCOT-to-Texas ratio		**93%**
ERCOT GDP	$	1,214,062

9 Appendix D: List of ERCOT counties

The list of ERCOT counties was determined based on the "Data Dictionary" database provided by ERCOT. Pursuant to methodology shared with us by ERCOT, all counties included in the database and featuring a 69 kV substation were determined as being part of ERCOT.

County name	Population (2012 est.)	2011 total PI in county (million current USD)
ANDERSON	58,321	$ 1,689.33
ANDREWS	14,528	$ 572.91
ARANSAS	28,548	$ 1,213.63
ARCHER	9,596	$ 438.43
ATASCOSA	47,314	$ 1,430.68
AUSTIN	29,835	$ 1,174.72
BANDERA	21,992	$ 800.29
BASTROP	87,236	$ 2,483.87
BAYLOR	3,989	$ 144.83
BEE	34,370	$ 917.58
BELL	301,718	$ 12,135.70
BLANCO	10,784	$ 507.31
BOSQUE	17,955	$ 582.30
BRAZORIA	336,748	$ 13,024.40
BRAZOS	180,328	$ 5,237.63
BREWSTER	9,559	$ 374.13
BRISCOE	1,869	$ 51.90
BROOKS	7,817	$ 237.82
BROWN	40,259	$ 1,293.76
BURLESON	19,133	$ 656.09
BURNET	50,648	$ 2,063.10
CALDWELL	40,137	$ 1,026.58
CALHOUN	23,702	$ 768.25
CALLAHAN	14,846	$ 496.03
CAMERON	433,449	$ 10,071.62
CHEROKEE	50,688	$ 1,466.05
CHILDRESS	7,976	$ 181.49
CLAY	11,229	$ 491.77
COKE	3,942	$ 128.21
COLEMAN	8,891	$ 293.47
COLLIN	927,466	$ 48,616.84
COLORADO	22,621	$ 882.90
COMAL	131,409	$ 5,850.20
COMANCHE	14,337	$ 522.96
CONCHO	3,797	$ 85.93
COOKE	41,728	$ 1,909.68
CORYELL	82,131	$ 3,033.26
COTTLE	1,882	$ 67.20
CRANE	4,356	$ 158.39
CROCKETT	4,659	$ 167.49
CROSBY	6,408	$ 200.45
DALLAS	2,484,816	$ 112,815.62
DAWSON	14,712	$ 391.71
DELTA	5,307	$ 165.51
DENTON	770,509	$ 32,647.24
DEWITT	20,669	$ 717.77
DICKENS	2,789	$ 75.63
DIMMIT	9,636	$ 331.28
DUVAL	11,808	$ 415.96
EASTLAND	18,857	$ 971.51
ECTOR	135,331	$ 5,194.68
EDWARDS	2,214	$ 74.53
ELLIS	171,178	$ 5,971.54
ERATH	40,680	$ 1,282.72
FALLS	18,780	$ 527.21
FANNIN	35,499	$ 1,054.60
FAYETTE	26,039	$ 1,040.78

County Name	Population (2012 est.)	2011 total PI in county (million current USD)
FISHER	4,128	$ 140.72
FOARD	1,577	$ 53.12
FORT BEND	632,821	$ 30,720.30
FREESTONE	20,955	$ 661.61
FRIO	18,221	$ 470.76
GALVESTON	303,754	$ 13,196.29
GILLESPIE	27,022	$ 1,284.90
GLASSCOCK	1,548	$ 49.93
GOLIAD	7,842	$ 233.18
GONZALES	20,692	$ 647.04
GRAYSON	123,128	$ 4,112.97
GUADALUPE	138,623	$ 5,150.81
HALL	3,852	$ 91.15
HAMILTON	9,119	$ 322.51
HARDEMAN	4,594	$ 144.05
HARRIS	4,259,769	$ 208,451.80
HASKELL	5,882	$ 167.31
HAYS	179,519	$ 5,870.27
HENDERSON	83,081	$ 2,649.54
HIDALGO	842,344	$ 18,211.48
HILL	37,975	$ 1,225.30
HOOD	57,697	$ 2,350.58
HOPKINS	35,072	$ 1,149.17
HOUSTON	24,771	$ 748.70
HOWARD	33,400	$ 1,061.49
HUNT	92,557	$ 2,937.39
IRION	1,818	$ 99.94
JACK	9,129	$ 346.02
JACKSON	15,533	$ 527.14
JEFF DAVIS	3,001	$ 105.85
JIM WELLS	42,991	$ 1,711.04
JOHNSON	179,994	$ 5,988.22
JONES	20,749	$ 554.70
KARNES	17,092	$ 467.93
KAUFMAN	116,473	$ 3,948.55
KENT	856	$ 26.85
KERR	47,491	$ 2,021.79
KIMBLE	4,842	$ 179.24
KING	380	$ 23.59
KLEBERG	31,730	$ 1,070.38
KNOX	4,266	$ 139.29
LA SALLE	5,982	$ 163.46
LAMAR	50,553	$ 1,672.90
LAMPASAS	23,628	$ 1,155.36
LAVACA	19,558	$ 739.16
LEON	17,246	$ 605.58
LIMESTONE	23,624	$ 718.67
LIVE OAK	12,369	$ 445.48
LLANO	19,798	$ 736.72
MARTIN	5,416	$ 173.64
MASON	3,860	$ 137.27
MATAGORDA	38,922	$ 1,295.60
MCCULLOCH	8,773	$ 342.38
MCLENNAN	238,787	$ 8,105.15
MCMULLEN	882	$ 46.58
MEDINA	46,874	$ 1,529.87
MENARD	2,444	$ 73.70
MIDLAND	133,004	$ 8,668.27

County Name	Population (2012 est.)	2011 total PI in county (million current USD)
MILAM	26,872	$ 859.98
MILLS	5,652	$ 201.72
MITCHELL	9,796	$ 244.92
MONTAGUE	20,436	$ 820.73
MOTLEY	1,414	$ 50.22
NAVARRO	53,144	$ 1,759.70
NOLAN	14,151	$ 465.77
NUECES	325,995	$ 12,531.57
PALO PINTO	30,165	$ 1,010.44
PARKER	125,155	$ 5,245.75
PECOS	17,932	$ 536.38
PRESIDIO	8,935	$ 252.05
RAINS	11,309	$ 340.75
REAGAN	3,085	$ 114.70
REAL	3,406	$ 103.19
RED RIVER	14,383	$ 455.42
REEVES	10,662	$ 250.61
REFUGIO	6,959	$ 278.07
ROBERTSON	17,083	$ 612.58
ROCKWALL	97,249	$ 4,970.98
RUNNELS	11,829	$ 347.24
RUSK	50,519	$ 1,557.05
SAN PATRICIO	71,271	$ 2,714.50
SAN SABA	6,445	$ 202.27
SCHLEICHER	3,248	$ 107.63
SCURRY	17,304	$ 657.03
SHACKELFORD	3,493	$ 179.88
SMITH	215,243	$ 8,290.08
SOMERVELL	9,028	$ 332.31
STARR	70,134	$ 1,349.03
STEPHENS	10,367	$ 419.33
STERLING	1,482	$ 53.11
STONE WALL	1,623	$ 56.81
SUTTON	4,731	$ 374.24
TARRANT	1,920,714	$ 78,682.05
TAYLOR	131,905	$ 4,897.90
TERRELL	1,106	$ 51.40
THROCKMORTON	1,890	$ 90.99
TOM GREEN	103,517	$ 3,859.01
TRAVIS	1,029,415	$ 44,468.67
UPTON	3,115	$ 140.27
UVALDE	28,215	$ 914.28
VAN ZANDT	54,700	$ 1,856.63
VICTORIA	90,043	$ 3,822.51
WALLER	44,217	$ 1,296.44
WARD	9,696	$ 375.23
WEBB	270,381	$ 6,755.47
WHARTON	44,220	$ 1,572.29
WICHITA	126,818	$ 4,499.12
WILBARGER	15,372	$ 531.43
WILLACY	22,342	$ 591.21
WILLIAMSON	482,433	$ 19,329.64
WILSON	48,469	$ 1,687.21
WINKLER	6,431	$ 228.26
WISE	64,376	$ 2,284.96
YOUNG	18,807	$ 752.24
ZAVALA	13,058	$ 273.25

Sources: Texas Department of State Health Services and BEA

Calculation of the personal income ERCOT-to-Texas ratio:

Area	2011 total PI (current million USD)	
All-ERCOT counties	$	859,757
All-Texas counties	$	1,061,410
ERCOT-to-Texas ratio		**81%**
ERCOT GDP	$	1,059,587

10 Appendix E: Sector breakdown of Texas GDP

Sector-level GDP data were downloaded on the BEA website for Texas and then segregated between commercial and industrial sectors (as defined by EIA for the purpose of Form EIA-861 filings by retail service providers):

Commercial sectors	Sector GDP (million current GDP)
Utilities	$ 24,234
Wholesale trade	$ 85,753
Retail trade	$ 76,625
Transportation and warehousing (air transportation only)	$ 8,284
Information	$ 44,903
Finance and insurance	$ 89,757
Real estate and rental and leasing	$ 109,657
Professional, scientific, and technical services	$ 92,107
Management of companies and enterprises	$ 12,411
Administrative and waste management services	$ 40,137
Educational services	$ 8,052
Health care and social assistance	$ 81,953
Arts, entertainment, and recreation	$ 7,727
Accommodation and food services	$ 35,777
Other services, except government	$ 31,209
Government	$ 146,162
Total commercial sectors GDP	**$ 894,748**
% of total Texas GDP	**68%**

Industrial sectors	Sector GDP (million current GDP)
Agriculture, forestry, fishing, and hunting	$ 9,897
Mining	$ 118,578
Construction	$ 57,970
Manufacturing	$ 192,024
Total industrial sectors GDP	**$ 378,469**
% of total Texas GDP	**29%**

Source: BEA

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