Public Utilities Commission of Sri Lanka

Estimation of the Cost of Energy not Served in Sri Lanka

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1. Introduction

Cost of Energy Not Served (ENS) provides an economic value to the losses incurred due to electricity interruptions. It is an important parameter used in medium-term/long term generation and transmission planning, technological up-gradation of assets (e.g.: smart grid technologies), design of regulatory incentives and compensation mechanisms, etc. As the cost of ENS affects many management decisions made on power systems, updating this figure is vital.

The cost of ENS figure used by the Transmission Licensee i.e. the Ceylon Electricity Board (CEB) in the Least Cost Generation Expansion Plan is different from the cost of ENS figure specified in the generation Planning Code approved by the Public Utilities Commission of Sri Lanka (PUCSL). In addition, neither of these figures is scientifically set.

Three main methods of assessing the cost of ENS are indirect analytical methods, customer surveys and case studies. Out of these three methods, the survey based method is the most preferred and extensively used method due to its ability to provide more accurate and customer specific data for the study. In 2002, the cost of ENS is assessed for Sri Lankan industries through a survey based approach[1]. Another survey based study has been conducted in 2015 to access the cost of ENS of residential, commercial and industrial sectors in Sri Lanka[2], [3], [4]. However, survey based studies do not link the cost of ENS with the socio-economic indicators and therefore, the cost of ENS figure cannot be updated.

This research intends to propose a hybrid approach to obtain the cost of ENS by combining customer surveys and analytical methods. Customer surveys are used in this approach to collect more accurate and customer specific data for the estimation of cost of ENS. In addition, this proposed approach considers the relationships of socio economic parameters with the cost of ENS in order to update the estimated cost of ENS figures. The proposed approach will be used to estimate the cost of ENS for Sri Lanka. Based on the proposed approach, a software platform will also be developed to provide up-to-date cost of ENS figures in a user friendly manner.

2. Objectives and the scope of work

The ultimate objective of this research is to develop a hybrid model to estimate and update the cost of ENS figures for Sri Lanka.

The specific objectives are;

- To develop a hybrid approach based on both customer surveys and analytical methods to estimate and update the cost of ENS.
- To estimate the cost of ENS figures for different sectors and a representative cost of ENS figure for Sri Lanka using the proposed approach.
- To develop a software platform based on the proposed approach to obtain updated cost of ENS figures for Sri Lanka.

3. Research methodology

The methodology of the research is given below.

- Study the available models/ methods used to estimate the cost of ENS
- Study the typical planned and unplanned interruptions prevalent in Sri Lanka
- Study the cost incurred by different sectors (like industry, hotel, and commercial) for a typical duration of the planned / unplanned interruptions using surveys and publicly available production data.
- Study the willingness to pay for minimum interruptions for domestic consumers using surveys.
- Estimate the cost of ENS for each sector and the cost of ENS figure for Sri Lanka by using the results of the surveys.
- Study the relationship of socio economic parameters with the cost of ENS and propose an analytical method to update the estimated cost of ENS figures
- Propose a hybrid approach to estimate and update the cost of ENS by combining the survey based method and the analytical method.
- Develop a software platform based on the proposed approach to obtain updated cost of ENS figures for Sri Lanka.

4. Timeline

Task	2020			2021												2022												2023			
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
Literature survey																															
Selection of method for the study																															
Design of questionnaire																															
Data collection for indirect analytical method																															
Pilot survey																															
Revising the questionnaire																															
Final survey																															
Data elimination																															
Estimation of the cost of ENS using survey results																															
Data analysis and modeling of the economic model																															
Development of the software platform																															
Documentation																															

5. Background study

5.1 Electricity interruptions

A preliminary step in assessing the cost of Energy Not Served is to understand the nature of electricity interruptions. In Literature, interruptions are found to be categorized based on the duration and the availability of prior notice. Based on the duration, interruptions could be grouped as Momentary and Non-Momentary. Momentary interruptions last for a very short stretch of time, typically for few seconds or even less than a second. Non- momentary interruptions last longer.

Non- momentary interruptions can be further classified into sporadic interruptions and chronic interruptions. Sporadic interruptions are caused by harsh weather conditions such as storms, floods or thunder storms and these are unplanned interruptions. They occur rarely, yet usually last for longer periods, may be for days and can cause blackouts. Chronic interruptions are resulted by many reasons such as insufficient power generation, the faults caused by the power system operation or overloading of the system, faults in the power system due to aging and service cuts due to maintenance work. Frequency of this group of interruption is much higher. Therefore, most of the studies focus on economic impacts of chronic interruptions when it comes to assessment of cost of ENS[5].

5.2 Economic losses due to electricity interruptions

To identify the best approach to evaluate the economic impact of Energy Not Served, the losses caused by interruption has to be properly classified.

1. Direct costs - Immediate expenses or losses that arise as a result of an outage
2. Indirect costs - Loss of opportunity caused by loss of time or productivity / foregone benefit

The monetary worth of direct costs is easy to assess when it is compared with indirect costs. Few examples can be listed as loss of production, loss of sales, damages on the equipment, shutdown costs, restart costs, spoiled goods, damages on the electronic data, accidents, injuries and interruption of services such as transportation, telecommunication etc.

Indirect costs are related to consequences that experienced aftermath of the interruption or the losses that take longer time periods to reveal true costs. These include overtime payments to the personnel to cover up the delayed production, cancellation of social activities, business opportunity losses and inconvenience caused due to lack of internet access, air conditioning or heating.

Though the direct economic losses seem to be the predominant component of the total losses of an interruption, the literature reveals that the direct economic losses are limited and subordinate to the indirect losses[5], [6], [7].

5.3 Factors affecting the cost of ENS

5.3.1 Sectorial characteristics

Each consumer's uses of electricity, dependency on electricity and consumption patterns are unique. Therefore, electricity interruptions result in different economic losses to different consumers. To simplify the analysis of economic losses of electricity interruptions, relatively homogeneous consumers are segmented into separate consumer categories. Most commonly observed consumer categories in literature are,

1. Industry sector
2. Commercial sector
3. Residential sector

Even within a sector, electricity intensities can vary significantly with the size, the production amount, the field of business and the equipment being used in those facilities. Therefore, dividing consumers into sub categories proved to provide more customer specific results[8].

5.3.2 Duration and timing of the interruption

The impact of the duration of the interruption is considered in several studies[5],[8]. According to the findings, industrial and commercial sectors show an inverse relationship between the duration and the cost of interruption, due to the effect of cost components such as shut down costs that occur once per interruption and are distributed over the total time span. Domestic consumers also tend to adapt to the situation with time, resulting a reduction in the marginal cost of interruption with the duration.

Timing of the interruption is important, as the cost of interruption can be considerably high in peak hours or an interruption in a weekend may cause more losses than that of a weekday for domestic consumers.

5.3.3 Geographical characteristics

Customer demographics and risk susceptibility vary across different regions and so does the cost of electricity interruptions. Information on the spatial variations of cost allows for evaluating investments and communicating risk to utility, thus facilitating their input in relevant policy processes [9].

5.3.4 Frequency of interruptions

An ongoing capacity shortage can be considered as a context for the frequent occurrence of interruptions. Such situation may encourage contingency measures, yet create barriers to economic activities and discourage the investment at the same time. Therefore, the effect of the frequency of interruption on the cost of ENS is considered to be uncertain.

5.3.5 Prior notice

Customers usually take measures if they are informed about an upcoming power cut. For example, change of plans, charging or fueling the backup supply source can be considered. As a result, the cost of a planned outage will be much lower than that of an unexpected one.

5.3.6 Experience

Lack of experience on a certain interruption scenario may lead people to overestimate or underestimate the potential negative consequences of an outage.

5.3.7 Mitigation measures taken

Precautionary and mitigation measures can significantly reduce the cost of outages[10].

5.4 Approaches to estimate the cost of ENS

Three main methods can be found in the literature for the estimation of Cost of ENS.

5.4.1 Customer surveys

Customer surveys are the most preferred and extensively used method for estimating the cost of ENS. In surveys, consumers are questioned about their previous experience or hypothetical interruption scenarios. This permits valuing losses incurred due to interruptions in consumers' perspective. Since questionnaires allow acquisition of wide range of data such as dependence of cost of ENS on customer type, duration, prior notice, etc., results obtained using survey methods are more accurate and customer specific. In addition, the survey based approach is considered as the best method to interpret the cost of non-material losses such as lost recreational benefits or stress in terms of monetary values. Therefore, this would be the most suitable method to assess the cost of ENS for the domestic sector.

The major drawback of this method is the immense amount of time, money and effort required to carry out the surveys. Moreover, accuracy of survey results relies on the design of the questionnaire and the sample size, and misleading and biased responses falsely affect the final conclusions of the study.

5.4.2 Indirect analytical method

The indirect analytical method uses publicly available, objective data such as gross domestic product, value added or turnover, electricity tariffs, and the annual electricity consumption of a customer group. In this method, a Customer Damage Function (CDF) which is defined as a monetary amount of damage against per outage, per kWh of un-served energy or per kWh annual consumption of energy, is obtained to illustrate the economic loss incurred by the customers due to power outages. This approach is quite straightforward, less time demanding, easy and inexpensive to apply, therefore, repeatable.

Disadvantages of this approach are broad and average results and inability to cope with indirect costs of electricity interruptions.

5.4.3 Case Studies

Case studies are carried out after large and significant blackouts [5],[6],[7],[10],[11]. Since the customers’ interruption experience is fresh and real, more accurate interruption cost data can be obtained. Therefore, this method can provide more reliable estimates. Due to this reason, this method is considered as the best way to cover indirect economic impact associated with interruptions.

There are several drawbacks of case studies. Application of this method is possible only after the occurrence of a large blackout. This method is expensive and time demanding to conduct and results obtained are not applicable for general situations because each blackout has its unique characteristics.

5.5 Research Techniques for measuring Cost of ENS

The three approaches discussed above have been applied individually or collectively in cost estimation studies of ENS. The uniqueness of each study is mostly based on the techniques used to extract data from customers and concepts used to assign a monetary value to the losses. Therefore, a discussion on these techniques is imperative.

Stated preference and revealed preference are two non-market valuation methods, commonly used for assessing the cost of ENS. The stated preference method measures the losses in terms of what customers say an interruption may cost to them, whereas revealed preference methods measure how they actually behave[8].

5.5.1 Stated preference method

The stated preference method is based on customers' valuation of interruption cost, therefore, solely rely on customer surveys[8]. In this method, hypothetical interruption scenarios are assumed and customers are asked to assign values for the losses incurred due to each scenario. Three variants of the stated preference method found in the literature are based on the types of questions asked in the survey, namely,

- Direct worth
- Contingent valuation
- Choice experiment method

Conjoint analysis is a type of choice experiment that is widely used in estimation of cost of ENS[12], [13], [14].

5.5.1.1 Direct worth approach

The direct worth approach involves with directly asking customers to evaluate their cost for a given interruption situation. The respondents have to identify the adverse effects of an electricity interruption and estimate a monetary value for those. The results of this approach are said to be less biased due to the open-ended question style, hence reliable. Yet survey design for this method is quite challenging. Every possible cost component related to each scenario should be carefully listed to extract a great deal of information from the respondents. Also, the complexity of the questionnaire can result in low response rates. Therefore this method is appropriate for the industrial and commercial sectors, where there are personnel knowledgeable on interruption costs[15].

5.5.1.2 Contingent valuation methods

Contingent valuation methods place monetary value for incremental changes of level of supply reliability[16]. Price proportional method and Rate related method (RRM) are different terminologies found in the literature for this method[17]. This method consists of the Willingness to Pay (WTP) and Willingness to Accept (WTA) approaches, i.e. how much consumers are willing to pay to avoid a certain interruption scenario or how much they are willing to accept as compensation for that defined interruption scenario. Usually, customers tend to specify low values for WTP and high values for WTA. Therefore, rather than a single value, this method outputs a range of costs where WTA sets the upper boundary and WTP set the lower boundary. It is found in the literature that these two values converge as consumer's experience about the defined interruption scenario grows, where WTP shows the least change. Therefore it is considered as the most stable measure for estimating the cost of ENS out of WTA and WTP[18].

5.5.1.3 Choice experiment method

Choice experiments present a number of choice sets of different interruption scenarios and ask respondents to select the most preferred option. Each choice is defined by a number of interruption attributes and a corresponding monetary value; cost or compensation. This method is generally preferred for cost estimation of ENS when trade-off between few attributes is considered. A similar technique is the Contingent Ranking Method (CRM) where customers are asked to rank a given set of scenarios with different reliability levels. Both variants can indirectly elicit the WTP values using statistical methods without giving respondents a difficult mental task. Therefore response rates for this method tend to be high[8], [19], [20].

5.5.2 Revealed preference approach

This approach is based on the economic principle of substitution; the value of substitute can be used to measure the worth of the original commodity[16]. In this method consumers are asked about real-life expenditure choices they have made relating to the context. One approach is considering investment activities such as installing backup generators or batteries, which is called as Preparatory Action Method(PAM) [21]. Market-based consumer decisions such as moving from an interruptible supplier to a more reliable but expensive supplier can be considered as another approach, but not applicable for natural monopolies such as grid-bound electricity supply[22].

5.5.3 Macroeconomic approach

The macroeconomic approach is an indirect analytical method. It is based on the assumption that generated output is linearly related to the input[23]. This method is considered more feasible since it uses publicly available, quantitative statistical data [24]. Based on the customer sector under consideration, two variants can be identified.

- Production function
- Household income

5.5.3.1 Production function approach

In this approach, it is assumed that electricity is an intermediate good for the production of goods or services. Therefore unavailability of electricity inevitably results in a reduction of production or total shutdown[25]. The cost estimation is done relating the production losses to the kWh not supplied. This approach enables estimating macroeconomic total loss by aggregating estimated sectorial production losses. Another option available is to establish links between sectors using input-output tables[24].

5.5.3.2 Household income approach

This approaches based on the monetization of lost leisure time due to electricity interruptions. Out of main household outputs; housekeeping, nutrition, and leisure, leisure is likely to be the most affected output by electricity interruptions[26]. Therefore, this approach is modeled based on consumer’s labor-leisure choice, allowing the valuation of a marginal hour of leisure time using the income per hour. This method is appropriate for a well-functioning labor market, where individuals have adequate choices for the number of working hours[24].

5.6 Cost of ENS figures estimated for Sri Lanka

Almost all the studies conducted in Sri Lanka to assess Cost of ENS are survey based approaches. Cost of ENS figures estimated for Sri Lanka in two previous studies are given in table 1. However, survey based studies do not link the cost of ENS with the socio-economic indicators and therefore, these cost of ENS figures cannot be updated [1], [27].

Table 5.1: Previous studies on estimating cost of ENS for Sri Lanka

Study	**Estimated cost of ENS**
Study conducted in 2002	Planned interruptions **US$ 0.66** Unplanned interruptions **US$ 1.06**
Study conducted in 2015	Momentary interruptions **145.51 LKR/kW** Non-momentary interruptions **195.65 LKR/kW**

6. The Survey Framework

In this study, a hybrid approach which is a combination of customer surveys and the indirect analytical method will be used for assessing the cost of ENS. This hybrid approach has the following advantages.

- Survey based approach of this hybrid model allows to reach more customer specific estimations of cost of ENS which will be useful for the utilities in their planning processes.
- Indirect analytical method in the hybrid approach is used to reveal a relationship between socio-economic indicators and the cost of ENS, based on which an econometric model can be developed to update the cost of ENS with a less effort.

Sub sections of this section present the basic considerations of the customer survey in the proposed approach.

6.1 Interruption categorization used in the questionnaire

Interruptions can be categorized into two types based on prior notice, i.e. unplanned interruptions and planned interruptions. Since interruptions caused by switching operations cannot be pre-informed, momentary interruptions are considered separately and following interruption categorization is used for the questionnaire

Momentary Interruptions

Non-momentary Interruptions - Planned Interruptions

Unplanned Interruptions

Non-momentary outages will be further divided based on the duration of interruptions.

6.2 Customer categorization used in the questionnaire

In Sri Lanka, electricity consumers are categorized into six major categories by the CEB in the tariff. They are industrial purpose, general-purpose, hotel purpose, government purpose, domestic purpose, and religious purpose. Assuming close consumption patterns, these categories were grouped into three main sectors which are commonly used in the literature. These three sectors are the industrial sector, the commercial sector and the residential sector.

The consumer categories included in each sector are given below.

Industrial sector	Industrial purpose
Commercial sector	General purpose
	Hotel purpose
	Government purpose
Domestic sector	Domestic purpose
	Religious purpose

Dependence on electricity may still greatly vary within each sector and therefore, each sector is subcategorized. Industry and commercial sectors are subcategorized using the International Standard of Industrial Classification (ISIC) which is used by the Central Bank of Sri Lanka. Reasons for selecting this classification are that it is based on the nature of the business activity and published data on the GDP contribution of each subsector are readily available. In most of the previously conducted studies, the residential sector has been considered a homogeneous sector[8]. However, in order to capture a representative data set, location and lifestyle variables of the residential population were taken into account when selecting the sample.

6.3 Design of the questionnaire

The design of the questionnaire involves selection and orderly arrangement of the questions for efficient extraction of data usable for assessing the cost of ENS from the consumers. This is a challenging task due to the consumers' unfamiliarity with the concept of the cost of ENS. Moreover, the impact of an interruption on the consumer depends upon many customer and interruption characteristics. Although it is desirable to consider all these factors that affect the cost of interruption, a lengthy questionnaire may exhaust the respondents causing low response rates. Also, some respondents may overlook possible loss components due to ignorance giving false results [3]. These issues must be appropriately addressed when preparing the questionnaire and listed below are some of the key considerations in designing the survey instrument.

1. The order of the questions in the questionnaire is of significant importance to raise the respondent's awareness of the cost of ENS.
2. The approach of the questions used for eliciting interruption cost figures should be selected carefully based on major losses each customer category undergoes due to interruptions and consumers' knowledge.

3. The simplicity of the questions should be assured by breaking down the questions into their smallest form to keep the respondents engaged till the end of the questionnaire.
4. Presentation of questions using sections and tabular formats helps to increase the clarity of the questionnaire.
5. The length of the questionnaire should be limited, since time taking questionnaires may reduce the quality of the responses.
6. It is required to include control questions for important variables and to select a sample in a way that alternative sources of data are available, so that the accuracy of the responses can be cross-checked.
7. Pre-testing and pilot testing are required to ensure the comprehensibility of the questionnaire and to identify any flaws in the survey design.

Three questionnaires are prepared for the three sectors by considering the above aspects and by referring to the questionnaires used in previous studies [3-5],[7],[21],[16] and modifying them appropriately.

6.3.1 Contents of the questionnaire

The contents of the questionnaires can be divided into three main sections based on the data expected to be collected using questions. The first section includes questions about the background information while the other two sections include questions regarding the interruption cost estimates and the variation of the impact of interruption with interruption characteristics.

6.3.2 Questions about background information

Background questions are primarily used to acquire data about the demographics of the customer which allows investigation of the impact of customer characteristics on the cost of ENS. In other words, it allows checking whether they act as explanatory variables and add intuition about the consumers' cost estimations[20].

Another benefit of customer demographic data is that they can be used to evaluate the representativeness of the selected sample by comparing average sample characteristics with population characteristics[7]. Therefore, the collection of background information is important, especially, for a survey that requires hard thinking to provide answers to certain questions, where non-response is inevitable.

The background information gathered from residential consumers would be,

1. Details about the respondent (Name, age, gender, occupation)
2. Household size and composition (Highest educational level, employment status)
3. Household income
4. Location of dwelling
5. Previous experience with interruptions
6. Available substitutes to electricity in the event of electricity interruption
7. Current electricity consumption and usage characteristics such as for what electricity is used

The relevant background questions included in the questionnaire prepared for industrial and commercial sectors are,

1. Details of the institution
2. Details of the person providing information
3. ISIC classification
4. Size of the facility (Number of employees, annual value-added)
5. Current electricity consumption
6. Availability of backup supply units

6.3.2.1 Questions about interruption characteristics

Identifying the variation of loss or inconvenience caused by interruption with interruption attributes can be useful in deriving cost estimations based on interruption statistics for forecasting purposes. Questions in this section intend to reveal how customers perceive the effect of interruption characteristics on the losses or inconvenience they incur. The attributes chosen to examine are,

1. Duration
2. Time of the day
3. Time of the year
4. Frequency

Selected attributes were split into attribute levels concerning electricity consumption patterns along with consumers' daily routine, seasonal climate changes, annual festivities etc. A summary of selected attribute levels is presented in table 2.

The rating scale method is adopted for assessing the variation of inconvenience associated with the interruption characteristics of the questionnaire prepared for the residential sector. By changing the levels of each selected interruption attribute within each scenarios group, four scenario groups are created for the consumers to rate. For the comparison purpose, a scenario common to all four groups is included in each scenario group. For the industrial and commercial sectors, a base case is given, and the variation of the interruption cost with each interruption characteristic is evaluated in terms of the percentage change in the interruption cost.

In the residential sector questionnaire, this section is placed prior to the cost questions expecting it would help to raise the consumer's awareness about the factors that affect the interruption cost.

Table 6.1 : Selected attribute levels for interruption characteristics

Attribute	**Attribute level**		**Remarks**
Duration	15 minutes 1 hour 2 hour 4 hour 8 hour 24 hour		Literature suggests that majority of the electricity interruptions typically lasts for short durations[7]. This fact was verified for Sri Lanka using CEB outage reports and attribute levels were chosen accordingly.
Time of the day	Residential sector	Industrial/ commercial sector	Attribute levels for the time of the day were formed considering the segments of the daily load curve, where 05.30-08.30 and 18.00-22.00 represent morning and evening peaks of load curve respectively. For the industrial and commercial sectors attribute levels were selected somewhat differently considering the presence of firms that may run around the clock or on shift basis.
	05.30- 08:30 08:30- 10:30 10:30- 16:00 16:00- 18:00 18:00- 22:00 22:00- 05:30	06.00 - 08.00 08.00 - 10.00 10.00 - 12.00 12.00 - 14.00 14.00 - 16.00 16.00 - 18.00 18.00 - 21.00 21.00 - 00.00 00.00 - 03.00 03.00 - 06.00	

Time of the year	January February March April May June July August September October November December	Since there's no distinct seasonal climate changes in Sri Lanka that affect severely on power consumption patterns, but cultural and socio-economic events that repeatedly takes place in certain times of the year, months of the year were used as attribute levels.
Frequency	Daily Weekly Monthly Yearly	-

6.3.2.2 Questions about interruption cost estimations

This study uses the following research techniques to elicit consumers' estimations of the cost of ENS.

- Direct Worth Method
- Contingent Valuation Method
- Preparatory Action Method (PAM)

The cost questions in the industrial and commercial sector questionnaires employ the Direct Worth approach, while the residential sector questionnaire exploits the Contingent Valuation Method. The Preparatory Action Method is used in all three questionnaires. The deciding factors for selecting estimation methods for questionnaires are the types of losses experienced by consumers in each sector, their ability to evaluate the losses in monetary terms, and the reduction of potential biases.

In industrial and commercial sectors, most of the interruption loss components are typically expressed in monetary terms. For instance, the production loss, spoilage of raw materials, and lost sales can be evaluated based on the market prices, and non-material costs can be considered negligible compared to material costs. Moreover, large industrial and commercial firms generally run downtime cost evaluations for their equipment, production plants, and networks. Thus respondents from these two sectors are most likely to know about the information required for estimating the cost of ENS. Therefore, using the Direct Worth approach for industrial and commercial sectors' questionnaires guarantees reliable and straightforward cost estimates for large enterprises. However, medium and small industries and businesses may encounter difficulty in estimating interruption costs and overlook cost components due to inexperience. Therefore, the interruption cost components suggested by previous studies are appropriately listed in the questionnaire for effective collection of data [39]. Cost components included in the questionnaire are shown in table 3.

Table 6.2 : Components of the interruption cost which are listed in the questionnaires for industrial and commercial sectors

Industrial Sector	Commercial Sector
Loss of raw material	Spoilage of goods
Loss of output	Lost business or sales
Loss due to finished products with low quality	Wages paid to staff who are unable to work
Cost of wages for the employers who are unable to work during interruption	Cost for overtime to make up lost sales
Cost for overtime to make up lost production	Shut down cost
Shut down cost	Startup cost
Startup cost	Equipment damage
Plant/equipment damage	Other costs (E.g.: Penalty cost for delayed work)
Other costs (E.g.: Penalty cost for delayed work)	

Unlike in industrial and commercial sectors, non-material costs cannot be disregarded when assessing the cost of ENS for residential sector since their contribution to the interruption cost is significant. Furthermore, residential consumers are inexperienced in assigning monetary values to the intangible costs such as inconvenience. Therefore, WTP and WTA questions are used for the residential sector consumers along with preparatory action questions.

For the contingent valuation questions a set of hypothetical scenarios are developed, including "close to real life" scenarios. Open-ended question style is used to avoid potential biases.

6.4 Design of the sample

The Sampling design is a crucial element in designing the survey framework as it highly affects the quality of the survey results. Proper sampling procedures allow hassle-free application of statistical analysis techniques to the survey data and justify the inference of survey results to the total population. In practical implementation, deviations from the standard methods may be unavoidable due to the reasons such as lack of master samples with required data, physical in-accessibility, and insufficient financial and human resources. These will eventually cause biased results. Therefore, it is imperative to construct a representative and sufficient sample complying with the resources available.

Determining the sample size, sample selection strategy and data collection modes are basic steps of the sample design.

6.4.1 Sizing of the sample

A primary requirement in determining sample size is to define the population and the population size. Housing units, industrial establishments, and commercial establishments in Sri Lanka can be identified as the statistical units for the three sectors under consideration of this study. Population data for these sectors can be obtained either from the Ceylon Electricity Board (CEB) databases or the Department of Census and Statistics Sri Lanka. Census data for housing units and industries have not been updated for the past seven-year period, thus we chose to use the CEB customer account database for determining population size. A summary of population data is presented in table 4.

Table 6.3 : Customer categorization based on the customer account database of CEB and LECO

Sector	CEB Accounts	LECO Accounts	Total number of Accounts
Industrial Sector	**64,241**	**3,399**	**67,640**
Industrial Purpose	64,241	3,399	67,640
Commercial Sector	**744,166**	**94,619**	**838,785**
General Purpose	739,122	94,118	833,240
Hotel	470	74	544
Government purpose	4,574	427	5,001
Residential Sector	**5,692,176**	**487,218**	**6,179,394**
Domestic Purpose	5,651,452	484,553	6,136,005
Religious Purpose	40,724	2,665	43,389
Total	**6,500,583**	**585,236**	**7,085,819**

Source: Statistical Digest 2019, CEB [28]

Strategies applicable to determine the sample sizes for each sector are using published sample size tables, imitating a sample sizes of similar studies and applying formulae [29]. Two formulas that can be used to calculate the sample size for a large population are presented below.

Cochran's Formula, $n_0 = \frac{Z^2pq}{e^2}$

where,

n_0 - Population size

Z -Z-score for selected confidence interval

e - Margin of error

p - Proportion of the population which has the attribute in question,

q =1 – p.

Yamane's Formula, $n = \frac{N}{1+N(e)^2}$

where,

N - Population size

e - Margin of error

Sample sizes calculated using the above two formulae adhering to the acceptable levels of the confidence interval, margin of error, and variability values for research studies are presented in the following table.

Table 6.4 : Sample size calculation using formulae

	Sample Size								
Formula used	Cochran's Formula						Yamane's Formula		
Maximum variability (p)	0.5						0.5		
Confidence Level	95% (Z= 1.96)			99%(Z=2.58)			95%		
Margin of Error (e)	±5%	±3%	±1%	±5%	±3%	±1%	±5%	±3%	±1%
Residential Sector	384	1067	9604	666	1849	16 641	400	1111	9984

Industrial Sector	384	1067	9604	666	1849	16 641	398	1093	8712
Commercial Sector	384	1067	9604	666	1849	16 641	400	1110	9882

To select a suitable combination of these statistics, the sample sizes used in similar studies were reviewed. The studies listed in table 6 have used a range of sample sizes.

Table 6.5 : Sample sizes used in similar studies

Study	Country	Sectors	Sample size
Pricing power outages in the Netherlands[13]	Netherlands	Residential consumers	12,409 (Response rate 27%)
		Small and medium sized enterprises (SME)	2481 (Response rate 7%)
The Value of Lost Load (VoLL) for Electricity in Great Britain[20]	Great Britain	Residential consumers	1,524
Does it matter when a power outage occurs? - A choice experiment study on the willingness to pay to avoid power outages[19]	Sweden	Residential consumers	1200 (Response rate 40%)
Willingness to pay among Swedish households to avoid power outages: A random parameter Tobit model approach[30]	Sweden	Residential consumers	3000 (Response rate 56%)
Development composite customer damage function using the customer survey based method for power system reliability	Thailand	Commercial and Industrial Customers	2,590
		Residential consumers	3,000

planning[31]			
Economic impact of electricity supply interruptions on the industrial sector of Bangladesh[32]	Bangladesh	Industrial consumers	208
Assessment of economic impact of electricity supply interruptions in the Sri Lanka industrial sector[1]	Sri Lanka	Industrial consumers	150
Estimation of power outage costs in the industrial sector of South Korea[33]	South Korea	Industrial consumers	430
Power Outage Cost Evaluation: Reasoning, Methods and an Application[6]	Austria	Residential consumers	894

The main issue with using these formulae is the underlying assumption that simple random sampling is used for obtaining the sample. However, when the cost of ENS is estimated in [3], the "Taro Yamane Approach" has been used for calculating the sample size.

The sample size eventually reflects the number of usable responses, not the number of questionnaires sent out. Therefore, when sample sizes are decided, response rates of previous studies must be taken into account and samples should be large enough to compensate for those who are not responding. On the other hand, limited availability of resources must be borne in mind.

Considering these factors, sample size obtained from the "Yamane's formula" for a confidence level of 95% and a margin of error of 5% is taken as a lower bound for the sample size. i.e. 400 respondents for each sector. Assuming very low response rates, due to the complexity of the questionnaire, at least 2000 participants from each sector are selected for the survey.

Since multiple regression will be used for the analysis of the data, the selected sample size should satisfy the required ratio of observations to the independent variables. The minimum acceptable ratio is five observations to an independent variable and ten is considered a more conservative ratio [34]. Therefore, the selected sample size allows for forty independent variables to be considered in a single model.

6.4.2 Selection of the sample

The aim of the sampling strategy in a survey is to draw a sample that represent the population of interest. Depending on the sub-categorization of the three sectors and availability of sampling frames different sampling strategies are chosen.

A two-stage stratified sampling method is selected for the residential sector based on two factors that are considered to affect the representativeness of the sample. They are the region of living and electricity consumption. The stratified sampling involves stratifying the population into strata and selecting samples using the probability sampling method within each stratum. Table 7 given below clearly illustrates the stages of stratification to be used and the corresponding strata.

Table 6.6 : Stages of stratification and corresponding strata

Stage of stratification	Strata
Stratification based on the region of living	Central province Eastern province Northern province Southern province Western province North Western Province North Central Province Uva Province Sabaragamuwa Province
Stratification based on the electricity consumption	Less than 30 units 31 to 60 units 61 to 90 units 91 to 120 units 121 to 180 units Over 180 units

In the first stage, proportions of the total sample size are allocated to each province, proportional to the housing population of each province. In the second stage, sub-samples allocated for each province is further stratified based on the proportions of residential electricity users in consumption categories.

Selecting a sample conforming to the above described strategy requires a sampling frame as illustrated in table 8 and this can be obtained from CEB.

Table 6.7 : Sampling frame for residential sector

Consumer Account Number	Address	Contact Number	Tariff Category	Region (Province)	Average Monthly Consumption

For industrial and commercial sectors, quota sampling strategy is selected. A quota of the total sample size is allocated to each industry sub-category based on the proportion of the total number of establishments in that category. When representative samples are selected, the emphasis is given to distribution densities of industrial and commercial firms in geographical regions of the country.

For the allocation of quota, population data for the industrial and commercial sector sub categories are obtained from the Department of Census and Statistics. The major issue with using Census data is that the published data are last updated in 2014 and therefore, dependable sample frames cannot be produced using these data. Even though, CEB data are up-to date, SICI sub categorization adopted in the survey is not available in CEB data. Therefore, to construct sampling frames for industry and commercial sector surveys, databases from following industry associations are used.

1. The Industrial Database of the Ceylon Chamber of Commerce
2. Sri Lanka Exporters Directory -Sri Lanka Export Development Board (EDB)
3. SME Directory - Sri Lanka Chamber of Small & Medium Industries (SLCSMI)

6.5 Methods of data collection

The four common modes of data collection for the surveys are mentioned below.

1. Mail survey
2. Online surveys
3. Personal interviews
4. Telephone interviews

Previous studies reveal that mail surveys and e-mail surveys have low response rates, while personal interviews and telephone interviews have high response rate. With the current pandemic situation in the country, opportunities for personal interviews are expected to be limited. Therefore, we hope to opt for online surveys and telephone interviews.

The domestic survey can be conducted mainly as an online and mail survey, while an e-mail survey and a telephone follow up procedure will be adopted in the industrial and commercial sector surveys. Since low response rates can be expected, several phases of data collection are defined for three sectors as shown in table 9.

Table 6.8 : Phases of data collection

	Residential	Commercial	Industrial
Phase I	Online survey	Email survey and telephone follow up	Email survey and telephone follow up
Phase II	Mail survey	Mail survey	Mail survey
Phase III	In-person interviews	In-person interviews	In-person interviews

6.6 Testing of the survey

6.6.1 Pre-test

A pre-test is conducted after the initial versions of the questionnaires are designed. Three to four interviewees from each sector are selected and asked to read and understand the questionnaires. Then, they are asked to explain what they understand from each question, whether they can find answers to the questions in the questionnaire, what their answers will be and etc. In addition, their feedback is obtained on the flow of the questions and the time taken to read and understand the questions.

6.6.2 Pilot test

A pilot survey is conducted to examine the understandability of the questionnaire, appropriateness of questions, and to decide the effectiveness of data collection modes. Based on the results of the pilot survey, questionnaire is reviewed and a comprehensive final survey is designed.

7. Estimation of Cost of ENS for the Residential Sector

7.1 Estimation of Cost of ENS for the Residential Sector using Survey Results

7.1.1 Research Methodology

The residential sector questionnaire used in this study employs the contingent valuation method as the main estimation method where WTP values are obtained from consumer inputs. The preliminary concept used to quantify the Cost of ENS for the residential sector using WTP data is given in (7.1).

$$\text{Cost of Unserved Energy} = \frac{\text{Willingness To Pay}}{\text{Energy Not Served}} \quad \textbf{(7. 1)}$$

The questionnaire extracts WTP values in terms of an additional payment that a customer is willing to pay with the monthly electricity bill if he/she wishes to avoid a certain interruption corresponding to different interruption scenarios defined for different interruption durations. Thus, each monetary value stated by a consumer in the survey response and used in these calculations is solely for avoiding an interruption with particular interruption duration.

Further, consumers' losses due to the expected interruptions may vary from that due to unexpected interruptions. Therefore, the amount they are willing to pay to avoid each of these two interruption scenarios would be different. As the number of unexpected interruptions can be reduced by frequent maintenance of distribution system, which will cause increased number of planned interruption, it is important to separately estimate the Cost of ENS for planned and unplanned interruptions.

7.1.1.1 Unexpected Outages (Unplanned Outages)

The Cost of ENS experienced by customer *k* due to an unexpected interruption $\mathrm{i_{un}}$ ($\mathrm{CENS_{k,i_{un}}}$) can be calculated as follows.

$$\mathrm{CENS_{k,i_{un}}} = \frac{\mathrm{WTP_{k,i_{un}}}}{\mathrm{E_{un,i_{un}}}} \quad \textbf{(7. 2)}$$

Where,

$WTP_{k,\mathrm{i_{un}}}$ – Additional amount consumer k is willing to pay to avoid the unplanned interruption $\mathrm{i_{un}}$

$E_{un,\mathrm{i_{un}}}$ – Energy not served to consumer *k* during the unplanned interruption $\mathrm{i_{un}}$.

As $E_{un,\mathrm{i_{un}}}$ is not a direct consumer input, it can be calculated as shown in (7.3).

$$E_{un,i_{un}} = \frac{X_k \text{ x } C \text{ x } t}{t_c} \quad \textbf{(7. 3)}$$

Where,

X_k – Monthly electricity consumption of consumer k

C – Proportion of energy consumption during the time period in which the adverse effects of unplanned interruptions are high

t –Interruption duration

t_c – Duration of time in a month in which the adverse effects of unplanned interruptions are high.

Note: It should be noted that the energy not served to consumer *k* due to a planned interruption (i_{pl}) ($E_{un,i_{pl}}$) is as same as that due to an unplanned interruption, if the interruption duration is the same.

To calculate Cost of ENS due to an unplanned interruptions scenario, i_{un}, i.e. $CENS_{i_{un}}$, values obtained from each consumer k for the unplanned interruption i_{un} is summed up and divided by the number of consumers, as shown in (7.4).

$$CENS_{i_{un}} = \frac{\sum_{k=1}^{N_R} CENS_{k,i_{un}}}{N_R} \quad \textbf{(7.4)}$$

Where,

N_R- Number of residential customers responded the survey

Then, the Cost of ENS due to unplanned interruptions in the residential sector ($CENS_{R,un}$) can be calculated by taking the sum of Cost of ENS due to the unplanned interruptions for each consumer as given in (7.5).

$$CENS_{R,un} = \frac{\sum_{i_{un}=1}^{q} (CENS_{i_{un}} \times P_{i_{un}})}{\sum_{i_{un}=1}^{q} P_{i_{un}}} \quad \textbf{(7.5)}$$

Where q is the number of unplanned outage scenarios

The probability of occurrence of the unplanned interruption scenario, i_{un} corresponding to a particular interruption duration ($P_{i_{un}}$) is calculated by dividing the number of unplanned interruptions occurred with that interruption duration by the total number of interruptions, as shown in (7.6).

$$P_{i_{un}} = \frac{\text{No of unplanned interrptions occured corresponding to the scenario } i_{un} \text{ witin a year}}{\text{Total no of interrptions occured within the year}} \quad \textbf{(7.6)}$$

7.1.1.2 Expected Outages (Planned Outages)

In this section, the Cost of ENS due to planned outages is calculated using a similar procedure described in section 7.1.1.1.

First, the Cost of ENS experienced by customer k due to a planned interruption i_p ($CENS_{k,i_p}$) can be calculated as follows.

$$CENS_{k,i_p} = \frac{WTP_{k,i_p}}{E_{un,i_p}} \quad \textbf{(7. 7)}$$

Where,

WTP_{k,i_p} – Additional amount consumer k is willing to pay to avoid the planned interruption i_p

E_{un,i_p} – Energy not served to consumer k during the unplanned interruption i_p

As E_{un,i_p} is not a direct consumer input, it can be calculated as shown in (7.8).

$$E_{un,i_p} = \frac{X_k \text{ x } C \text{ x } t}{t_c} \quad \textbf{(7. 8)}$$

Where,

X_k – Monthly electricity consumption of consumer k

C – Proportion of energy consumption during the time period in which the adverse effects of planned interruptions are high

t –Interruption duration

t_c – Duration of time in a month in which the adverse effects of planned interruptions are high.

Note: It should be noted the values of X_k, C and t_c are considered to be same for both planned and unplanned outages. Therefore, the energy not served to consumer k due to a planned interruption (i_{pl}) ($E_{un,i_{pl}}$) is as same as that due to an unplanned interruption, if the interruption duration is the same.

To calculate Cost of ENS due to an planned interruptions scenario, i_p, i.e. $CENS_{i_p}$, values obtained from each consumer k for the planned interruption i_p is summed up and divided by the number of consumers, as shown in (7.9).

$$CENS_{i_p} = \frac{\sum_{k=1}^{N_R} CENS_{k,i_p}}{N_R} \quad \textbf{(7.9)}$$

Where,

N_R- Number of residential customers responded the survey

Then, the Cost of ENS due to planned interruptions in the residential sector ($CENS_{R,p}$) can be calculated by taking the sum of Cost of ENS due to the planned interruptions for each consumer as given in (7.10).

$$CENS_{R,p} = \frac{\sum_{i_p=1}^{q}(CENS_{i_p} \times P_{i_p})}{\sum_{i_p=1}^{q} P_{i_p}} \quad \textbf{(7.10)}$$

Where q is the number of planned outage scenarios

The probability of occurrence of the planned interruption scenario, i_p corresponding to a particular interruption duration (P_{i_p}) is calculated by dividing the number of planned interruptions occurred with that interruption duration by the total number of interruptions, as shown in (7.11).

$$P_{i_p} = \frac{\text{No of planned interrptions occured corresponding to the scenario } i_p \text{ witin a year}}{\text{Total no of interrptions occured within the year}} \quad \textbf{(7.11)}$$

7.1.1.3 Cost of ENS for the Residential Sector

Cost of ENS can be estimated for the residential sector as shown in (7.12) by combining CENS estimated separately for unplanned and planned outages in (7.5) and (7.10), with the use of probability of occurrence of planned and unplanned outages given in the last column of Table 7.2.

$$CENS_R = \frac{CENS_{R,un} \times P_{un} + CENS_{R,p} \times P_p}{P_{un} + P_p} \quad \textbf{(7.12)}$$

Where,

$CENS_R$= Cost of ENS estimated for the residential sector

$CENS_{R,un}$= Cost of ENS estimated for the residential sector considering unplanned outages

$CENS_{R,p}$= Cost of ENS can be estimated for the residential sector considering planned outages

7.1.2 Results

The main variables used to estimate the Cost of ENS for the residential sector are WTP values and the amount of energy that goes unserved during each interruption. Unfortunately, obtaining accurate data on energy not served directly from consumers through surveys is difficult. To work around this issue, monthly energy consumption data is utilized to estimate the amount of energy not served during interruptions. According to the daily load curve in Sri Lanka, the peaks of demand occur after 6.00pm. Therefore, to consider worst scenarios, interruptions occur after 6 pm are taken into account. However, using an hourly average energy consumption to determine the amount of energy not served during interruptions with interruption durations less that one hour is deemed unsuitable.

To address this issue, a weighted approach is taken to derive hourly energy consumption data according to the variations in daily load curve. An approximate fraction of energy consumption from 6:00 pm to 1:00 am, which accounts for 40% of the total energy consumption for the residential sector is obtained. Time period 6:00 pm to 1:00 am is considered as time period of the day residential consumers experience the most adverse effects of interruptions. Considering this, the duration of time in a month in which consumers experience adverse effects of interruptions, t_c is calculated as 210 hours.

By substituting values for t_c and C in 7.3, it can be simplified to (7.13).

$$E_{un} = \frac{X_k \text{ x } 0.4 \text{ x } t}{210}$$

$$E_{un} = \frac{X_k \text{ x } t}{525} \tag{7. 13}$$

Once the Cost of ENS is calculated for each consumer corresponding to each unplanned interruption scenario using (7.2), (7.4) is used to calculate the average Cost of ENS corresponding to each unplanned interruption scenario. Then, the Cost of ENS due to unplanned interruptions is calculated using (7.5). Similarly, the Cost of ENS for each consumer corresponding to each planned interruption scenario, the average Cost of ENS corresponding to each planned interruption scenario, and the Cost of ENS due to planned interruptions are calculated using (7.7), (7.9) and (7.10). Finally, the Cost of ENS for the residential sector is obtained using (7.12). The probabilities of occurrence of unplanned and planned interruption scenarios used in (7.5), (7.10) and (7.12) are derived using a previous study conducted in 2018 [27]. The probability data is available for interruption duration intervals; 5mins – 30mins, 30mins – 1hr, 1hr – 2hr, 2hr – 4hr, 4hr - 8hr, 8hr – 16hr, 16hr - 24hr. Therefore, to comply with WTP data we have obtained, few alterations are made such as regrouping of interruption duration intervals and censoring of probability data above 8hr interruptions.

Table 7.1: Probabilities of occurrence of each interruption type after regrouping of interruption duration intervals and censoring of probability data above 8hr interruptions

	Probability				
Duration bin (hrs)	**1**	**2**	**4**	**8**	**Total**
Unplanned	0.651	0.037	0.026	0.011	0.725
Planned	0.156	0.008	0.014	0.050	0.228
Total	0.807	0.045	0.040	0.061	0.953

Table 7.2: Final probabilities of occurrence of each interruption type

	Probability				
Duration bin (hrs)	**1**	**2**	**4**	**8**	**Total**
Unplanned	0.683	0.039	0.027	0.012	0.761
Planned	0.164	0.008	0.015	0.052	0.239
Total	0.847	0.047	0.042	0.064	1

The values obtained for the Cost of ENS due to planned and unplanned interruptions and the Cost of ENS for the residential sector on average are summarized in table 7.3.

Table 7.3: Summary of Cost of ENS values for the residential sector

Interruption Category	Cost of ENS
Unplanned Interruption	528.45 LKR/kWh
Planned Interruptions	480.47 LKR/kWh
Combined	516.97 LKR/kWh

7.1.3 Discussion

The results presented in the table 7.3 in section 7.1.2 shows the estimated Cost of Energy Not Served (ENS) for unplanned and planned interruptions, as well as the combined Cost of Energy Not Served for the residential sector in Sri Lanka. The Cost of ENS for unplanned interruptions is 528.45 LKR/kWh, and this figure is slightly higher, when compared to the Cost of ENS for planned interruptions, which is 480.47 LKR/kWh. This suggests that unplanned interruptions are somewhat disruptive and costly to consumers compared to planned interruptions. Furthermore, on average, the cost of energy not served during an interruption in the residential sector in Sri Lanka is estimated to be around 516.97 LKR per kWh. This cost includes both planned and unplanned interruptions and it is worth noting that in this study, the total Cost of ENS for the residential sector is the weighted sum of the two cost components for planned and unplanned interruptions. The weights are determined by the respective probabilities of occurrence of planned and unplanned interruptions, therefore, unplanned interruptions contributing significantly to the overall cost.

Table 7.4: Calculation of weighted sum of the planned and unplanned components of CENS

Interruption Category	**CENS Components**	**Probability**	**Weighted CENS**
Unplanned Interruption	528.45 LKR/kWh	0.761	402.02 LKR/kWh
Planned Interruptions	480.47 LKR/kWh	0.239	114.95 LKR/kWh
Total Cost of ENS for the Residential Sector			516.97 LKR/kWh

These data highlight the importance of reducing the frequency and duration of unplanned interruptions to minimize the overall cost of energy not served for consumers. It also highlights the need for effective planning and management of planned interruptions to minimize the impact on consumers. Using proper strategies to minimize interruptions, utilities can improve customer satisfaction and ensure a more reliable and sustainable energy supply for the residential sector in Sri Lanka, by reducing the total cost of ENS.

Furthermore, these results can be compared with past data for validation and given below in table 7.4 is a comparison of results of this study with a previous study conducted in Sri Lanka in 2018. It is the only study available in the local context to compare the present results obtained for the residential sector. Unfortunately, previous studies do not provide Cost of ENS figures separately for planned and unplanned interruptions experienced by the residential consumers.

Table 7.4: Comparison of estimated Cost of ENS of the residential sector with that in previous studies

Year of Study	**Cost of ENS for the residential sector**
2018	232.39 LKR/kWh
2023	516.97 LKR/kWh

According to the data presented in the table 7.4, the Cost of ENS for the residential sector has increased significantly from 232.39 LKR/kWh in 2018 to 516.97 LKR/kWh in 2023. Generally, this increase in cost can be attributed to several factors, such as inflation, changes in energy demand and consumption patterns, changes in the cost of electricity generation and distribution, and possible increase in the frequency and duration of interruptions, which could contribute to the overall cost of ENS. Since Sri Lanka is undergoing a period of economic downturn, it's reasonable to assume that skyrocketing inflation, changes in electricity tariff and frequent interruptions imposed by demand management program have mainly contributed to the increased cost of ENS for residential sector. Furthermore, it can be argued that a significant portion of this increase in Cost of ENS can be attributed to the rise in Cost of ENS over the past year due the Economic and societal incidents took place in Sri Lanka in year 2022.

7.2 Updating of Cost of ENS for the Residential Sector using Economic Parameters

7.2.1 Research Methodology

The Indirect analytical method of estimating Cost of ENS for the residential sector reasons and uses macroeconomic data such as hourly income rate as the monetary value of Cost of ENS for the residential sector [24]. A study with limited number of survey responses presents the relationship between outage cost and net income earning rate is shown in figure 7.1 [26].

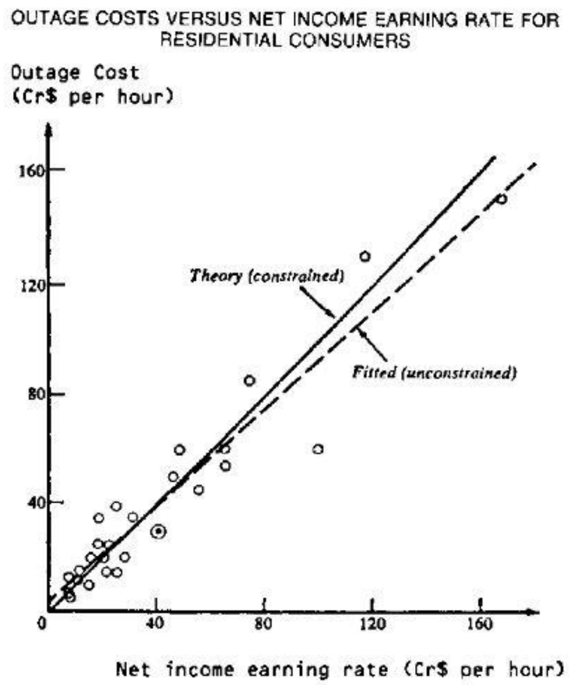


Figure 7.1: The relationship between outage cost and net income earning rate [26].

Initial Ordinary Least Square(OLS) model equation for the data is given in (7.12).

$$OC_i = \beta_1 + \beta_2 Y_i + U_i \quad \textbf{(7.12)}$$

Where,

OC_i - Outage cost for customer i

Y_i - Net income earning rate of customer i per hour

U_i - Random disturbances term for customer i

β_1 = 3.355 and β_2 = 0.896

The curve is later fitted to the restricted equation in (7.13), which is derived from the theoretical concept, within the statistical limitations as illustrated by solid line in figure 7.1.

$$OC = Y + U \tag{7.13}$$

The intention of the method developed in our study is to apply the above theory, i.e. the linear relationship between Cost of ENS and hourly income rate to update the cost of ENS for the residential sector for the coming years.

Based on this approach, the updating method of Cost of ENS for the residential sector is developed by analyzing the relationship of household hourly income with Cost of ENS for the residential sector. The household hourly income rate is calculated using the mean monthly household income data published in Household Income and Expenditure Survey by Department of Census and Statistics Sri Lanka for approximately every three year's interval.

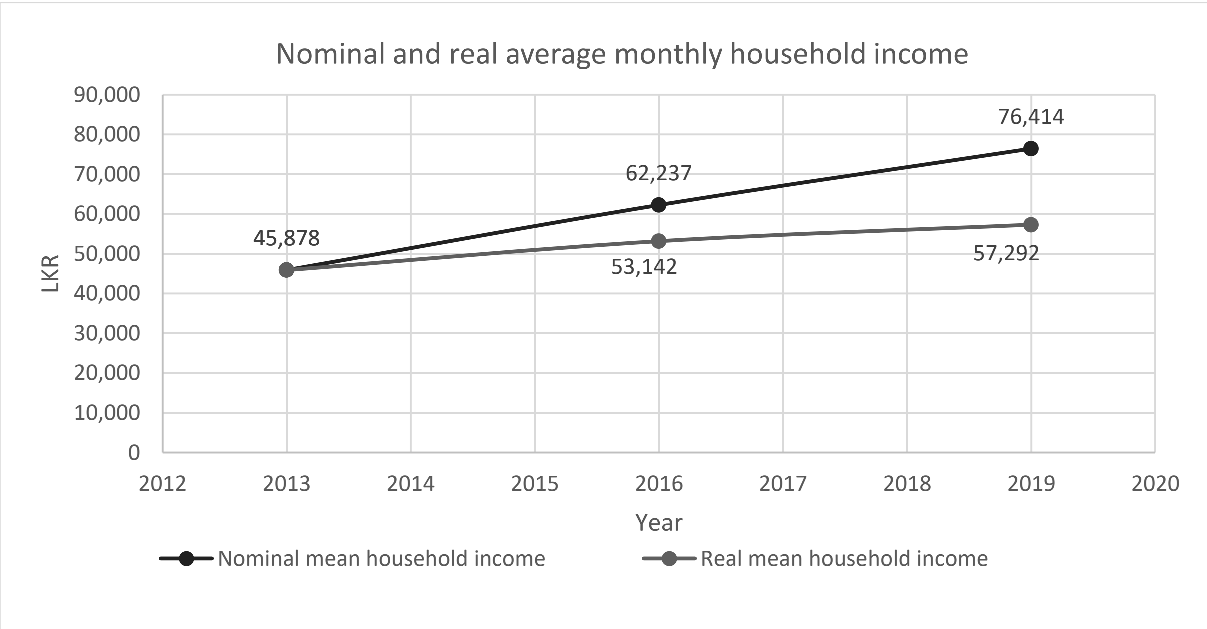


Figure 7.2 : Mean monthly household income data

Considering average work hours per week is 40hrs (calculated using data on average annual hours actually worked published by Organization for Economic Cooperation and Development

(OECD)), hourly income rate for each year considered is calculated as follows. The real values of based year 2013 are used for the calculation to extract the inflation factor.

Table 7.5: Calculation of mean hourly household income

Year	Mean monthly household income (Base 2013)	Mean hourly household income
2013	45,878	287
2016	53,142	389
2019	57,292	478

Cost of ENS data for residential sector is available only for the years 2018 and 2022. Since the monthly household income data has been adjusted for the inflation of prices using the National Consumer Price Index (NCPI), the Cost of ENS data are also converted using the following formula to obtain their real values.

$$\text{Real value in base year} = \frac{\text{Nominal value in year of Interest}}{\text{Inflation index of year of Interest}} \text{ x } \text{Inflation index of base year} \qquad \textbf{(7.14)}$$

Converted data are as follows.

Table 7.6: Calculation of real value of Cost of ENS for Sri Lanka considering 2013 as the base year

Year	NCPI (2013 =100)	Nominal CENS	Real CENS (Base 2013)
2018	126.5	232.39	183.71
2022	231.5	516.97	223.31

Since income data and CENS data are not available for the considered range of years, visualizing available data in a single chart is used as a means of comparing the two variables over time.

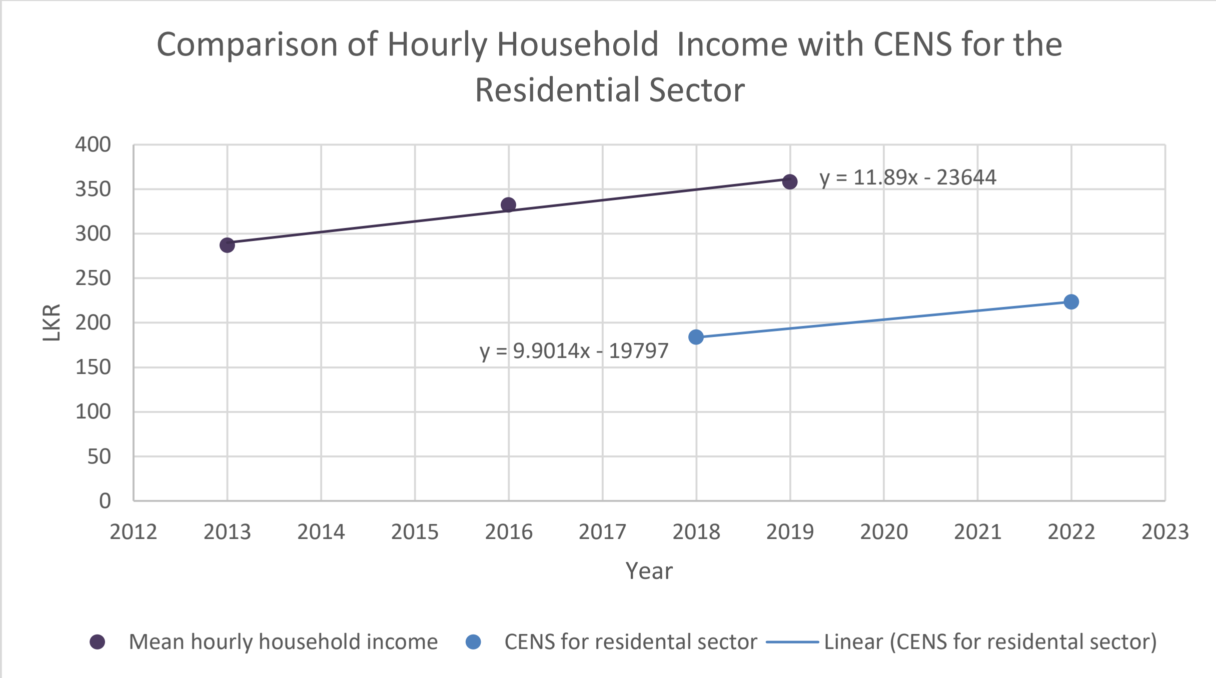


Figure 7.3 : Comparison of hourly household income with Cost of ENS for the Residential Sector

Although the available data are limited, assumptions were made that both the variables are following a linear trend over time and linear equations (7.15) and (7.16) obtained from the graph were utilized to estimate the incomplete data across the entire time spectrum.

$$\text{Mean hourly household Income} = -23644 + 11.89 \text{ x Year} \tag{7.15}$$

$$\text{CENS}_r = -19797 + 9.9014 \text{ x Year} \tag{7.16}$$

Table 7.7: Estimation of incomplete hourly income data and CENS data

Year	Hourly income (LKR/hour)	CENS (LKR/kWh)
2007	219.23	75.1098
2008	231.12	85.0112
2009	243.01	94.9126
2010	254.90	104.814
2011	266.79	114.7154
2012	278.68	124.6168
2013	290.57	134.5182
2014	302.46	144.4196
2015	314.35	154.321
2016	326.24	164.2224
2017	338.13	174.1238
2018	350.02	184.0252
2019	361.91	193.9266
2020	373.80	203.828

Estimated Cost of ENS data for the residential sector was graphed against the estimated mean hourly household income data as illustrated in figure 7.3 and the following relationship between the two variables were obtained.

$$CENS_{R,est} = \alpha_1 + \alpha_2 I \quad \textbf{(7.17)}$$

Where,

$CENS_{R,est}$ – Estimated Cost of ENS for the residential sector

I – Mean hourly household income

α_1 = -107.45 and α_2 = 0.8328

Figure 7.4 shows the variation of the real value of Cost of ENS estimated for the residential sector with the real value of estimated mean hourly household income data according to the relationship found in (7.17).

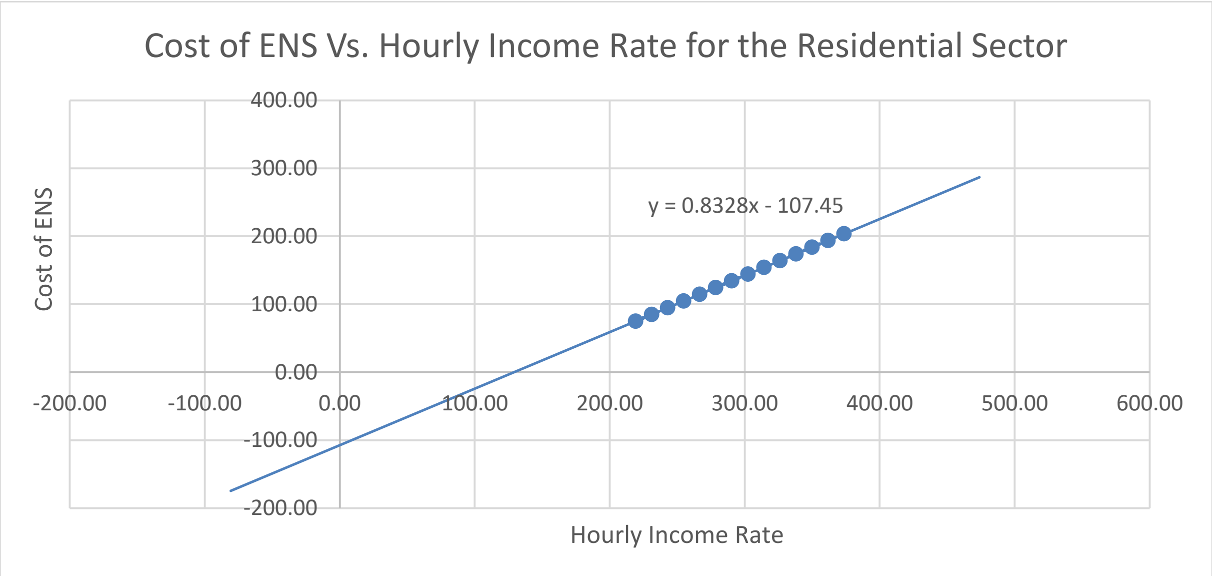


Figure 7.4 : Cost of ENS vs. hourly income rate for the residential sector

7.2.2 Results

The equation (7.17) derived in the previous section can be used to estimate the Cost of ENS for the residential sector utilizing the mean monthly household income data periodically published by Department of Census and Statistics of Sri Lanka. Since real values of each variable for the base year of 2013 are used for the derivation, converting the data into real values before substitution is reccommonded for accurate results. On the other hand, performing the nominalization on the estimated figures proir to using the data for making informed decisions is important for visualizing data in present context.

Table 7.8: Nominalization of updated Cost of ENS for the Residential Sector

Year	NCPI (2013 =100)	$CENS_{R,est}$ (LKR/kWh) (Base - 2013)	$CENS_{R,est}$ (LKR/kWh) (Nominal)
2013	100	134.52	134.52
2014	106.2	144.42	153.37
2015	109.1	154.32	168.36
2016	116.1	164.22	190.66
2017	123.4	174.12	214.87
2018	126.5	184.03	232.79
2019	129.2	193.93	250.55
2020	137.3	203.83	279.86
2021	145.7	213.73	311.40
2022	231.5	223.63	517.71

Cost of ENS figures for the residential sector since the year 2013 are chosen to update, due to the inavailability of NCPI data for the previous years. Since NCPI data are available monthy then onwards, NCPI for the month of June in every year is considered for the above estimation.

NCPIs used to convert real values of Cost of ENS estimated for the residential sector, estimated real values of Cost of ENS and nominal values of Cost of ENS obtained after the conversion are tabulated in Table 7.6.Figure 7.5 illustrates the variation of updated Cost of ENS for the the Residential Sector over the time.

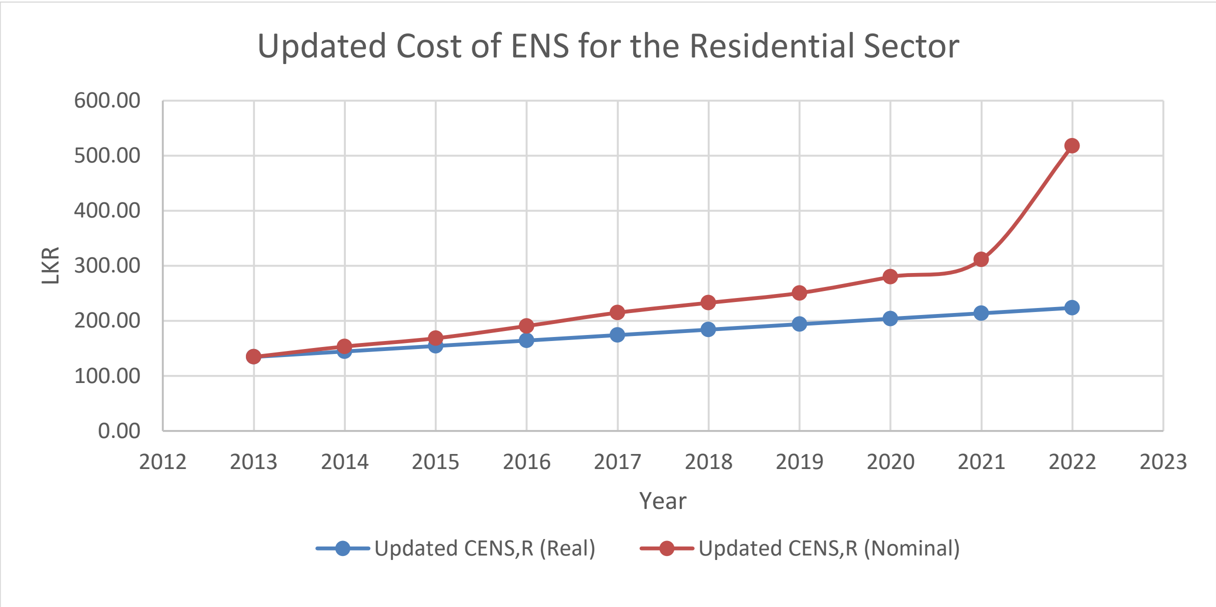


Figure 7.5 : Updated Cost of ENS for the residential sector

7.2.3 Discussion

This work studies the relationship between the hourly household income and the Cost of ENS of the residential sector in Sri Lanka. Then, a method is proposed to update the Cost of ENS values estimated for the residential sector of Sri Lanka with the use of hourly household income data. This study was conducted with the limited number of survey based Cost of ENS figures estimated in 2018 and 2022. It is recommended to update the equation derived to find the Cost of ENS using the hourly household income, whenever new survey based Cost of ENS figures are available. This will increase the accuracy of the updates provided by the method suggested in this work.

8. Estimation of cost of ENS for the Industrial Sector

8.1 Estimation of Cost of ENS for the Industrial Sector using Survey Results

8.1.1 Research Methodology

This section describes the method used to estimate CENS for the industrial sector using the customer survey.

In this study, the responses collected from industrial consumers are grouped into following subcategories, by referring to the consumer categorization in the department of census which is in accordance with the International Standard Industry Classifications (ISIC).

1. Mining and quarrying.
2. Manufacture of food, beverages, and tobacco products.
3. Manufacture of textiles, apparel and leather related products.
4. Manufacture of wood, products of wood and cork except furniture.
5. Manufacture of paper products, printing, and reproduction of media products.
6. Manufacture of coke and refined petroleum products.
7. Manufacture of chemical products and basic pharmaceutical products.
8. Manufacture of rubber and plastic products.
9. Manufacture of other non-metallic mineral products.
10. Manufacture of basic metals and fabricated metal products.
11. Manufacture of machinery and equipment.
12. Other manufacturing, and repair and installation of machinery and equipment.
13. Electricity, gas, steam, and air conditioning supply.
14. Water collection, treatment, and supply.
15. Sewerage, waste treatment and disposal activities.

Survey responses collected from each subsector consists of costs of damages experienced by consumers under following damage types. These costs are considered in the estimation of Cost of ENS for the industrial sector.

- Loss of raw material.
- Loss of production.
- Loss due to the low quality of finished products
- Wages paid to employees for the idle time caused by the interruption.
- Overtime payments paid to cover the production lost due to the interruption.

- Shutdown cost
- Start-up cost
- Equipment damages
- Other costs

A detailed description of the method used to estimate the CENS for the industrial sector is provided under this sub section in step by step using equations.

8.1.1.1 Cost of ENS Due to Unplanned Outages

First, the Cost of ENS experienced by a single customer k in the subsector s due to an unexpected interruption with the interruption duration t i.e. $C_{k,s,t,u}$ is calculated using (8.1) by considering the cost of damages corresponding to each damage type [27].

$$C_{k,s,t,u} = \frac{\sum_{i=1}^{N_D} D_{i,k,s,t,u}}{E_{k,s,t,u}} \quad \textbf{(8. 1)}$$

Where,

$C_{k,s,t,u}$= Cost of ENS experienced by the customer k in the subsector s due to an unplanned interruption with the interruption duration t

$E_{k,s,t,u}$ = Estimated energy not served for the customer k in the subsector s during the unplanned interruption duration t

$D_{i,k,s,t,u}$= Cost of damages experienced by the customer k in the subsector s from damage type i, due to an unplanned interruption with the interruption duration t

N_D=Number of different damage types under consideration

Cost of ENS experienced by the customer k in the subsector s due to an unplanned interruption (i.e., $C_{k,s,u}$) can be obtained as shown in (8.2) by considering the combined effect of unplanned interruptions with different interruption durations.

$$C_{k,s,u} = \frac{\sum_{t=1}^{r}(C_{k,s,t,u} \times P_{t,u})}{\sum_{t=1}^{r} P_{t,u}} \quad \textbf{(8.2)}$$

Where,

$P_{t,u}$ = Probability of occurrence of an unplanned interruption with interruption duration t

$$P_{t,u} = \frac{N_{t,u}}{N_T} \quad \textbf{(8.3)}$$

$N_{t,p}$ = Number of unplanned interruptions with interruption duration t occurred during the considered time period.

N_T = Total number of interruptions occurred during the considered time period.

Probabilities of occurrence of unplanned interruptions are calculated for interruption durations under consideration, using historical data and tabulated in the second row of Table 8.1.

Table 8.1 : Probabilities of occurrence of unplanned/planned interruptions

Interruption duration, t (hrs.)	0.25	0.75	1.5	3	6	Total probability
Probability of occurrence of an unplanned interruption, $P_{t,u}$	0.547	0.104	0.037	0.026	0.011	0.740
Probability of occurrence of a planned interruption, $P_{t,p}$	0.151	0.005	0.008	0.014	0.050	0.260
Total probability	0.698	0.109	0.045	0.040	0.061	1.000

Cost of ENS experienced by customers in the subsector s due to an unplanned interruption ($C_{s,u}$) can be obtained as shown in (8.4) by considering the electricity consumption of each customer as a weighting factor.

$$C_{s,u} = \frac{\sum_{k=1}^{N_s}(C_{k,s,u} \times x_k)}{\sum_{k=1}^{N_s} x_k} \tag{8.4}$$

Where,

x_k= Average electricity consumption of consumer k

N_s= Number of customers considered in the study from subsector s

GDP contribution from each subsector of the given year can be used to obtain a value for the Cost of ENS due to unplanned interruptions by considering the combined effect of different subsectors in the industrial sector as shown in (8.5).

$$C_{u,I} = \frac{\sum_{s=1}^{N_I}(C_{s,p} \times GDP_s)}{\sum_{s=1}^{N_I} GDP_s} \tag{8.5}$$

Where,

$C_{u,I}$ = Cost of ENS for industrial sector considering unplanned outages

GDP_s= GDP contribution of the subsector s to the GDP of the industrial sector in the year under consideration

N_I=Number of subsectors in the industrial sector

8.1.1.2 Cost of ENS Due to Planned Outages

Similarly, the Cost of ENS experienced by a single customer k in the subsector s due to an expected interruption with the interruption duration t i.e., $C_{k,s,t,p}$ is calculated using (8.6) by considering the cost of damages corresponding to each damage type.

$$C_{k,s,t,p} = \frac{\sum_{i=1}^{N_D} D_{i,k,s,t,p}}{E_{k,s,t,p}} \quad \textbf{(8.6)}$$

Where,

$C_{k,s,t,p}$= Cost of ENS experienced by the customer k in the subsector s due to a planned interruption with the interruption duration t

$E_{k,s,t,p}$ =Estimated energy not servered for the customer k in the subsector s during the planned interruption duration t

$D_{i,k,s,t,p}$= Cost of damages experienced by the customer k in the subsector s from damage type i, due to a planned interruption with the interruption duration t

N_D=Number of different damage types under consideration

Cost of ENS experienced by the customer k in the subsector s due to a planned interruption (i.e. $C_{k,s,p}$) can be obtained as shown in (8.7) by considering the combined effect of planned interruptions with different interruption durations.

$$C_{k,s,p} = \frac{\sum_{t=1}^{r} (C_{k,s,t,p} \times P_{t,p})}{\sum_{t=1}^{r} P_{t,p}} \quad \textbf{(8.7)}$$

Where,

$P_{t,p}$ =Probability of occurrence of a planned interruption with interruption duration t

$$P_{t,p} = \frac{N_{t,p}}{N_T} \quad \textbf{(8. 8)}$$

$N_{t,p}$ = Number of planned interruptions with interruption duration t occurred during the considered time period.

N_T = Total number of planned interruptions occurred during the considered time period.

r = Number of different interruption durations under consideration

Probabilities of occurrence of planned interruptions are calculated for interruption durations under consideration, using historical data and tabulated in the third row of Table 8.1.

Cost of ENS experienced by customers in the subsector s due to a planned interruption ($C_{s,p}$) can be obtained as shown in (8.9) by considering the combined effect of Cost of ENS due to planned interruptions experienced by each customer in the subsector s.

$$C_{s,p} = \frac{\sum_{k=1}^{N_s}(C_{k,s,p} \times x_k)}{\sum_{k=1}^{N_s} x_k} \tag{8. 9}$$

Where,

x_k= Average electricity consumption of consumer k

N_s= Number of customers considered in the study from subsector s

GDP contribution from each subsector of the given year can be used to obtain a value for the Cost of ENS due to planned interruptions by considering the combined effect of different subsectors in the industrial sector as shown in (8.10).

$$C_{p,I} = \frac{\sum_{s=1}^{N_I}(C_{s,p} \times GDP_s)}{\sum_{s=1}^{N_I} GDP_s} \tag{8. 10}$$

Where,

$C_{p,I}$ = Cost of ENS for industrial sector considering planned outages

GDP_s= GDP contribution of the subsector s to the GDP of the industrial sector in the year under consideration

N_I= Number of subsectors in the industrial sector

8.1.1.3 Cost of ENS for the Industrial Sector

Cost of ENS can be estimated for the industrial sector as shown in (8.11) by combining CENS estimated separately for unplanned and planned outages in (8.5) and (8.10), with the use of probability of occurrence of planned and unplanned outages given in the last column of Table 8.1.

$$CENS_I = \frac{C_{u,I} \times P_u + C_{p,I} \times P_p}{P_u + P_p} \tag{8. 11}$$

Where,

$CENS_I$= Cost of ENS estimated for the industrial sector

$C_{u,I}$= Cost of ENS estimated for the industrial sector considering unplanned outages

$C_{p,I}$= Cost of ENS can be estimated for the industrial sector considering planned outages

8.1.1.4 Cost of ENS for the subsectors of the Industrial Sector

Cost of ENS can be estimated for each subsector of the industrial sector as shown in (8.12) by combining CENS estimated separately for unplanned and planned outages of each subsector using (8.4) and (8.9), with the use of probability of occurrence of planned and unplanned outages given in the last column of Table 8.1.

$$CENS_{s,I} = \frac{C_{s,u} \times P_u + C_{s,p} \times P_p}{P_u + P_p} \quad \textbf{(8. 12)}$$

Where,

$CENS_{s,I}$ = Cost of ENS estimated for the subsector s of the industrial sector

$C_{s,u}$= Cost of ENS estimated for the subsector s of the industrial sector considering unplanned outages

$C_{s,p}$= Cost of ENS can be estimated for the subsector s of the industrial sector considering planned outages

8.1.2 Results

The methodology described in subsection 8.1.1 is used to estimate CENS for the industrial sector and results are presented in this subsection.

8.1.2.1 Cost of ENS Due to Unplanned Outages

Cost of ENS experienced by customers in each subsector due to an unplanned interruption is estimated using (8.4) and tabulated in Table 8.2, illustrated in Fig. 8.1

Table 8.2: CENS for Unexpected Outages

Subsector of the industrial sector	LKR/kWh
1. Mining and quarrying.	610.90
2. Manufacture of food, beverages, and tobacco products.	895.92
3. Manufacture of textiles, wearing apparel and leather related products.	1194.65
4. Manufacture of wood, products of wood and cork except furniture.	1080.39
5. Manufacture of paper products, printing, and reproduction of media products.	753.00
6. Manufacture of coke and refined petroleum products.	-
7. Manufacture of chemical products and basic pharmaceutical	-

products.	
8. Manufacture of rubber and plastic products.	516.35
9. Manufacture of other non-metallic mineral products.	475.01
10. Manufacture of basic metals and fabricated metal products.	561.01
11. Manufacture of machinery and equipment.	884.84
12. Other manufacturing, and repair and installation of machinery and equipment.	654.42
13. Electricity, gas, steam, and air conditioning supply.	-
14. Water collection, treatment, and supply.	-
15. Sewerage, waste treatment and disposal activities.	-

8.1.2.2 Cost of ENS Due to Planned Outages

Cost of ENS experienced by customers in each subsector due to a planned interruption is estimated using (8.9) and tabulated in Table 8.3 , illustrated in Fig. 8.2

Table 8.3: CENS for Expected Outages

Subsector of the industrial sector	LKR/kWh
1. Mining and quarrying.	470.84
2. Manufacture of food, beverages, and tobacco products.	702.69
3. Manufacture of textiles, wearing apparel and leather related products.	644.37
4. Manufacture of wood, products of wood and cork except furniture.	743.34
5. Manufacture of paper products, printing, and reproduction of media products.	429.34
6. Manufacture of coke and refined petroleum products.	-
7. Manufacture of chemical products and basic pharmaceutical products.	-
8. Manufacture of rubber and plastic products.	382.99
9. Manufacture of other non-metallic mineral products.	267.81
10. Manufacture of basic metals and fabricated metal products.	342.26
11. Manufacture of machinery and equipment.	561.69
12. Other manufacturing, and repair and installation of machinery and equipment.	431.76
13. Electricity, gas, steam, and air conditioning supply.	-
14. Water collection, treatment, and supply.	-
15. Sewerage, waste treatment and disposal activities.	-

8.1.2.3 Cost of ENS for Each Subcategory

Cost of ENS is estimated for each subsector using (8.12) and tabulated in Table 8.4 , illustrated in Fig. 8.3.

Table 8.4: Cost of ENS estimated for subsectors.

Subsector of the industrial sector	LKR/kWh
1. Mining and quarrying.	550.25
2. Manufacture of food, beverages, and tobacco products.	809.76
3. Manufacture of textiles, wearing apparel and leather related products.	1013.04
4. Manufacture of wood, products of wood and cork except furniture.	952.77
5. Manufacture of paper products, printing, and reproduction of media products.	643.82
6. Manufacture of coke and refined petroleum products.	-
7. Manufacture of chemical products and basic pharmaceutical products.	-
8. Manufacture of rubber and plastic products.	461.68
9. Manufacture of other non-metallic mineral products.	405.44
10. Manufacture of basic metals and fabricated metal products.	484.77
11. Manufacture of machinery and equipment.	769.58
12. Other manufacturing, and repair and installation of machinery and equipment.	572.90
13. Electricity, gas, steam, and air conditioning supply.	-
14. Water collection, treatment, and supply.	-
15. Sewerage, waste treatment and disposal activities.	-

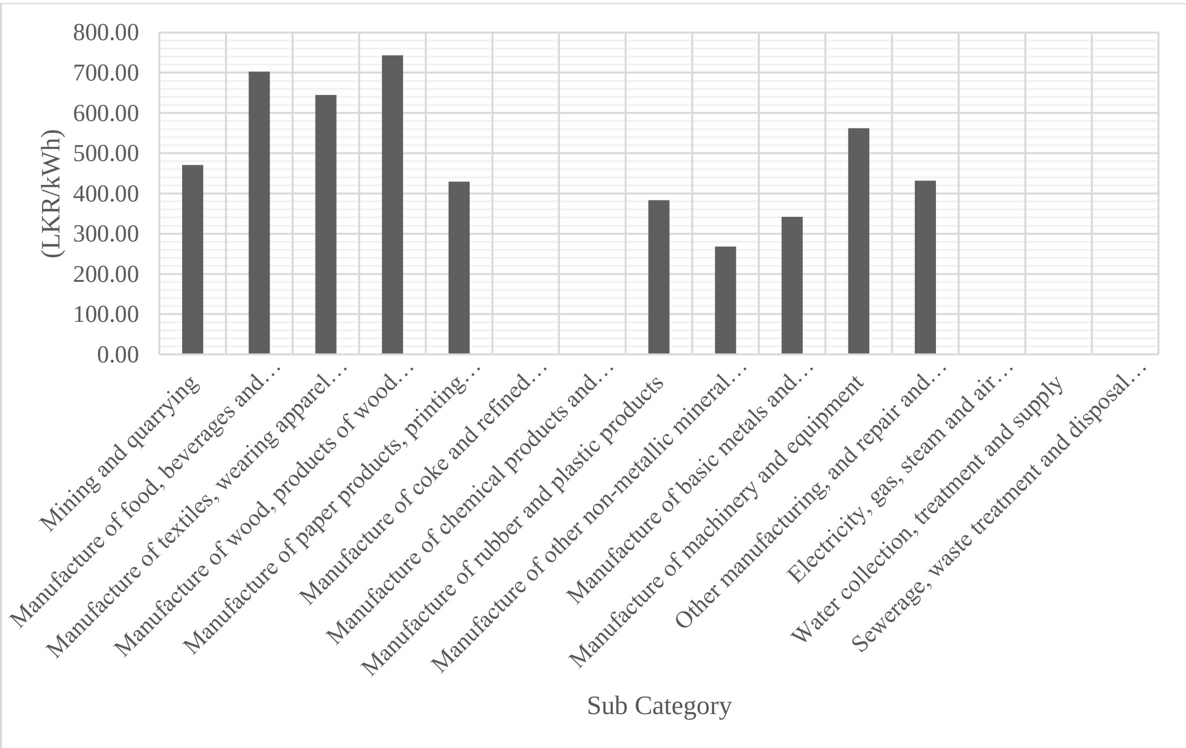


Fig. 8.1 : Cost of ENS due to expected outages.

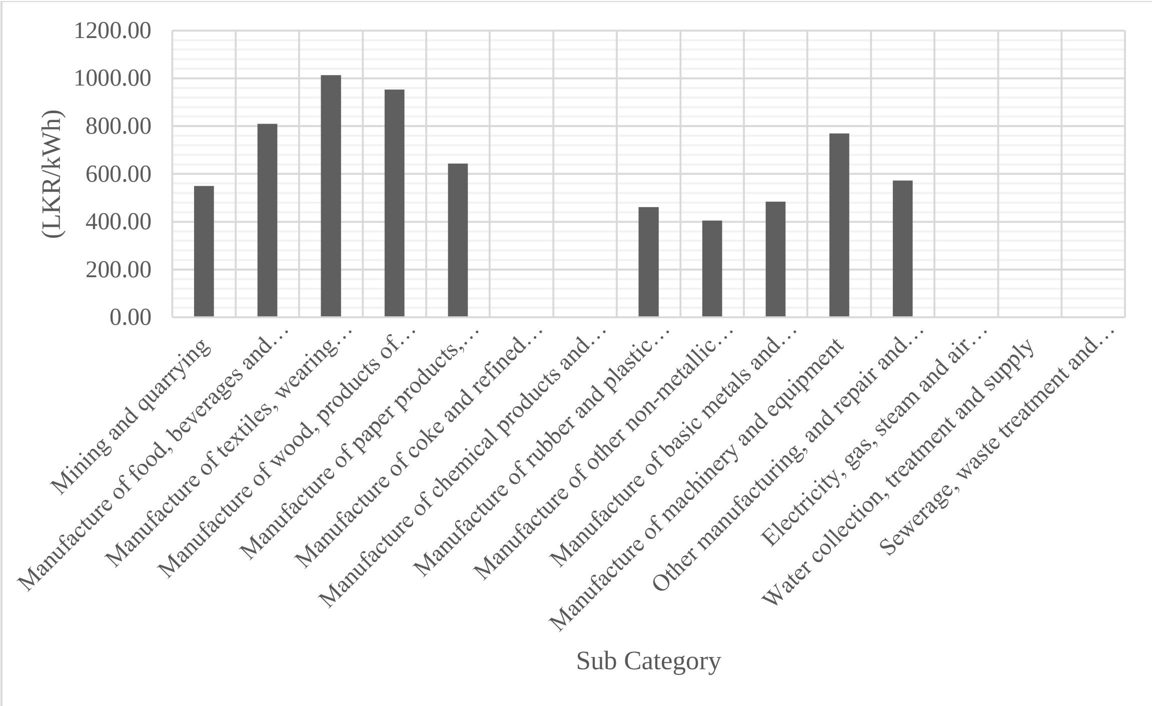


Fig. 8.2 : Cost of ENS due to unexpected outages

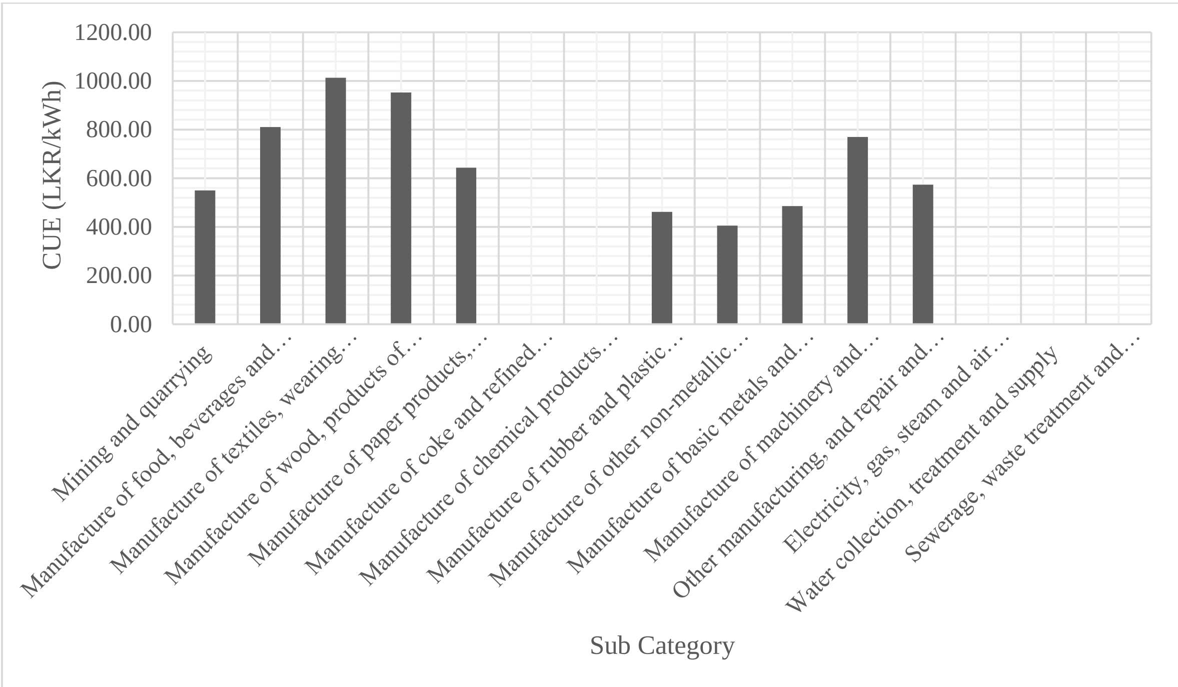


Fig. 8.3 : Cost of ENS for subsectors

8.1.2.4 Cost of ENS for the Industrial Sector

Cost of ENS due to unplanned and planned outages and the overall Cost of ENS figure estimated for the industrial sector using (8.5), (8.10) and (8.11), respectively are tabulated in Table 8.5.

Table 8.5: Cost of ENS for the Industrial Sector

Cost of ENS due to unplanned outages	1,007.98 LKR/kWh
Cost of ENS due to planned outages	692.94 LKR/kWh
Cost of ENS for the industrial sector	888.78 LKR/kWh

8.1.3 Discussion

This study utilizes data obtained from a consumer survey to estimate Cost of ENS for the industrial sector. Consumers are categorized into subsectors and Cost of ENS due to planned and unplanned outages is separately estimated for each sub-sector. These results shown in Table 8.2 and Table 8.3 are graphically presented using Fig. 8.1 and Fig. 8.2. It can be observed that all subsectors in the industrial sector have a higher Cost of ENS value for unexpected outages than that of expected outages. The difference between the two figures is considerably high for some subsectors such as “manufacture of food, beverages, and tobacco products”, “manufacture of wood, products of wood and cork except furniture”, “manufacture of paper products, printing, and reproduction of media products” and “manufacture of rubber and plastic products”. As planned outages are known in advance these subsectors can do adjustments to their manufacturing schedules etc. and therefore, damages that the consumers in these subsectors experience due to planned outages are significantly less compared to that of unplanned outages.

Then, Cost of ENS values estimated for planned and unplanned outages of each sub-sector are combined to obtain Cost of ENS for each subsector of the industrial sector and the results are shown in Table 8.4 and Fig. 8.3. The subsector “manufacture of textiles, wearing apparel and leather related products” exhibits the highest Cost of ENS value. This can be largely attributed to the fact that manufacturers in the textile and apparel industry often operate their facilities continuously, which renders them susceptible to both planned and unplanned service disruptions. It's worth noting that during the data collection period in 2021 and 2022, the survey results may have been significantly influenced by several factors. These include the impact of COVID-19 and extensive demand management schedules implemented by utilities.

These factors may have had a particularly pronounced effect on subcategories such as "manufacture of textiles, wearing apparel, and leather-related products".

Further, Cost of ENS values estimated for planned and unplanned outages of each sub-sector are combined to estimate Cost of ENS for planned and unplanned of the industrial sector. These values are further combined to estimate Cost of ENS for the industrial sector. These results tabulated in Table 8.5 shows that Cost of ENS estimated for the unplanned outages of the industrial sector is significantly higher than that of the planned outages. As planned outages are known in advance they allow for adjustments and therefore, the damages that the consumers experience due to planned outages are less compared to that of unplanned outages.

8.2 Updating of Cost of ENS for Industrial Sector using Economic Parameters

8.2.1 Research Methodology

The value-added data and annual energy consumption of the industrial sector is relatively easy to acquire when compared to collecting responses from consumers for the questionnaire in the direct survey-based method. Hence, this section develops a method to update the Cost of ENS figure for the industrial sector without conducting time consuming customer surveys. This proposed method intends to utilize Cost of ENS values previously estimated through customer surveys together with macro-economic data.

In this work, we make a reasonable assumption i.e., the value added of an industrial facility is directly proportional to its production output.

$$Production \sim \text{Value added} \tag{8.13}$$

In an industrial setting, it is assumed that uninterrupted production relies on a continuous power supply. Therefore, this infers that the value added of an industrial facility relies on the supply of power.

Therefore, the customer interruption cost (CIC_{va}) can be calculated using (8.14) as the ratio between the value added per year and the annual electricity consumption.

$$CIC_{va} = \frac{Value\ added\ per\ one\ year\ (LKR)}{Annual\ electricity\ consumption\ (kWh)} \tag{8.14}$$

However, in the industrial environment losses can occur in other forms such as, restart losses, spoiling material losses, damages to machinery and other costs [35]. To account for this a weighting factor (K) can be introduced and the interruption cost experienced by an industrial facility (CIC) can be calculated as shown in (8.15)

$$CIC = K_u \times CIC_{va} \quad \textbf{(8.15)}$$

This will be further discussed under subsections 8.2.1.3 and 8.2.1.4 in estimating CIC for unplanned and planned outages for subsectors of the industrial sector.

8.2.1.1 Annual Value Added

Annual value-added values of the industrial sector are estimated by the Department of Census and Statistic through annual surveys. These values are readily available and the Department of Census and Statistic provide economic indicators for the following divisions of the industrial sector [36].

1. Mining and quarrying.
2. Manufacture of food, beverages, and tobacco products.
3. Manufacture of textiles, wearing apparel and leather related products.
4. Manufacture of wood, products of wood and cork except furniture.
5. Manufacture of paper products, printing, and reproduction of media products.
6. Manufacture of coke and refined petroleum products.
7. Manufacture of chemical products and basic pharmaceutical products.
8. Manufacture of rubber and plastic products.
9. Manufacture of other non-metallic mineral products.
10. Manufacture of basic metals and fabricated metal products.
11. Manufacture of machinery and equipment.
12. Other manufacturing, and repair and installation of machinery and equipment.
13. Electricity, gas, steam, and air conditioning supply.
14. Water collection, treatment, and supply.
15. Sewerage, waste t reatment and disposal activities.

Hence, the customer interruption cost can be estimated for each industrial subcategory s, as shown in (8.16)

$$CIC_{va,s} = \frac{Value\ added\ of\ the\ subsector\ s\ for\ one\ year\ (LKR)}{Annual\ electricity\ consumption\ of\ subsector\ s\ (kWh)} \quad \textbf{(8.16)}$$

Where, $CIC_{va,s}$ is the customer interruption cost for the subsector s of the industrial sector.

The data needed for the sample calculation provided here is obtained from the 2019 Annual Survey of Industries conducted by the Department of Census and Statistics in Sri Lanka. Consequently, the calculation will depict the outcome for the year 2018 [36] and we intend to compare the values obtained using the analytical method with that obtained using the survey results in 2018.

Table 8.6 Annual Value Added for year 2018

Subsector of the industrial sector	Annual value added (LKR)
1. Mining and quarrying.	21,470,683,599.00
2. Manufacture of food, beverages, and tobacco products.	622,845,370,783.00
3. Manufacture of textiles, wearing apparel and leather related products.	612,618,145,435.00
4. Manufacture of wood, products of wood and cork except furniture.	8,502,016,677.00
5. Manufacture of paper products, printing, and reproduction of media products.	59,418,551,284.00
6. Manufacture of coke and refined petroleum products.	41,709,599,168.00
7. Manufacture of chemical products and basic pharmaceutical products.	82,988,971,099.00
8. Manufacture of rubber and plastic products.	90,104,367,877.00
9. Manufacture of other non-metallic mineral products.	59,664,535,504.00
10. Manufacture of basic metals and fabricated metal products.	46,540,986,333.00
11. Manufacture of machinery and equipment.	68,501,462,824.00
12. Other manufacturing, and repair and installation of machinery and equipment.	17,504,125,093.00
13. Electricity, gas, steam, and air conditioning supply.	58,833,801,609.00
14. Water collection, treatment, and supply.	18,778,878,740.00
15. Sewerage, waste treatment and disposal activities.	2,002,355,671.00

8.2.1.2 Annual Electricity Consumption

Annual electricity consumption of each industrial subsector is required to obtain $CIC_{va,s}$ for each subsector s. However, value of electricity consumption per each subsector is not available in the "Annual Survey of Industries" published by the Department of Census and Statistics, Sri Lanka. It only provides the total energy consumption of the industrial sector. In this work, we propose the following two methods to obtain an estimate for the annual electricity consumption of each subsector. However, if the annual electricity consumption is directly available for each subcategory, it should be directly utilized as it would yield more precise and reliable results.

8.2.1.2.1 Electricity Intensity Method (EI Method)

In this method, annual electricity consumption of each subsector per year (e_s) is calculated as shown in (8.17) considering energy intensity of that subsector.

$$e_s = \frac{E_s \times \lambda_s}{e_{unit}} \tag{8.17}$$

$$e_{unit} = \frac{Rev_{ind}}{Units_{ind}} \tag{8.18}$$

Where,

e_s = Annual electricity consumption of the subsector s (kWh)

E_s= Expenditure on annual energy consumption of the subsector s (LKR)

e_{unit} = Average electricity unit price of industrial sector (LKR/kWh)

Rev_{ind} = Annual revenue generated by the utility form electricity sales in the industrial sector (LKR)

$Units_{ind}$ = Annual electricity sales within the industrial sector (kWh)

λ_s= Expenditure on annual electricity consumption of subsector s as a percentage of expenditure on total annual energy consumption of that subsector (%)

For the year 2018, e_{unit} can be calculated using (8.18) as follows. [28].

$$e_{unit} = \frac{63{,}160.966\ LKR\ milions}{4289.997\ GWh} = 14.72\ LKR/kWh$$

Expenditure on annual energy consumption are obtained for each subsector from the "Annual Survey of Industries 2019" published by the Department of Census and Statistics, Sri Lanka [36] and shown in Table 8.7.

Table 8.7: Expenditure on annual energy consumption (2018) of the subsector s, E_s

Subsector of the industrial sector	Annual energy usage (LKR)
1. Mining and quarrying.	1,540,610,222
2. Manufacture of food, beverages, and tobacco products.	46,983,815,594
3. Manufacture of textiles, wearing apparel and leather related products.	32,348,882,740
4. Manufacture of wood, products of wood and cork except	1,204,520,328

furniture.	
5. Manufacture of paper products, printing, and reproduction of media products.	2,377,959,249
6. Manufacture of coke and refined petroleum products.	212,559,339
7. Manufacture of chemical products and basic pharmaceutical products.	4,660,689,273
8. Manufacture of rubber and plastic products.	5,949,321,103
9. Manufacture of other non-metallic mineral products.	15,522,808,532
10. Manufacture of basic metals and fabricated metal products.	5,899,885,702
11. Manufacture of machinery and equipment.	3,272,740,673
12. Other manufacturing, and repair and installation of machinery and equipment.	1,144,128,013
13. Electricity, gas, steam, and air conditioning supply.	41,464,763,826
14. Water collection, treatment, and supply.	4,244,238,303
15. Sewerage, waste treatment and disposal activities.	25,222,460

Expenditure on annual electricity consumption of subsector s as a percentage of expenditure on total annual energy consumption of that subsector is not readily available and therefore, this figure is calculated as shown in (8.19) by

$$\lambda_s = \frac{e_{industry} \times e_{unit}}{\sum_{i=1}^{7}(E_i \times P_i)} \times \delta_s \tag{8.19}$$

Where,

$e_{industry}$= Electricity usage of whole industrial sector

δ_s= Correction factor for electricity intensity of subsector (%)

E_i = Energy consumed from energy form i

P_i= Unit price of energy form i

i= Energy form (e.g., electricity, coal, firewood, kerosene, fuel oil, diesel, LPG)

Relevant data for energy consumption and unit price are listed in [37] and the δ_s defined based on [20] considering expert opinions and Sri Lankan industrial diversity.

Table 8. 8 : Energy consumption of industrial sector (2018)

Energy form	Usage in industrial sector		Average unit price (LKR)
Electricity	4330.3 GWh		14.72
LPG	72.5 kt	72,500,000 kg	370.63
Kerosine	4 kt	4,938,271.6 l	110.00
Disel	17.1 kt	19,883,720.93 l	112.00
Fuel oil	75.2 kt	7,827,247.919 l	80.00
Coal	70.1 kt	70,100,000 kg	17.85
Firewood	4724.5 kt	4,724,500,000 kg	15.00

In order to guarantee that the calculated e_s values satisfy (8.17) δ_s is defined. In this study, the value of δ_s is found to be as

$$\sum_{s=1}^{15} e_s = e_{total} \tag{8. 20}$$

Where:

$e_s =$ Annual electrical energy consumption of the subsector s (kWh)

$e_{Total} =$ Total electricity consumed by industrial sector according to the utility.

Table 8. 9 : Electricity intensity correction factor for each sub-sector

Subsector of the industrial sector	δ_s
1. Mining and quarrying.	0.60
2. Manufacture of food, beverages, and tobacco products.	1.72
3. Manufacture of textiles, wearing apparel and leather related products.	1.40
4. Manufacture of wood, products of wood and cork except furniture.	0.80
5. Manufacture of paper products, printing, and reproduction of media products.	1.30
6. Manufacture of coke and refined petroleum products.	-
7. Manufacture of chemical products and basic pharmaceutical products.	2.00
8. Manufacture of rubber and plastic products.	1.28
9. Manufacture of other non-metallic mineral products.	0.50
10. Manufacture of basic metals and fabricated metal products.	1.40
11. Manufacture of machinery and equipment.	1.20
12. Other manufacturing, and repair and installation of machinery and equipment.	1.00
13. Electricity, gas, steam, and air conditioning supply.	0.10
14. Water collection, treatment, and supply.	0.70
15. Sewerage, waste treatment and disposal activities.	1.00

Total electricity consumption of the industrial sector shown in Table 8.10 are obtained from the Sales and generation data book 2019 published by Ceylon Electricity Board [38] and the Statistical digest 2019 published by Lanka Electricity (Pvt) Limited. [39]

Table 8.10 Electricity Sales 2018

Electricity Sales Industrial Sector 2018 (GWh)	
Ceylon Electricity Board	4289.997
Lanka Electricity Company (Pvt) Limited	286.42
Total	4,576.42

Values calculated for the expenditure on annual electricity consumption of subsector s as a percentage of expenditure on total annual energy consumption of that subsector (λ_s) are shown in Table 8. 11

Table 8. 11 : Expenditure on annual electricity consumption of subsector s as a percentage of expenditure on total annual energy consumption of that subsector (λ_s)

Subsector of the industrial sector	λ_s
1. Mining and quarrying.	23%
2. Manufacture of food, beverages, and tobacco products.	66%
3. Manufacture of textiles, wearing apparel and leather related products.	54%
4. Manufacture of wood, products of wood and cork except furniture.	31%
5. Manufacture of paper products, printing, and reproduction of media products.	50%
6. Manufacture of coke and refined petroleum products.	77%
7. Manufacture of chemical products and basic pharmaceutical products.	77%
8. Manufacture of rubber and plastic products.	49%
9. Manufacture of other non-metallic mineral products.	25%
10. Manufacture of basic metals and fabricated metal products.	54%
11. Manufacture of machinery and equipment.	46%
12. Other manufacturing, and repair and installation of machinery and equipment.	38%
13. Electricity, gas, steam, and air conditioning supply.	14%
14. Water collection, treatment, and supply.	27%
15. Sewerage, waste treatment and disposal activities.	38%

Calculated values for electricity consumption of each subcategory with the use of (8.17) are given in Table 8. 12.

Table 8. 12 : Annual Electricity Usage calculated for each subsector using EI Method

Industrial Subcategory	Annual electricity usage (kWh)
1. Mining and quarrying.	24,092,840.12
2. Manufacture of food, beverages, and tobacco products.	2,106,302,306.82
3. Manufacture of textiles, wearing apparel and leather related products.	1,180,405,690.71
4. Manufacture of wood, products of wood and cork except furniture.	25,115,862.33
5. Manufacture of paper products, printing, and reproduction of media products.	80,573,408.01
6. Manufacture of coke and refined petroleum products.	11,116,783.32
7. Manufacture of chemical products and basic	242,954,036.23

pharmaceutical products.	
8. Manufacture of rubber and plastic products.	198,482,102.90
9. Manufacture of other non-metallic mineral products.	202,294,594.51
10. Manufacture of basic metals and fabricated metal products.	215,285,909.97
11. Manufacture of machinery and equipment.	102,361,540.47
12. Other manufacturing, and repair and installation of machinery and equipment.	29,820,752.09
13. Electricity, gas, steam, and air conditioning supply.	108,074,483.65
14. Water collection, treatment, and supply.	77,435,797.18
15. Sewerage, waste treatment and disposal activities.	657,402.60

8.2.1.2.2 Number of Establishments Method (NoE Method)

This method assumes that the electricity consumption of a subcategory is nearly proportional to the number of establishments in that subcategory. With that assumption, this method calculates the annual electricity consumption of each subsector per year (e_s) as shown in (8.21).

$$e_s = \frac{N_s}{N_{total}} \times e_{Total} \tag{8.21}$$

Where,

e_s= Annual electricity consumption of the s subsector (kWh)

N_s= Number of establishments in the subsector s

N_{total}= Total number of establishments in the industrial sector

e_{Total}= Total annual electricity consumption of the industrial category (kWh)

Number of establishments in each subcategory are obtained from the Annual Survey of Industries 2019 published by Department of Census and Statistics [36] and are shown in Table 8.13. Total number of establishments in the industrial sector is calculated using (8.22)

$$N_{total} = \sum_{s=1}^{15} N_s \tag{8.22}$$

Total annual electricity consumption of the industrial category is obtained by referring to Table 8.8.

Table 8.13 : Number of Establishments

Subsector of the industrial sector	Number of establishments
1. Mining and quarrying.	2947
2. Manufacture of food, beverages, and tobacco products.	5390
3. Manufacture of textiles, wearing apparel and leather related products.	5251
4. Manufacture of wood, products of wood and cork except furniture.	1306
5. Manufacture of paper products, printing, and reproduction of media products.	741
6. Manufacture of coke and refined petroleum products.	2
7. Manufacture of chemical products and basic pharmaceutical products.	699
8. Manufacture of rubber and plastic products.	510
9. Manufacture of other non-metallic mineral products.	1902
10. Manufacture of basic metals and fabricated metal products.	667
11. Manufacture of machinery and equipment.	902
12. Other manufacturing, and repair and installation of machinery and equipment.	475
13. Electricity, gas, steam, and air conditioning supply.	180
14. Water collection, treatment, and supply.	174
15. Sewerage, waste treatment and disposal activities.	112

Calculated values for the electricity consumption of each subcategory with the use of Number of Establishments Method are shown in Table 8. 14.

Table 8. 14 : Annual Electricity Usage calculated for each subsector using Number of Establishments Method

Subsector of the industrial sector	Annual electricity usage (kWh)
1. Mining and quarrying.	634,429,433.58
2. Manufacture of food, beverages, and tobacco products.	1,160,357,871.39
3. Manufacture of textiles, wearing apparel and leather related products.	1,130,433,985.65
4. Manufacture of wood, products of wood and cork except furniture.	281,155,358.08
5. Manufacture of paper products, printing, and reproduction of media products.	159,522,297.35
6. Manufacture of coke and refined petroleum products.	430,559.51
7. Manufacture of chemical products and basic pharmaceutical products.	150,480,547.70
8. Manufacture of rubber and plastic products.	109,792,674.29
9. Manufacture of other non-metallic mineral products.	409,462,091.17
10. Manufacture of basic metals and fabricated metal products.	143,591,595.59

11. Manufacture of machinery and equipment.	194,182,337.66
12. Other manufacturing, and repair and installation of machinery and equipment.	102,257,882.91
13. Electricity, gas, steam, and air conditioning supply.	38,750,355.63
14. Water collection, treatment, and supply.	37,458,677.11
15. Sewerage, waste treatment and disposal activities.	24,111,332.39

8.2.1.3 Cost of ENS Due to Unplanned Outages

Due to an unexpected power interruption, an industrial facility can experience different types of losses such as:

- Loss of raw material.
- Loss of production
- Loss due to the low quality of finished products
- Wages paid to employees for the idle time caused by the interruption.
- Overtime payments paid to cover the production loss due to the interruption.
- Shutdown cost.
- Startup cost.
- Plant/machinery/equipment damage.
- Other costs.

Total losses experienced by an industrial facility due to an unexpected power interruption can be calculated by adding all cost components as shown in (8. 23)

$$\begin{aligned} &\text{Total losses}(100\%) \\ &= \text{Losses of raw materials} + \text{Losses of producution} \\ &+ \text{ losses due to the low quality} + \text{wages paid to employees for the idle time} \\ &+ \text{overtime payment to cover the prodction lost due to the interuption} \\ &+ \text{shutdown costs} + \text{startup costs} + \text{equipment damages} + \text{other costs} \end{aligned} \quad \textbf{(8. 23)}$$

As discussed under section 8.2.1 when deriving (8. 23) it is reasonable to assume that the production loss is linearly proportional to the value added. Hence, a weighting factor (K_{ui}) is introduced for the unexpected outages in each industry type i of the industrial sector as shown in (8. 24)

$$\mathrm{K_{u,i}} = \frac{100\%}{\text{Production losses in the industry type i as a percentage of its total losses}} \quad \textbf{(8. 24)}$$

The determination of specific $K_{u,i}$ values for industries in Sri Lanka can be achieved through a comprehensive survey approach that involves gathering all necessary data across various subcategories, as outlined in 8.1. It is important to note that the values of $K_{u,i}$ are predominantly influenced by the industry type rather than the geographical location or country. Therefore, for this study, $K_{u,i}$ values are obtained from the data available in [40] for similar industries. Calculated $K_{u,i}$ values are tabulated in Table 8. 15 for different industry types together with the average value of the weighting factor (K_u) obtained for unplanned outages in the industrial sector.

Table 8. 15 : $K_{u,i}$ Values

Type of the industry	$K_{u,i}$
Food	1.99
Metal	1.68
Paper	1.72
Chemical	2.51
Timber	1.52
Electricity	1.6
Average value for the industrial sector (K_u)	**1.58**

As discussed in 8.2.1, interruption cost experienced by an industrial facility belongs to subsector s due to an unexpected power interruption ($CIC_{u,s}$) can be calculated as shown in (8.25) with the use of the average value of the weighting factor (K_u).

$$CIC_{u,s} = K_u \times CIC_{va,s} \tag{8.25}$$

Where,

$CIC_{u,s}$ is the interruption cost experienced by an industrial facility belongs to subsector s due to an unexpected power interruption. As discussed in 8.2.1, $CIC_{va,s}$ can be calculated using equation (8.26) by using the data in Table 8.6 and Table 8. 12 or Table 8. 14.

$$CIC_{va,s} = \frac{\text{Value added per one year in subsector s (LKR)}}{\text{Annual electricity consumption of subsector s (kWh)}} \tag{8.26}$$

8.2.1.4 Cost of ENS Due to Planned Outages

Types of losses incurred by an industrial facility due to an expected power interruption can be slightly different from those of unexpected outages and may consist of the following.

- Loss of production
- Wages paid to employees for the idle time caused by the interruption.
- Overtime payments paid to cover the production loss due to the interruption.
- Startup cost.

Therefore, total losses experienced by an industrial facility due to an expected power interruption (L_p) can be calculated by adding losses of production, losses of restart and extra expenses incurred due to power interruptions as shown in (8.27) These components can be considered as loss components that occur even when the interruption is anticipated. Importantly, these components do not decrease significantly even when the outage is known in advance. [35]

$$\begin{aligned}&\text{Total losses percentage considered in expected outge}(L_p)\\&= \text{Losses of producution} + \text{wages paid to employees for the idle time}\\&+ \text{overtime payment to cover the prodction lost due to the interuption}\\&+ \text{startup costs}\end{aligned} \quad \textbf{(8.27)}$$

As discussed under section 8.2.1 when deriving (8.13) it is reasonable to assume that the production loss is linearly proportional to the value added. Hence, a weighting factor (K_{pi}) is introduced for planned outages in each industry type i of the industrial sector as shown in (8.28)

$$K_{p,i} = \frac{L_p}{\text{Production losses as a percentage of total losses}} \quad \textbf{(8.28)}$$

The determination of specific $K_{p,i}$ values for industries in Sri Lanka can be achieved through a comprehensive survey approach that involves gathering all necessary data across various subcategories, as outlined in section 8.1. It is important to note that the values of $K_{p,i}$ are predominantly influenced by the industry type rather than the geographical location or country. Therefore, for this study, $K_{p,i}$ values are obtained from the data available in [40] for similar industries. Calculated $K_{p,i}$ values are tabulated in Table 8. 16: $\boldsymbol{K_{p,i}}$ Values for different industry types together with the average value of the weighting factor K_p obtained for planned outages in the industrial sector.

Table 8. 16: $K_{p,i}$ Values

Type of the industry	$K_{p,i}$
Food	1.06
Metal	1.12
Paper	1.26
Chemical	1.64
Timber	1.19
Electricity	1.11
Average value for the industrial sector (K_p)	**1.23**

As discussed in 8.2.1, interruption cost experienced by an industrial facility belongs to subsector s due to a planned power interruption ($CIC_{p,s}$) can be calculated as shown in (8.29) with the use of the average value of the weighting factor K_p.

$$CIC_{p,s} = K_p \times CIC_{va,s} \tag{8.29}$$

The same values calculated for $CIC_{va,s}$ in subsection 8.2.1.3 using equation (8.13) by using the data in Table 8.6 and Table 8. 14 or Table 8. 12 are utilized in finding $CIC_{p,s}$.

8.2.1.5 Interruption Cost for Each Subsector and the Industrial Sector

Interruption cost for the each subsector in the industrial sector and the interruption cost for the industrial sector can be analytically calculated using a similar method explained in subsections 8.1.1.1, 8.1.1.2, 8.1.1.3 and 8.1.1.4.

8.2.2 Unadjusted Results

8.2.2.1 Unadjusted Interruption Costs for Subcategories

Values estimated for interruption costs due to unplanned and planned outages i.e., $CIC_{u,s}$ and $CIC_{p,s}$ found using the electricity intensity method and the number of establishments method are shown in Table 8. 17 and Table 8. 18, respectively. This report refers to these values as unadjusted values, as we intend to study the changes in these values upon introducing some adjustments considering practical scenarios in the coming subsections.

Table 8. 17 : Unadjusted CIC Values estimated using the EI method.

Subsector of the industrial sector	Unplanned $CIC_{u,s}$	Planned $CIC_{p,s}$	Combined $CIC_{c,s}$
1. Mining and quarrying.	1,336.75	1,069.40	1,294.51
2. Manufacture of food, beverages, and tobacco products.	443.56	354.85	429.54
3. Manufacture of textiles, wearing apparel and leather related products.	778.48	622.79	753.88
4. Manufacture of wood, products of wood and cork except furniture.	507.77	406.21	491.72
5. Manufacture of paper products, printing, and reproduction of media products.	1,106.17	884.94	1,071.21
6. Manufacture of coke and refined petroleum products.	5,627.92	4,502.34	5450.08
7. Manufacture of chemical products and basic pharmaceutical products.	512.37	409.90	496.18
8. Manufacture of rubber and plastic products.	680.95	544.76	659.43
9. Manufacture of other non-metallic mineral products.	442.41	353.93	428.43
10. Manufacture of basic metals and fabricated metal products.	324.27	259.42	314.03
11. Manufacture of machinery and equipment.	1,003.82	803.05	972.10
12. Other manufacturing, and repair and installation of machinery and equipment.	880.47	704.37	852.64
13. Electricity, gas, steam, and air conditioning supply.	816.57	653.26	790.77
14. Water collection, treatment, and supply.	363.76	291.01	352.27
15. Sewerage, waste treatment and disposal activities.	3,045.86	2,436.69	2,949.61

Table 8. 18 : Unadjusted CIC Values estimated using the NoE method.

Subsector of the industrial sector	Unplanned $CIC_{u,s}$	Planned $CIC_{p,s}$	Combined $CIC_{c,s}$
1. Mining and quarrying.	53.74	41.63	49.16
2. Manufacture of food, beverages, and tobacco products.	852.39	660.23	779.71
3. Manufacture of textiles, wearing apparel and leather related products.	860.59	666.58	787.21
4. Manufacture of wood, products of wood and cork except furniture.	48.02	37.19	43.93
5. Manufacture of paper products, printing, and reproduction of media products.	591.50	458.15	541.06
6. Manufacture of coke and refined petroleum products.	-	-	-
7. Manufacture of chemical products and basic pharmaceutical products.	875.77	678.34	801.10

8.	Manufacture of rubber and plastic products.	1,303.24	1,009.43	1,192.12
9.	Manufacture of other non-metallic mineral products.	231.39	179.23	211.66
10.	Manufacture of basic metals and fabricated metal products.	514.70	398.67	470.82
11.	Manufacture of machinery and equipment.	560.20	433.91	512.43
12.	Other manufacturing, and repair and installation of machinery and equipment.	271.83	210.55	248.65
13.	Electricity, gas, steam, and air conditioning supply.	2,411.03	1,867.48	2,205.45
14.	Water collection, treatment, and supply.	796.10	616.63	728.22
15.	Sewerage, waste treatment and disposal activities.	131.88	102.15	120.63

8.2.2.1.1 Outliers and Deviation

- **Unusual low/ high number of establishments**

When using the "Number of establishment method," the electricity consumption of a subcategory is directly linked to the number of establishments within that subcategory. However, if a subcategory exhibits an unusually low or high number of establishments, the results obtained from this method tend to be inaccurate.

As illustrated in Table 8.13, the number of establishments for the "Manufacture of coke and refined petroleum products" subcategory is unusually low, with only two establishments, which is in stark contrast to other categories. Consequently, this category is excluded when employing the "Number of establishment method". Nevertheless, we can derive a value for this particular category using the "Electricity intensity method", as indicated in the results. However, for the sake of result comparison, we exclude this specific category when computing the final combined values.

- **Mismatching results provided by the EI and NoE methods.**

Most of the category's values generally follow a consistent trend. However, it has been observed that the two methods do not yield the same results in certain categories where the number of establishments does not accurately reflect their value-added capability. For instance, in the electricity or mining subcategory, there is a high value-added output with a relatively low number of establishments. In such cases of mismatch, it appears that the "Electricity intensity method" provides more accurate estimations.

8.2.2.2 Unadjusted Interruption Costs for the industrial sector

Analytically calculated Cost of ENS values for the industrial sector using EI and NoE methods considering 2018 data are shown in Table 8. 19 and Table 8. 20, respectively.

Table 8. 19 : Analytically calculated unadjusted Cost of ENS for the Industrial Sector using EI method and 2018 data.

Unexpected Outages	539.60 LKR/kWh
Expected Outages	431.68 LKR/kWh
Combined	519.96 LKR/kWh

Table 8. 20 : Analytically calculated unadjusted Cost of ENS for the Industrial Sector using NoE method and 2018 data.

Unexpected Outages	500.69 LKR/kWh
Expected Outages	400.55 LKR/kWh
Combined	482.47 LKR/kWh

8.2.3 Correction Factors

The analytical method used to estimate the customer interruption cost assumes that uninterrupted production relies on a continuous power supply, and the annual value added, and the annual electricity usage are taken as main inputs to estimate the damage due to electricity interruptions. Even though the annual value-added of a subsector gives an overall economical estimation for that subsector, the relationship of that and the electricity usage it may not be directly related to the usage of electricity the same for each subsector. It is observed that electricity is a crucial factor for the production process of some industrial subsectors, while value added is barely affected by electricity interruptions in some subsectors. Therefore, some correction factors should be introduced to estimate more accurate values for customer interruption costs.

8.2.3.1 Critical Electricity Consumption Correction

It is important to consider the end use of the electricity in each subsector. In some subsectors electricity is used for the operation of critical machines such as motors, high temperature processers, compressors etc., while some subsectors may use electricity mainly for lighting and air conditioning. Therefore, following scenario is defined to find the impact of criticality of electricity usage on value added for each subsector where electricity in industrial facility is used in processes such as high temperature process, low temperature process drying/separation motors, compressed air, lighting, refrigeration, space heating/cooling and other processes.

- All electricity consumed for space heating, lighting, other purposes and 50% of motors is assumed to be non-critical to the production process.

Values for such scenarios can be calculated through surveys by collecting electricity usage data in different subcategories. The calculations in this report are based on values obtained from [20] within comparable industrial subcategories.

Table 8. 21 : Critical Electricity Consumption Factor

Industrial Subcategory	Critical Electricity Consumption Factor
1. Mining and quarrying.	76%
2. Manufacture of food, beverages, and tobacco products.	78%
3. Manufacture of textiles, wearing apparel and leather related products.	52%
4. Manufacture of wood, products of wood and cork except furniture.	63%
5. Manufacture of paper products, printing, and reproduction of media products.	79%
6. Manufacture of coke and refined petroleum products.	62%
7. Manufacture of chemical products and basic pharmaceutical products.	70%
8. Manufacture of rubber and plastic products.	63%
9. Manufacture of other non-metallic mineral products.	76%
10. Manufacture of basic metals and fabricated metal products.	84%
11. Manufacture of machinery and equipment.	60%
12. Other manufacturing, and repair and installation of machinery and equipment.	63%
13. Electricity, gas, steam, and air conditioning supply.	63%
14. Water collection, treatment, and supply.	63%
15. Sewerage, waste treatment and disposal activities.	50%

8.2.3.2 Low-Capacity Utilization

It should be considered that factories and industrial facilities may not operate at full capacity all the time. If a facility is operating at less than 100% utilization when a power failure occurs, it should have provisions to recover some of the lost production in the future. The capacity utilization factor can be used as a correction factor for customer interruption functions. The value for low-capacity utilization in Sri Lankan industries for the year 2018 can be obtained from the Central Bank of Sri Lanka's annual report for 2019 [41].

Table 8. 22 : Capacity Utilization Factors for 2018

Industrial Subcategory	Capacity utilization factor
1. Mining and quarrying.	81%
2. Manufacture of food, beverages, and tobacco products.	78%
3. Manufacture of textiles, wearing apparel and leather related products.	85%
4. Manufacture of wood, products of wood and cork except furniture.	84%
5. Manufacture of paper products, printing, and reproduction of media products.	60%
6. Manufacture of coke and refined petroleum products.	61%
7. Manufacture of chemical products and basic pharmaceutical products.	74%
8. Manufacture of rubber and plastic products.	86%
9. Manufacture of other non-metallic mineral products.	82%
10. Manufacture of basic metals and fabricated metal products.	73%
11. Manufacture of machinery and equipment.	71%
12. Other manufacturing, and repair and installation of machinery and equipment.	78%
13. Electricity, gas, steam, and air conditioning supply.	75%
14. Water collection, treatment, and supply.	81%
15. Sewerage, waste treatment and disposal activities.	50%

8.2.4 Adjusted Results

8.2.4.1 Adjusted Interruption Costs for Subcategories

Table 8.23 : Adjusted CIC Values estimated using the EI method.

Subsector of the industrial sector	Unplanned $CIC_{u,s}$	Planned $CIC_{p,s}$	Combined $CIC_{c,s}$
1. Mining and quarrying.	822.90	658.32	796.90
2. Manufacture of food, beverages, and tobacco products.	269.86	215.89	261.33
3. Manufacture of textiles, wearing apparel and leather related products.	344.09	275.27	333.22
4. Manufacture of wood, products of wood and cork except furniture.	268.71	214.97	260.22
5. Manufacture of paper products, printing, and reproduction of media products.	524.32	419.46	507.76
6. Manufacture of coke and refined petroleum products.	2,128.48	1,702.78	-
7. Manufacture of chemical products and basic pharmaceutical products.	265.41	212.33	257.02
8. Manufacture of rubber and plastic	368.94	295.15	357.28

products.			
9. Manufacture of other non-metallic mineral products.	275.71	220.57	267.00
10. Manufacture of basic metals and fabricated metal products.	198.84	159.08	192.56
11. Manufacture of machinery and equipment.	427.63	342.10	414.11
12. Other manufacturing, and repair and installation of machinery and equipment.	432.66	346.13	418.99
13. Electricity, gas, steam, and air conditioning supply.	385.83	308.66	373.64
14. Water collection, treatment, and supply.	185.63	148.50	179.76
15. Sewerage, waste treatment and disposal activities.	761.46	609.17	737.40

Table 8. 24 : Adjusted CIC Values estimated using the NoE method.

Subsector of the industrial sector	Unplanned $CIC_{u,s}$	Planned $CIC_{p,s}$	Combined $CIC_{c,s}$
1. Mining and quarrying.	33.08	25.63	30.26
2. Manufacture of food, beverages, and tobacco products.	518.59	401.68	474.38
3. Manufacture of textiles, wearing apparel and leather related products.	380.38	294.63	347.95
4. Manufacture of wood, products of wood and cork except furniture.	25.41	19.68	23.25
5. Manufacture of paper products, printing, and reproduction of media products.	280.37	217.16	256.46
6. Manufacture of coke and refined petroleum products.	-	-	-
7. Manufacture of chemical products and basic pharmaceutical products.	453.65	351.38	414.97
8. Manufacture of rubber and plastic products.	706.09	546.91	645.89
9. Manufacture of other non-metallic mineral products.	144.21	111.70	131.91
10. Manufacture of basic metals and fabricated metal products.	315.62	244.46	288.71
11. Manufacture of machinery and equipment.	238.64	184.84	218.30
12. Other manufacturing, and repair and installation of machinery and equipment.	133.58	103.46	122.19
13. Electricity, gas, steam, and air conditioning supply.	1,139.21	882.39	1,042.08
14. Water collection, treatment, and supply.	406.25	314.66	371.61
15. Sewerage, waste treatment and disposal activities.	67.30	52.13	61.56

8.2.4.2 Adjusted Interruption Costs for the industrial sector

Analytically calculated and adjusted Cost of ENS values for the industrial sector using EI and NoE methods considering 2018 data are shown in Table 8.25 and Table 8.26, respectively.

Table 8.25 : Analytically calculated adjusted Cost of ENS for the Industrial Sector using EI method and 2018 data.

Unexpected Outages	279.74 LKR/kWh
Expected Outages	270.90 LKR/kWh
Combined	276.71 LKR/kWh

Table 8.26 : Analytically calculated adjusted Cost of ENS for the Industrial Sector using NoE method and 2018 data.

Unexpected Outages	264.75 LKR/kWh
Expected Outages	211.80 LKR/kWh
Combined	255.11 LKR/kWh

8.2.5 Discussion

8.2.5.1 Comparison of Cost of ENS with survey-based Cost of ENS estimations for Subcategories

Cost of ENS values shown in Table 8.27 are calculated in [27] for the following subcategories based on the customer survey conducted in 2018.

- Food, beverage, and tobacco products
- Textile, apparel, and leather products
- Chemical, petroleum, rubber, and plastic products
- Non-metallic mineral products
- Fabricated metal products
- Machinery and transport equipment

Table 8.27 : Cost of ENS for the Industrial Sector based on 2018 customer survey.

Subcategory	Unplanned (LKR/kWh)	Planned (LKR/kWh)	Combined (LKR/kWh)
Food, beverage, and tobacco products	116.42	97.58	111.52
Textile, apparel, and leather products	325.71	62.86	257.37
Chemical, petroleum, rubber, and plastic products	512.93	154.41	419.71
Non-metallic mineral products	2821.05	2772.69	2808.48
Fabricated metal products	216.71	53.26	174.21
Machinery and transport equipment	307.88	308.86	308.13

In this line of work, comparing results from different studies presents challenges. Several difficulties were encountered during this study when attempting to compare findings from various research efforts.

At the sub-sector level, it's unlikely that the same subcategories were selected for all studies. Even when the subcategory names appear identical, it's difficult to ascertain whether both studies considered the same types of responses within that category. For instance, one study might include all responses related to food under "Manufacture of food, beverages, and tobacco products," while another might focus exclusively on food products intended for human consumption. Additionally, one study might treat "Manufacture of food, beverages, and tobacco products" as a sub-category, whereas another study might consider only "Manufacture of food" as a subcategory.

In both parts of this study (survey-based and analytical methods), all the sub-categories were selected in accordance with the International Standard Industry Classifications (ISIC) for clarity and consistency.

Although it is not entirely precise to compare a survey-based approach with an analytical method, we have plotted analytically derived Cost of ENS values for 2018 using the EI and NoE methods alongside the survey-based Cost of ENS estimations published in [27]. This visual comparison is provided in Fig. 8. 4 to Fig. 8. 13. for reference.

Subcategories considered in the previously published study in [27] for estimating Cost of ENS slightly differ from the subcategories considered in our study.

For a fair comparison, we have limited our analysis to the subcategories that are common to both studies, as listed below. Nevertheless, it is important to acknowledge that not all subcategories in the two studies may align precisely with each other.

- Manufacture of food, beverages, and tobacco products.
- Manufacture of textiles, wearing apparel and leather related products.
- Manufacture of chemical products and basic pharmaceutical products, manufacture of rubber and plastic products.
- Manufacture of other non-metallic mineral products.
- Manufacture of basic metals and fabricated metal products.
- Manufacture of machinery and equipment.

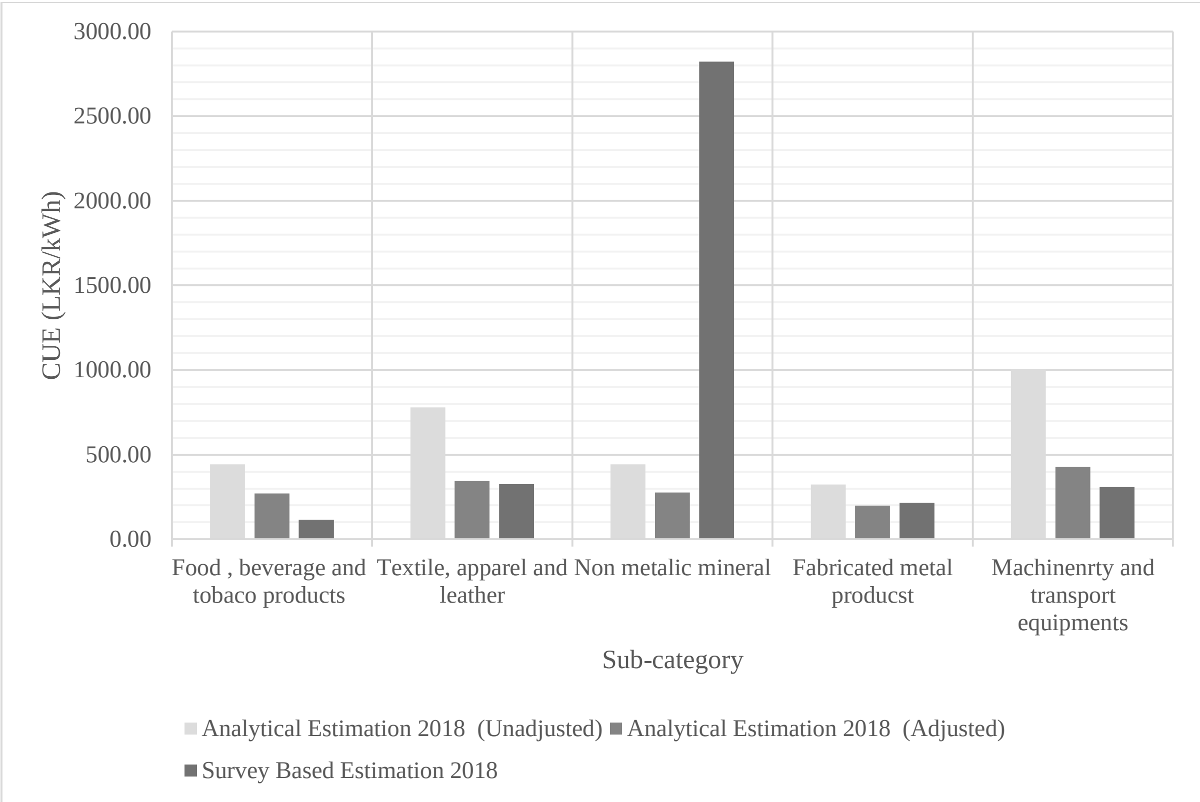


Fig. 8. 4 : Adjusted and unadjusted analytical estimation (EI Method – unexpected outages) for 2018 with survey-based estimation 2018 considering comparable categories only.

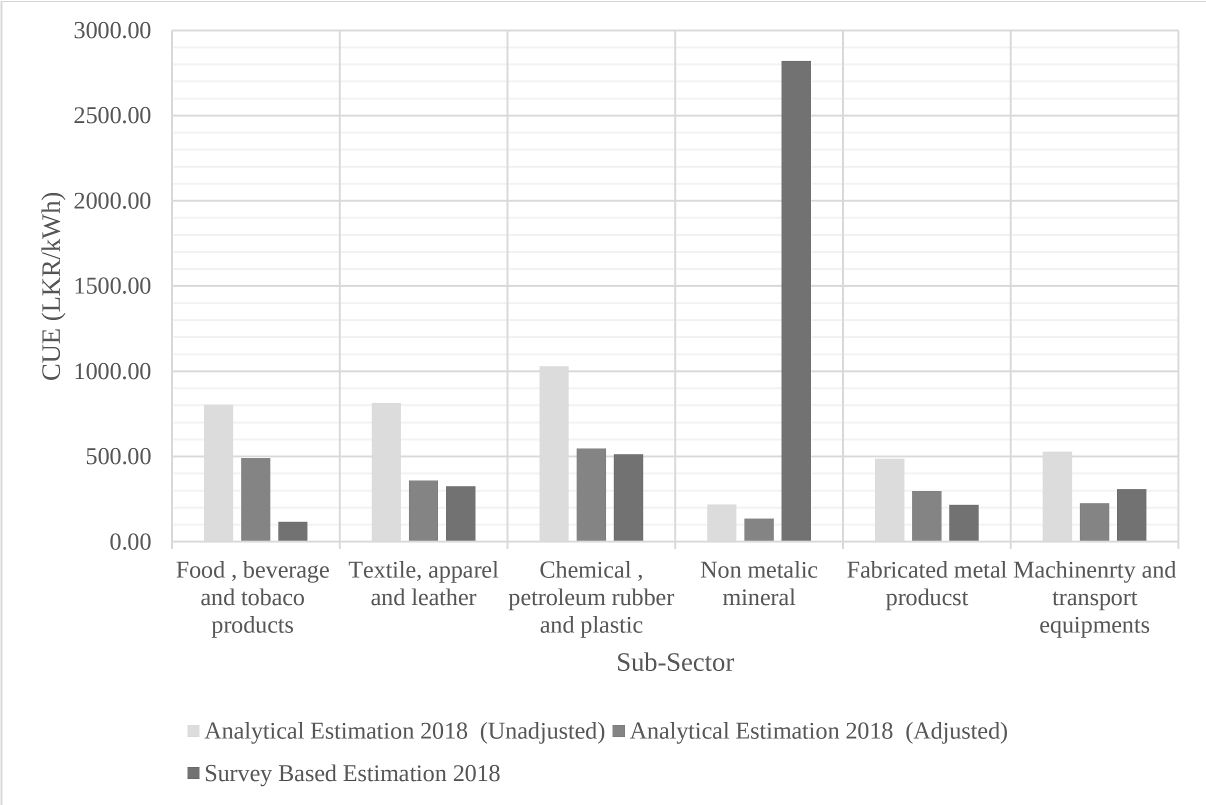


Fig. 8. 5 : Adjusted and unadjusted analytical estimation (NoE Method – unexpected outages) for 2018 with survey-based estimation 2018 considering comparable categories only.

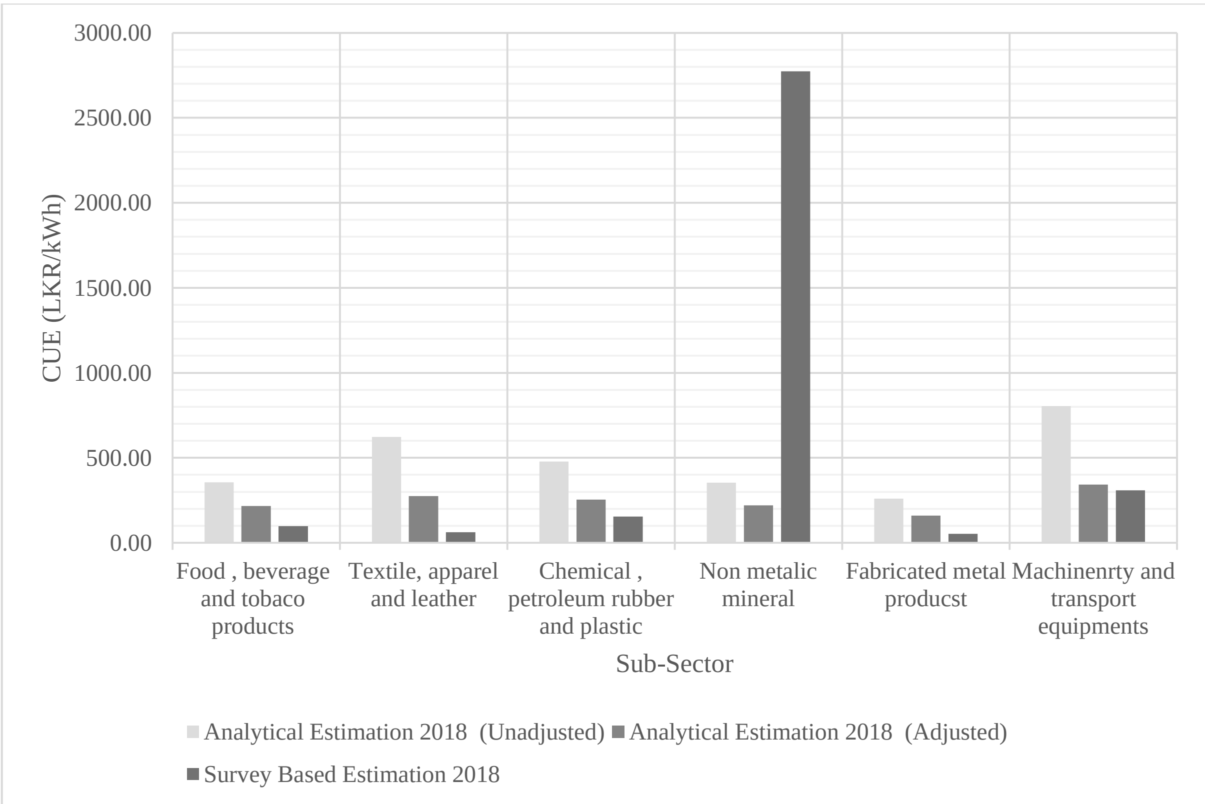


Fig. 8. 6 : Adjusted and unadjusted analytical estimation (EI Method – expected outages) for 2018 with survey-based estimation 2018 considering comparable categories only.

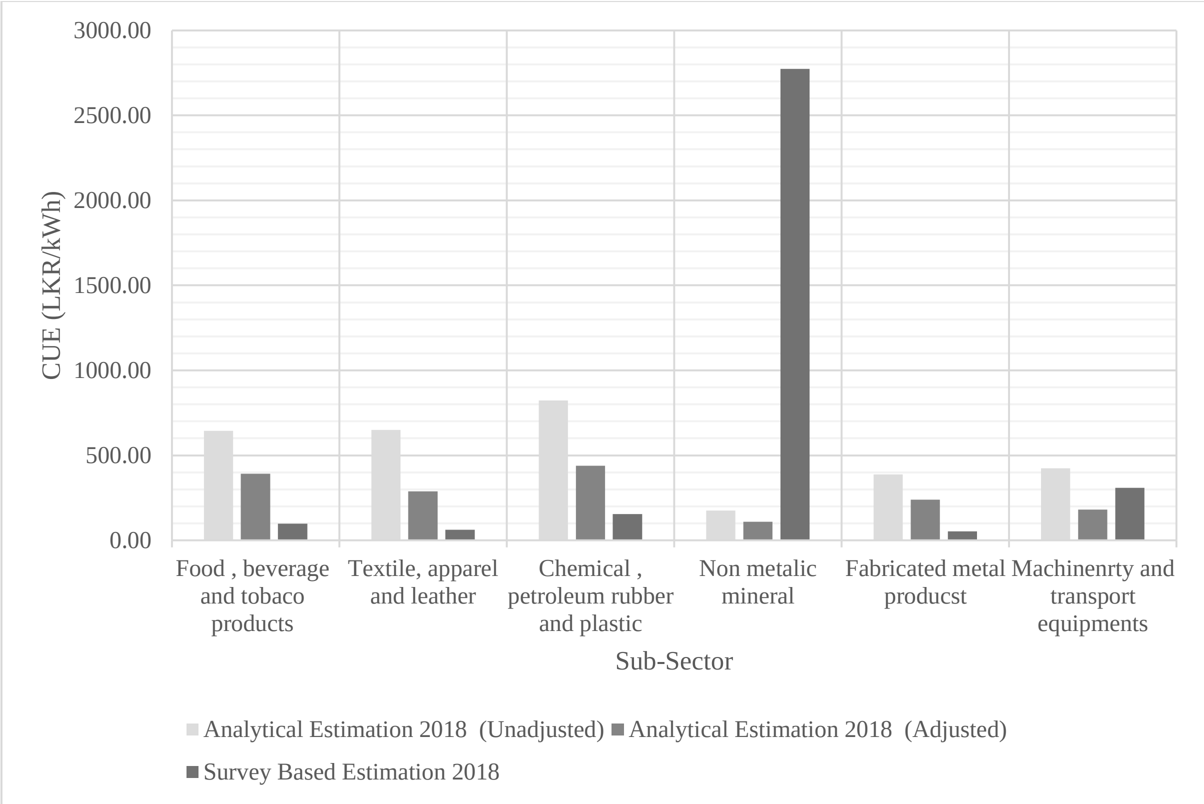


Fig. 8. 7 : Adjusted and unadjusted analytical estimation (EI Method – expected outages) for 2018 with survey-based estimation 2018 considering comparable categories only.

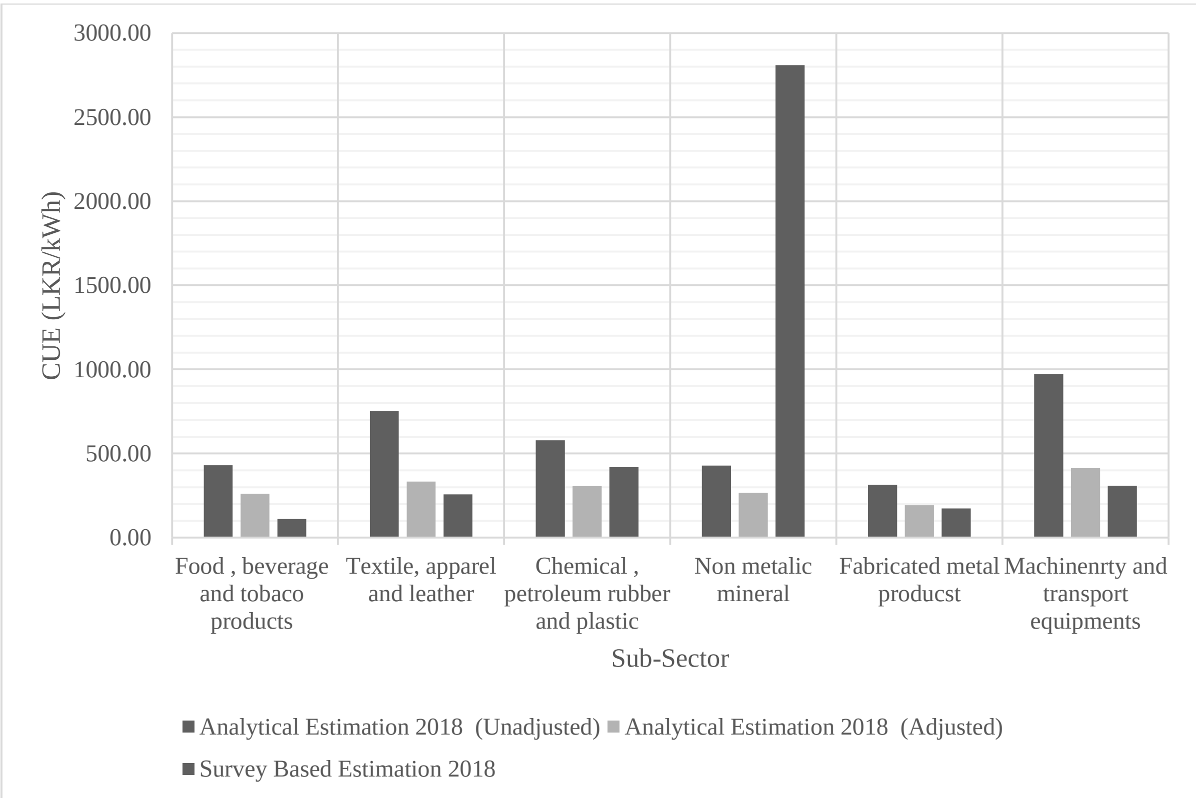


Fig. 8. 8 : Adjusted and unadjusted analytical estimation (EI Method – combined outages) for 2018 with survey-based estimation 2018 considering comparable categories only.

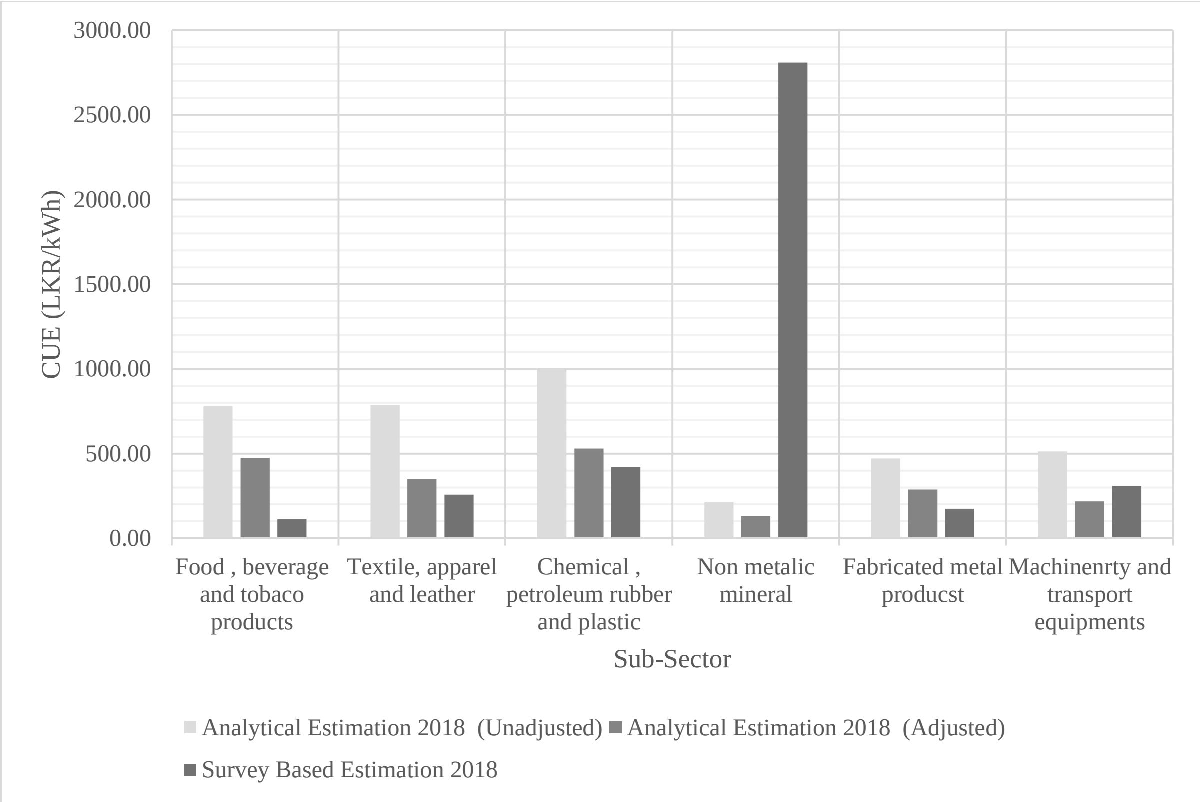


Fig. 8. 9 : Adjusted and unadjusted analytical estimation (NoE Method – combined outages) for 2018 with survey-based estimation 2018 considering comparable categories only.

In most cases, except for the non-metallic and mineral groups, the estimated economic values in both methods tend to be slightly higher than the direct values obtained from the survey-based method. Both [8] and [3] have indicated that the estimated economic parameters may exceed the directly obtained values. [8] specifically noted that the difference between the estimated and survey-based direct methods is more pronounced in shorter outage duration and diminishes in longer outage duration. However, in the current situation, where previous data is insufficient for comparison, a detailed analysis is not feasible.

It is noteworthy that jewelry, categorized as a micro category within the “non-metallic minerals” group, may exhibit an unusually high impact, which could be attributed to its heavy reliance on a stable electricity supply. If more survey responses received for the “non-metallic minerals” group are from jewelry related electricity consumers, it may lead to a high Cost of ENS figure for the “non-metallic minerals” group. However, from an analytical economic perspective it is challenging to estimate Cost of ENS considering one micro category of non-metallic minerals, like gems or jewelry. In this context, the contribution of the subcategory “non-metallic minerals” is considered as a part of the larger sector which also includes glass manufacturing, glass products, and non-metallic mineral manufacturing etc. It's essential to emphasize that the analytical estimation approach may not emphasize the contribution of a particular micro category towards Cost of ENS of a subcategory of the industrial sector.

Compared to other available categories, analytically estimated Cost of ENS of “food, beverage, and tobacco products” category exhibits a slight deviation from prior survey-based studies. Nevertheless, this category encompasses a significant portion of the market and has many establishments. It should be noted that Cost of ENS values derived from survey-based methods are highly contingent on the specific responses received, whereas the estimating method considers the overall impact of the industry. Therefore, for such subsectors, analytically estimated Cost of ENS can deviate from survey-based estimations.

8.2.5.2 Comparison of Cost of ENS with survey-based Cost of ENS estimations for the industrial sector

Analytically calculated Cost of ENS values for the industrial sector using EI and NoE methods considering 2018 data are shown in Table 8. 28 and Table 8. 29, while survey-based estimation for 2018 showed in Table 8. 30 respectively. Comparison between analytically calculated values with survey-based estimation for 2018 is illustrated in Fig. 8. 10 and Fig. 8. 11

Table 8. 28 : Analytically calculated adjusted Cost of ENS for the Industrial Sector using EI method and 2018 data.

	Unadjusted (LKR/kWh)	Adjusted (LKR/kWh)
Unexpected Outages	539.60	279.74
Expected Outages	431.68	270.90
Combined	519.96	276.71

Table 8. 29 : Analytically calculated adjusted Cost of ENS for the Industrial Sector using NoE method and 2018 data.

	Unadjusted (LKR/kWh)	Adjusted (LKR/kWh)
Unexpected Outages	500.69	264.75
Expected Outages	400.55	211.80
Combined	482.47	255.11

Table 8. 30 : Survey based estimation 2018.

Unexpected Outages	315.88 LKR/kWh
Expected Outages	191.93 LKR/kWh
Combined	257.43 LKR/kWh

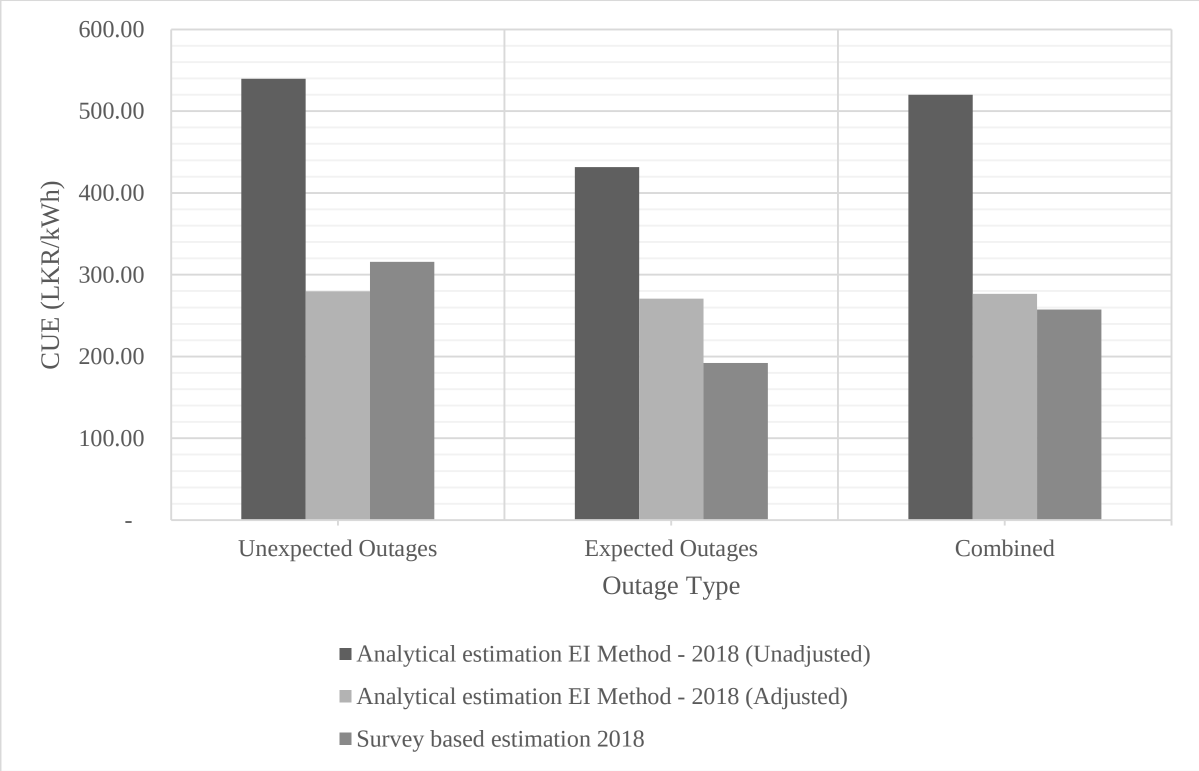


Fig. 8. 10 : Adjusted and unadjusted analytical estimation using EI method for 2018 with survey-based estimation 2018.

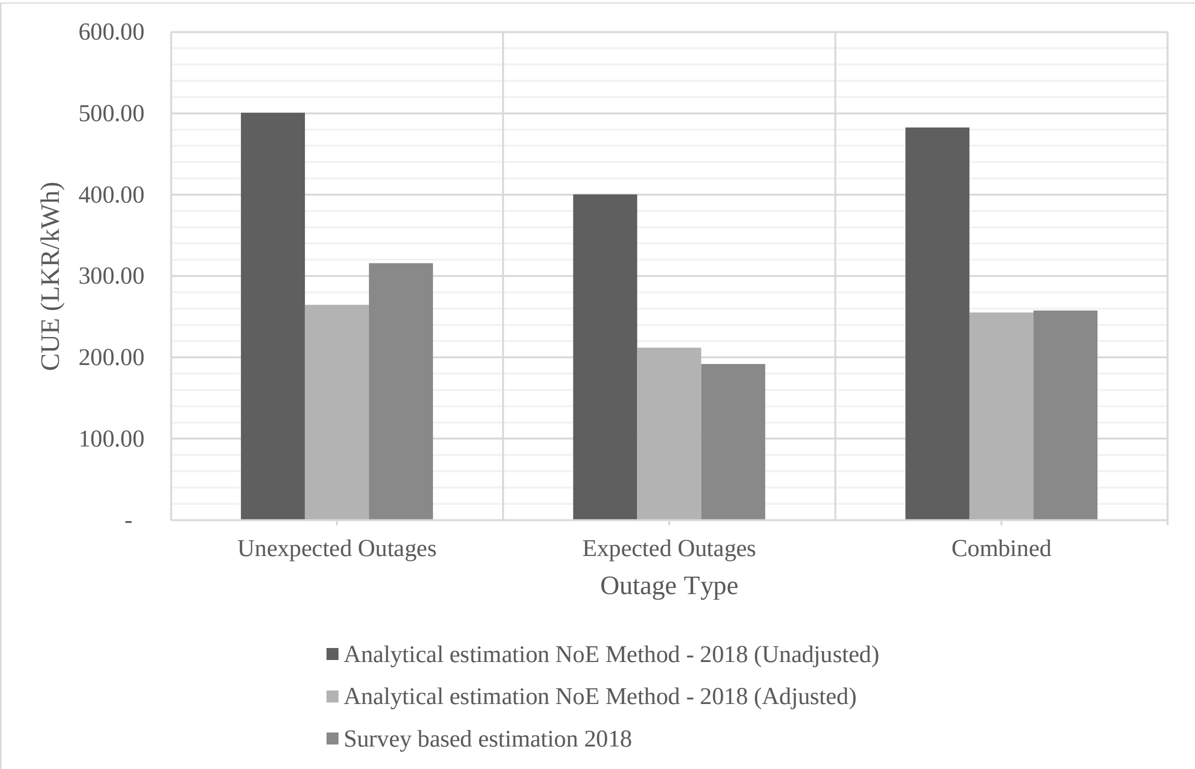


Fig. 8. 11 : Adjusted and unadjusted analytical estimation using NoE method for 2018 with survey-based estimation 2018.

As evident in Fig. 8. 10 and Fig. 8. 11, we observe that Cost of ENS values obtained from both the EI and NoE methods prior to adjustment exhibit higher values than the survey-based estimates for 2018 in both expected and unexpected outage scenarios. However, after adjustment, the estimated method yields slightly lower values in unplanned outages and slightly higher values in planned outages. Ultimately, it converges to similar values as per the survey-based estimation in combined outages. It's worth noting that the EI method results in slightly higher values compared to the NoE method.

Considering the reasons given in 8.2.5.1 we extend our comparison furthermore to obtained more detailed insight by comparing the final values calculated only using the comparable sub categories mentioned in 8.2.5.1

Considering comparable subcategories only, Cost of ENS values are estimated using analytical methods with 2018 data. Those values and 2018 survey results are tabulated in Table 8.31, Table 8.32, Table 8.33 and illustrated in Fig. 8. 12 and Fig. 8. 13

Table 8.31 : Analytically calculated Cost of ENS Using EI method for the Industrial Sector using 2018 data by only considering comparable subcategories.

	Unadjusted (LKR/kWh)	Adjusted (LKR/kWh)
Unexpected Outages	570.68	300.14
Expected Outages	456.55	240.11
Combined	549.91	289.22

Table 8.32 : Analytically calculated Cost of ENS Using NoE method for the Industrial Sector using 2018 data by only considering comparable subcategories.

	Unadjusted (LKR/kWh)	Adjusted (LKR/kWh)
Unexpected Outages	776.99	447.68
Expected Outages	621.59	346.76
Combined	748.71	429.66

Table 8.33 : Cost of ENS Estimated for the Industrial Sector Based on 2018 Survey by only considering comparable subcategories [3]

Unexpected Outages	421.02 LKR/kWh
Expected Outages	283.84 LKR/kWh
Combined	397.64 LKR/kWh

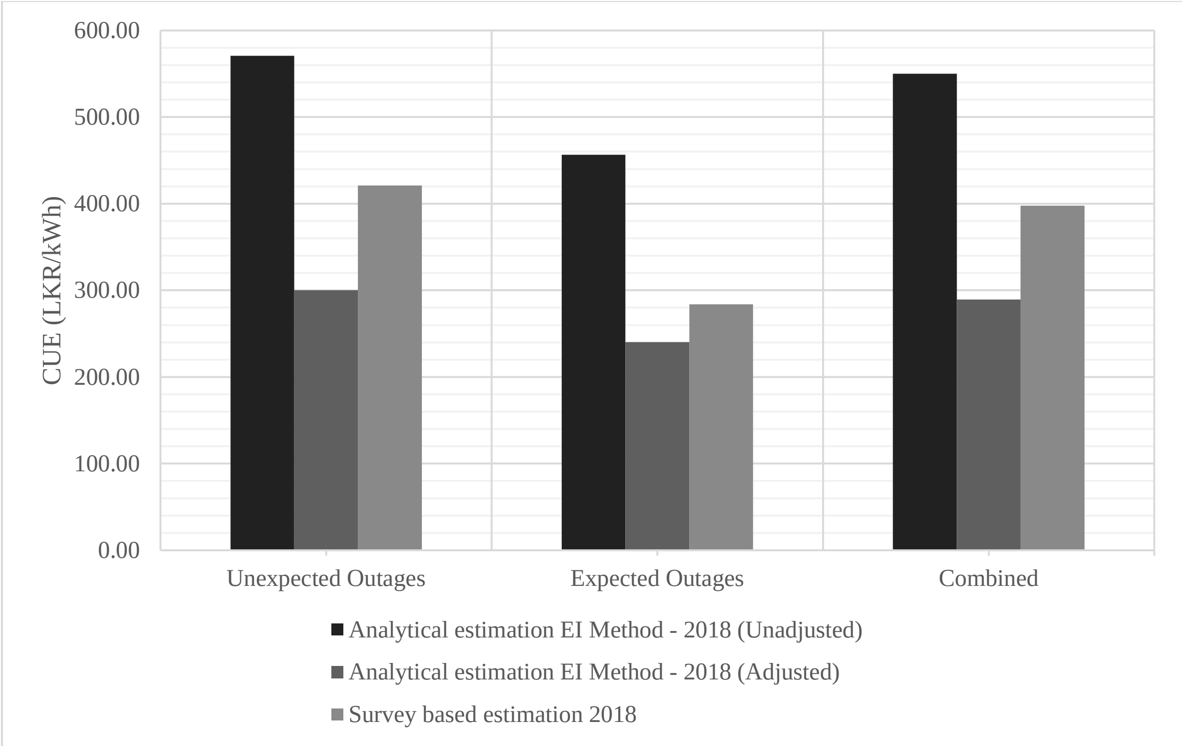


Fig. 8. 12 : Adjusted and unadjusted analytical estimation using EI method for 2018 with survey-based estimation 2018 considering comparable categories only.

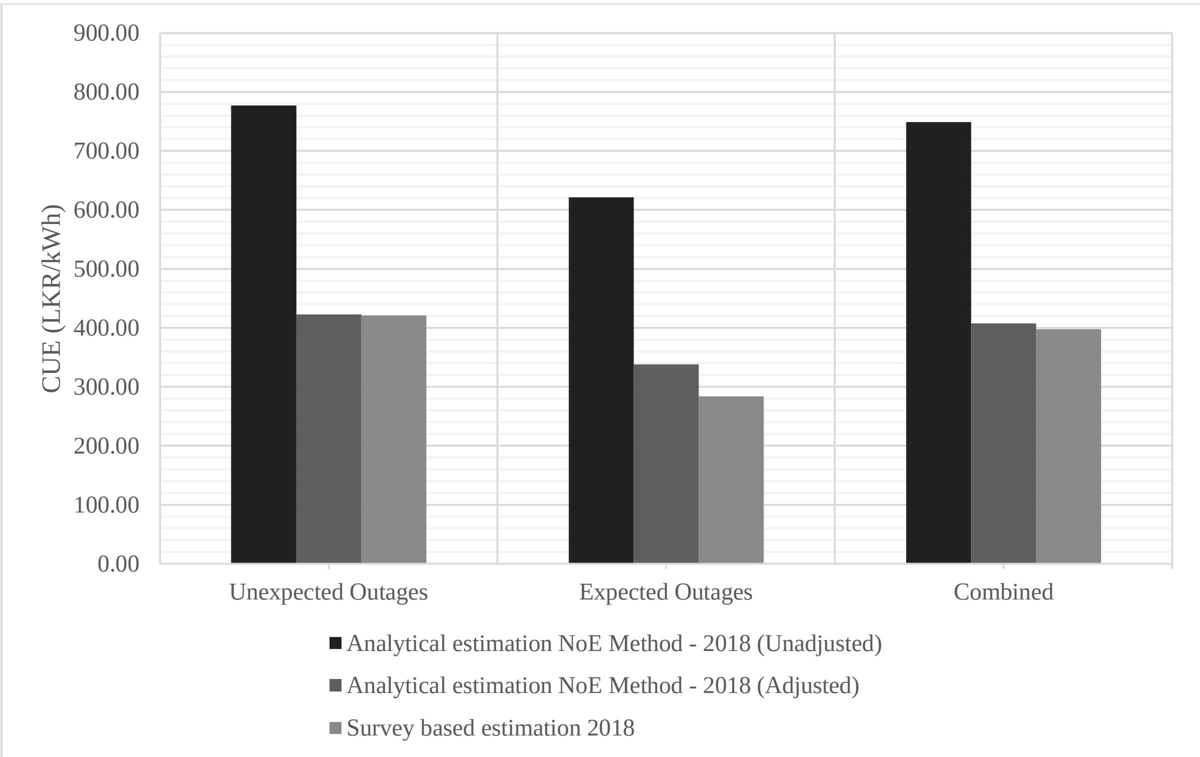


Fig. 8. 13 : Adjusted and unadjusted analytical estimation using NoE method for 2018 with survey-based estimation 2018 considering comparable categories only.

As can be seen in Fig. 8. 12, Cost of ENS values obtained from EI method shows lesser value than 2018 survey based values in both expected and unexpected outages, owing to the compared survey results having a high value for one sub-category which is Manufacture of other non-metallic mineral products, the reason is described in 8.1.1.4.

However as showed in Fig. 8. 13 whereas NoE method shows fairly similar values with the survey-based estimation values when only the comparable categories considered than EI method.

It has been observed that direct comparisons of each subcategory with all other subcategories may not be feasible due to potential subcategory mismatches and the likelihood of aggregation bias. Different studies might combine subcategories or define them differently. However, when we examine the final values for both the groups being compared (Fig. 8. 13 : Adjusted and unadjusted analytical estimation using NoE method for 2018 with survey-based estimation 2018 considering comparable categories only) and for all categories (see Fig. 8. 10 : Adjusted and unadjusted analytical estimation using EI method for 2018 with survey-based estimation 2018 Fig. 8. 11 : Adjusted and unadjusted analytical estimation using NoE method for 2018 with survey-based estimation 2018), it becomes evident that estimated methods yield slightly higher values than direct survey methods. Moreover, the 'number of establishments' method generates values that are more in line with survey-based methods compared to the 'electricity intensity' method, which consistently provides slightly higher values. Therefore, the 'number of establishments' technique can be identified as an analytical method which can be considered as a better alternative to the survey-based method.

9. Estimation of Cost of ENS for the Commercial Sector

9.1 Estimation of Cost of ENS for the Commercial Sector using Survey Results

9.1.1 Research Methodology

This subsection aims to describe the method of calculating the Cost of ENS for the commercial sector.

In this study, the responses collected from commercial consumers are grouped into following subcategories.[42]

1. Wholesale and retail trade
2. Transportation of goods and passengers including warehousing
3. Postal and courier activities
4. Accommodation, food, and beverage service activities
5. Programming and broadcasting activities and audio video productions
6. Telecommunication
7. IT programming consultancy and related activities
8. Financial service activities and auxiliary financial services
9. Insurance, insurance and pension funding
10. Real estate activities, including ownership of dwelling
11. Professional services
12. Public administration and defense, compulsory social security
13. Education
14. Human health activities, residential care and social work activities
15. Other personal service activities

Survey responses collected from each subsector consists of costs of damages experienced by consumers under following damage types. These costs are considered in the estimation of Cost of ENS for the commercial sector.

- Spoilage of goods.
- Lost business or sales.
- Wages paid to staff who are unable to work during interruption.
- Overtime payments to cover lost sales.
- Shutdown cost.
- Shutdown cost.

- Startup cost.
- Equipment damage.
- Other costs.

Although the method used to estimate the CENS for the commercial sector is similar to that of the industrial sector, we provide a description of the method in this subsection for the completeness of the report.

9.1.1.1 Cost of ENS Due to Unplanned Outages

First, the Cost of ENS experienced by a single customer k in the subsector s due to an unexpected interruption with the interruption duration t i.e. $\mathrm{C_{k,s,t,u}}$ is calculated using (9. 1) by considering the cost of damages corresponding to each damage type [27].

$$\mathrm{C_{k,s,t,u}} = \frac{\sum_{\mathrm{i=1}}^{\mathrm{N_D}} \mathrm{D}_{i,\mathrm{k,s,t,u}}}{E_{k,s,t,u}} \tag{9. 1}$$

Where,

$\mathrm{C_{k,s,t,u}}$= Cost of ENS experienced by the customer k in the subsector s due to an unplanned interruption with the interruption duration t

$\mathrm{E_{k,s,t,u}}$ = Estimated energy not served for the customer k in the subsector s during the unplanned interruption duration t

$\mathrm{D}_{i,\mathrm{k,s,t,u}}$= Cost of damages experienced by the customer k in the subsector s from damage type i, due to an unplanned interruption with the interruption duration t

$\mathrm{N_D}$= Number of different damage types under consideration

Cost of ENS experienced by the customer k in the subsector s due to an unplanned interruption (i.e. $\mathrm{C_{k,s,u}}$) can be obtained as shown in (9.2) by considering the combined effect of unplanned interruptions with different interruption durations.

$$\mathrm{C_{k,s,u}} = \frac{\sum_{\mathrm{t=1}}^{\mathrm{r}} (\mathrm{C_{k,s,t,u}} \times \mathrm{P_{t,u}})}{\sum_{\mathrm{t=1}}^{\mathrm{r}} \mathrm{P_{t,u}}} \tag{9. 2}$$

Where,

$\mathrm{P_{t,u}}$ =Probability of occurrence of an unplanned interruption with interruption duration t

$$\mathrm{P_{t,u}} = \frac{\mathrm{N_{t,u}}}{\mathrm{N}_T} \tag{9. 3}$$

$N_{t,u}$ = Number of unplanned interruptions with interruption duration t occurred during the considered time period.

N_T = Total number of unplanned interruptions occurred during the considered time period.

r = Number of different interruption durations under consideration

Probabilities of occurrence of unplanned interruptions are given in the second row of Table 8.1 given in subsection 8.1.1.1.

Cost of ENS experienced by customers in the subsector s due to an unplanned interruption ($C_{s,u}$) can be obtained as shown in (9.4) by considering the combined effect of Cost of ENS due to unplanned interruptions experienced by each customer in the subsector s.

$$C_{s,u} = \frac{\sum_{k=1}^{N_s}(C_{k,s,u} \times x_k)}{\sum_{k=1}^{N_s} x_k} \tag{9. 4}$$

Where,

x_k=Average electricity consumption of consumer k

N_s= Number of customers considered in the study from subsector s

GDP contribution from each subsector of the given year can be used to obtain a value for the Cost of ENS due to unplanned interruptions by considering the combined effect of different subsectors in the commercial sector as shown in (9. 5)

$$C_{p,C} = \frac{\sum_{s=1}^{N_C}(C_{s,p} \times GDP_s)}{\sum_{s=1}^{N_C} GDP_s} \tag{9. 5}$$

Where,

$C_{p,C}$ = Cost of ENS for commercial sector considering unplanned outages

GDP_s= GDP contribution of the subsector s to the GDP of the commercial sector in the year under consideration

N_C= Number of subsectors in the commercial sector

9.1.1.2 Cost of ENS Due to Planned Outages

Similarly, the Cost of ENS experienced by a single customer k in the subsector s due to an expected interruption with the interruption duration t i.e. $C_{k,s,t,p}$ is calculated using (9. 6) by considering the cost of damages corresponding to each damage type.

$$C_{k,s,t,p} = \frac{\sum_{i=1}^{N_D} D_{i,k,s,t,p}}{E_{k,s,t,p}} \tag{9. 6}$$

Where,

$C_{k,s,t,p}$= Cost of ENS experienced by the customer k in the subsector s due to a planned interruption with the interruption duration t

$E_{k,s,t,p}$ = Estimated energy not served for the customer k in the subsector s during the planned interruption duration t

$D_{i,k,s,t,p}$= Cost of damages experienced by the customer k in the subsector s from damage type i, due to a planned interruption with the interruption duration t

N_D= Number of different damage types under consideration

Cost of ENS experienced by the customer k in the subsector s due to a planned interruption (i.e. $C_{k,s,p}$) can be obtained as shown in (9. 7) by considering the combined effect of planned interruptions with different interruption durations.

$$C_{k,s,p} = \frac{\sum_{t=1}^{r}(C_{k,s,t,p} \times P_{t,p})}{\sum_{t=1}^{r} P_{t,p}} \tag{9. 7}$$

Where,

$P_{t,p}$ =Probability of occurrence of a planned interruption with interruption duration t

$$P_{t,p} = \frac{N_{t,p}}{N_T} \tag{9. 8}$$

$N_{t,p}$ = Number of planned interruptions with interruption duration t occurred during the considered time period.

N_T = Total number of planned interruptions occurred during the considered time period

r = Number of different interruption durations under consideration

Probabilities of occurrence of planned interruptions are shown in the third row of Table 8.1 given in subsection 8.1.1.1.

Cost of ENS experienced by customers in the subsector s due to a planned interruption ($C_{s,p}$) can be obtained as shown in (9. 9) by considering the combined effect of Cost of ENS due to planned interruptions experienced by each customer in the subsector s.

$$C_{s,p} = \frac{\sum_{k=1}^{N_s}(C_{k,s,p} \times x_k)}{\sum_{k=1}^{N_s} x_k} \tag{9. 9}$$

Where,

x_k=Average electricity consumption of consumer k

N_s= Number of customers considered in the study from subsector s

GDP contribution from each subsector of the given year can be used to obtain a value for the Cost of ENS due to planned interruptions by considering the combined effect of different subsectors in the commercial sector as shown in (9. 10)

$$C_{p,C} = \frac{\sum_{s=1}^{N_C}(C_{s,p} \times GDP_s)}{\sum_{s=1}^{N_C} GDP_s} \tag{9. 10}$$

Where,

$C_{p,C}$ =Cost of ENS for commercial sector considering planned outages

GDP_s= GDP contribution of the subsector s to the GDP of the commercial sector in the year under consideration

N_C= Number of subsectors in the commercial sector

9.1.1.3 Cost of ENS for the commercial Sector

Cost of ENS can be estimated for the commercial sector as shown in (9. 11) by combining CENS estimated separately for unplanned and planned outages in (9.5) and (9.10), with the use of probability of occurrence of planned and unplanned outages given in the last column of Table 8.1 : Probabilities of occurrence of unplanned/planned interruptions

$$CENS_C = \frac{C_{u,C} \times P_u + C_{p,C} \times P_p}{P_u + P_p} \tag{9. 11}$$

Where,

$CENS_C$= Cost of ENS estimated for the commercial sector

$C_{u,C}$ = Cost of ENS estimated for the commercial sector considering unplanned outages

$C_{p,C}$ = Cost of ENS can be estimated for the commercial sector considering planned outages

9.1.1.4 Cost of ENS for the subsectors of the commercial Sector

Cost of ENS can be estimated for each subsector of the commercial sector as shown in (9. 12) by combining CENS estimated separately for unplanned and planned outages of each subsector using (9.4) and (9.9), with the use of probability of occurrence of planned and unplanned outages given in the last column of Table 8.1.

$$\mathrm{CENS}_{s,C} = \frac{C_{s,u} \times P_u + C_{s,p} \times P_p}{P_u + P_p} \qquad \textbf{(9. 12)}$$

Where,

$\mathrm{CENS}_{s,C}$=Cost of ENS estimated for the subsector s of the commercial sector

$C_{s,u}$= Cost of ENS estimated for the subsector s of the commercial sector considering unplanned outages

$C_{s,p}$= Cost of ENS can be estimated for the subsector s of the commercial sector considering planned outages

9.1.2 Results

The methodology described in subsection 9.1.1 is used to estimate CENS for the commercial sector and results are presented in this subsection.

9.1.2.1 Cost of ENS Due to Unplanned Outages

Cost of ENS experienced by customers in each subsector due to an unplanned interruption is estimated using (9.4) and tabulated in Table 9. 1.

Table 9. 1 CENS for Unexpected Outages

Subsector of the commercial sector	LKR/kWh
1. Wholesale and retail trade	1097.04
2. Transportation of goods and passengers including warehousing	491.77
3. Postal and courier activities	776.51
4. Accommodation, food and beverage service activities	445.16
5. Programming and broadcasting activities and audio video productions	94.22
6. Telecommunication	165.54
7. IT programming consultancy and related activities	615.83
8. Financial service activities and auxiliary financial services	320.27
9. Insurance, insurance and pension funding	1518.03

10. Real estate activities, including ownership of dwelling	315.75
11. Professional services	434.73
12. Public administration and defense, compulsory social security	31.35
13. Education	100.88
14. Human health activities, residential care and social work activities	2939.74
15. Other personal service activities	755.67

9.1.2.2 Cost of ENS Due to Planned Outages

Cost of ENS experienced by customers in each subsector due to a planned interruption is estimated using (9. 9) and tabulated in Table 9. 2.

Table 9. 2 : CENS for Expected Outages

Subsector of the commercial sector	LKR/kWh
1. Wholesale and retail trade	1008.56
2. Transportation of goods and passengers including warehousing	531.24
3. Postal and courier activities	285.04
4. Accommodation, food and beverage service activities	493.75
5. Programming and broadcasting activities and audio video productions	380.78
6. Telecommunication	248.06
7. IT programming consultancy and related activities	453.28
8. Financial service activities and auxiliary financial services	168.61
9. Insurance, reinsurance, and pension funding	1388.39
10. Real estate activities, including ownership of dwelling	412.05
11. Professional services	810.50
12. Public administration and defense, compulsory social security	95.65
13. Education	224.41
14. Human health activities, residential care and social work activities	1922.78
15. Other personal service activities	582.60

9.1.2.3 Cost of ENS for Each Subcategory

Cost of ENS is estimated for each subsector using (9. 12) and tabulated in Table 9. 3.

Table 9. 3 : Cost of ENS estimated for subsectors.

Subsector of the commercial sector	LKR/kWh
1. Wholesale and retail trade	1025.31
2. Transportation of goods and passengers including warehousing	477.66

3. Postal and courier activities	627.96
4. Accommodation, food, and beverage service activities	435.32
5. Programming and broadcasting activities and audio video productions	155.13
6. Telecommunication	176.58
7. IT programming consultancy and related activities	549.83
8. Financial service activities and auxiliary financial services	270.64
9. Insurance, insurance, and pension funding	1417.13
10. Real estate activities, including ownership of dwelling	322.87
11. Professional services	499.97
12. Public administration and defense, compulsory social security	44.54
13. Education	124.30
14. Human health activities, residential care, and social work activities	2569.71
15. Other personal service activities	680.69

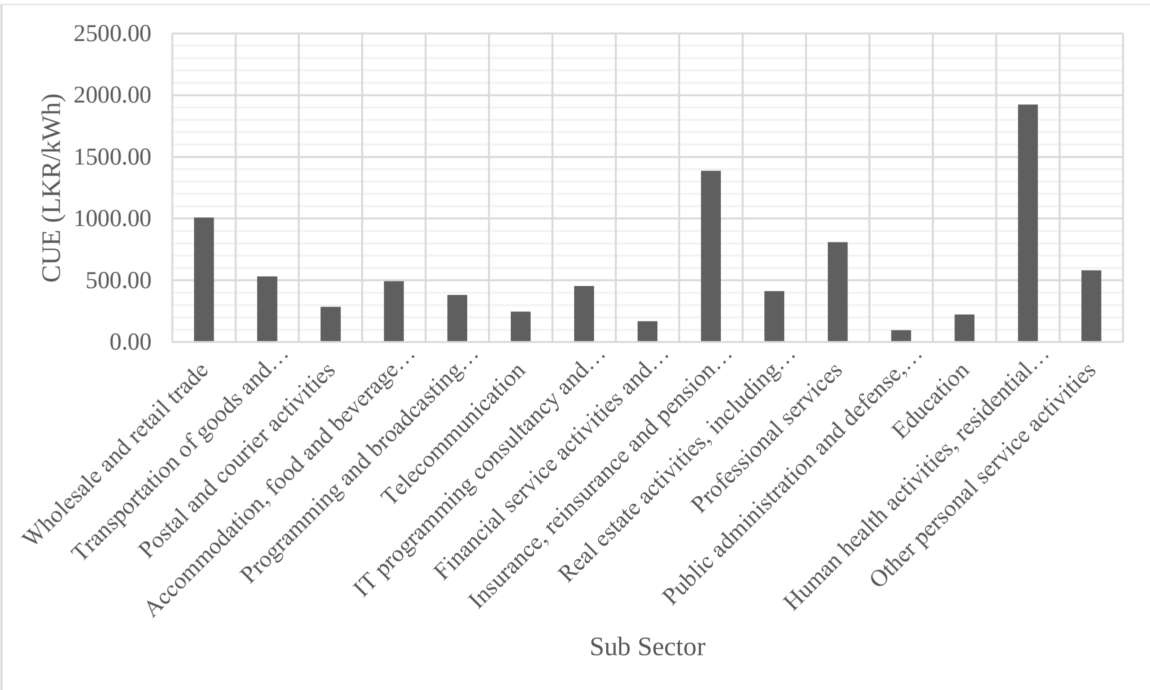


Fig. 9. 1: Cost of ENS due to expected outages.

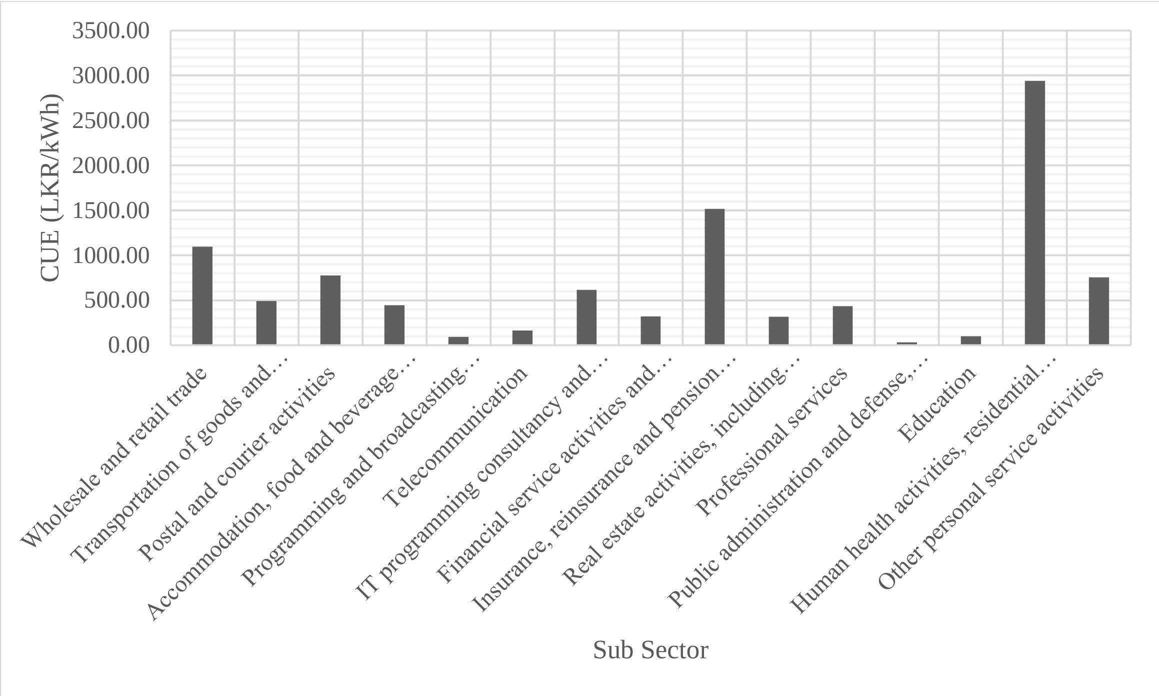


Fig. 9. 2 : Cost of ENS due to unexpected outages

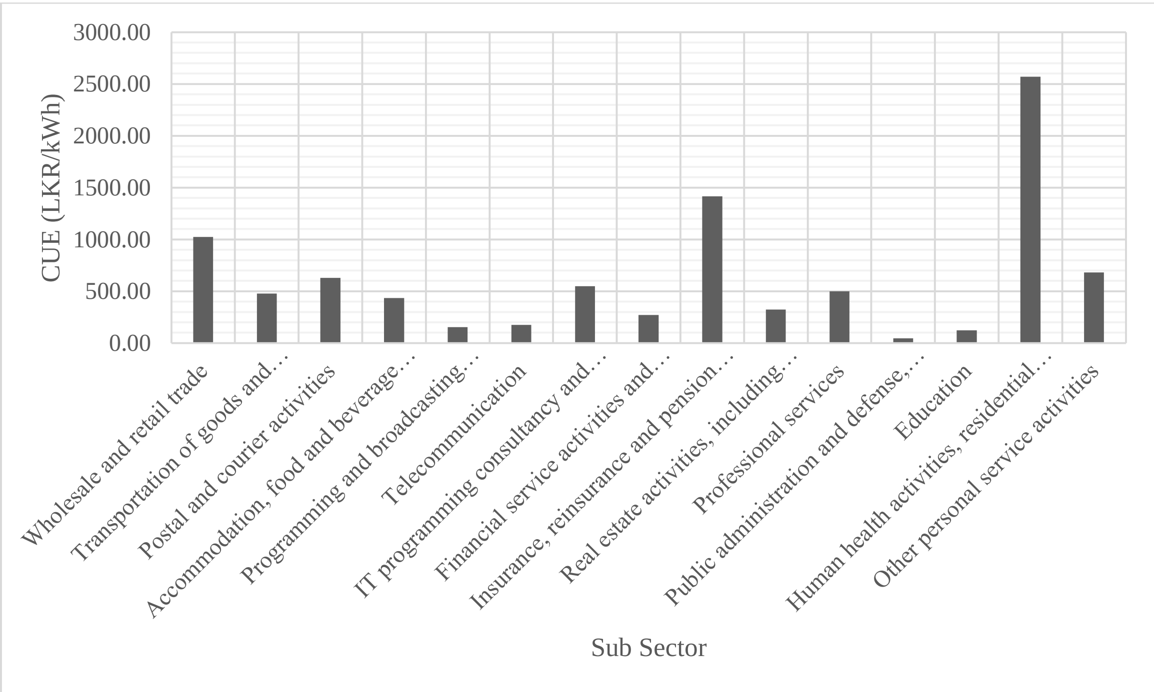


Fig. 9. 3 : Cost of ENS for subsectors

9.1.2.4 Cost of ENS for the Commercial Sector

Cost of ENS due to unplanned and planned outages and the overall Cost of ENS figure estimated for the commercial sector using (9. 5),(9. 10) and (9. 11), respectively are tabulated in Table 9. 4.

Table 9. 4 : Cost of ENS for the commercial sector

Cost of ENS due to unplanned outages	657.67 LKR/kWh
Cost of ENS due to planned outages	596.18 LKR/kWh
Cost of ENS for the commercial sector	612.74 LKR/kWh

9.1.3 Discussion

This study utilizes data obtained from a consumer survey to estimate Cost of ENS for the commercial sector. Consumers are categorized into subsectors and Cost of ENS due to unplanned and planned outages is separately estimated for each sub-sector. These results shown in Table 9. 1 and Table 9. 2 are graphically presented using Fig. 9. 1 and Fig. 9. 2. It can be observed that many subsectors in the commercial sector have either higher Cost of ENS value for unexpected outages than that of expected outages or similar values for both outages except for categories like "professional services, programming and broadcasting activities, education, transportation of goods and passengers including warehousing" which have higher Cost of ENS value for expected outages than that of unexpected outages. The reason for this pattern can be attributed to the fact that the categories mentioned above exhibit a similar behavior: they are not significantly affected by short-term power outages, allowing them to easily postpone or rearrange work with minimal disruption for short durations. However, in the case of long-duration power outages, they would be severely affected due to the high cost of backup power or might be unable to provide their services entirely, even when the outage is anticipated. The Cost of ENS value for unexpected is considerably high for some subsectors such as "wholesale and retail trade, human health activities, residential care and social work activities, postal and courier activities" which are either very time sensitive or the revenue depends on service hours.

Then, Cost of ENS values estimated for planned and unplanned outages of each sub-sector are combined to obtain Cost of ENS for each subsector of the commercial sector and the results are shown in Table 9. 3 and Fig. 9. 3 The subsector "human health activities, residential care and social work activities" exhibits the highest Cost of ENS value. Which can be identified as due to the highly time sensitive nature of such work.

Further, Cost of ENS values estimated for planned and unplanned outages of each sub-sector are combined to estimate Cost of ENS for planned and unplanned of the commercial sector. These values are further combined to estimate Cost of ENS for the commercial sector. These results tabulated in Table 9. 4 show that Cost of ENS estimated for the unplanned outages of the commercial sector is slightly higher than that of the planned outages but not as significant as in industrial sector. Even though planned outages are known in advance, not much significant can be done in commercial service sector as much as in industrial facility.

9.2 Updating of Cost of ENS for Commercial Sector using Analytical Data

9.2.1 Research Methodology

The value-added data and annual energy consumption of the commercial sector is relatively easy to acquire when compared to collecting responses from consumers for the questionnaire in the direct survey-based method. Hence, this section develops a method to update Cost of ENS figure for the commercial sector without conducting time-consuming customer surveys. This proposed method intends to utilize Cost of ENS values previously estimated through customer surveys together with macro-economic data.

In this work, we make a reasonable assumption i.e., the value added of a commercial facility is directly proportional to the sales.

$$\text{Sales} \sim \text{Value adde} \qquad \textbf{(9. 13)}$$

In a commercial setting, it is assumed that there are no sales during the duration of power failure time period. Therefore, this infers that the value added of a commercial facility relies on the supply of power.

Therefore, the customer interruption cost (CIC_{va}) can be calculated using (9.14) as the ratio between the value added per year and the annual electricity consumption.

$$\mathrm{CIC_{va}} = \frac{\text{Value added per one year (LKR)}}{\text{Annual electricity consumption (kWh)}} \qquad \textbf{(9.14)}$$

9.2.1.1 Annual Value Added

Annual value-added values of the commercial sector are estimated by the Department of Census and Statistic through annual surveys. These values are readily available and the

Department of Census and Statistic provide economic indicators for the following divisions of the commercial sector [36]

1. Wholesale and retail trade; repair of motor vehicles and motorcycles.
2. Transportation and storage.
3. Accommodation and food service activities.
4. Information and communication.
5. Real estate activities.
6. Professional, scientific, and technical activities.
7. Administrative and support service activities.
8. Education.
9. Human health and social work activities.
10. Art, entertainment, and recreation.
11. Other service activities.

Hence, the customer interruption cost can be estimated for each commercial subcategory s, as shown in (9.15)

$$\mathrm{CIC}_{\mathrm{va,s}} = \frac{\text{Value added of the subsector 's' for one year (LKR)}}{\text{Annual electricity consumption of subsector (kWh)}} \tag{9.15}$$

Where, $CIC_{va,s}$ is the customer interruption cost for the subsector s of the commercial sector. The data needed for the sample calculation provided here is obtained from the 2019 Annual Survey of trade & services conducted by the Department of Census and Statistics in Sri Lanka. Consequently, the calculation will depict the outcome for the year 2018 [36] and we intend to compare the values obtained using the analytical method with that obtained using the survey results in 2018.

Table 9. 5 : Annual Value Added

Subsector of the commercial sector	Annual value added (LKR)
1. Wholesale and retail trade; repair of motor vehicles and motorcycles.	833,169,441,280.00
2. Transportation and storage.	246,492,946,441.00
3. Accommodation and food service activities.	245,879,079,522.00
4. Information and communication.	314,386,012,615.00
5. Real estate activities.	13,543,958,936.00
6. Professional, scientific, and technical activities.	46,538,264,199.00

7. Administrative and support service activities.	96,112,582,491.00
8. Education.	99,848,462,952.00
9. Human health and social work activities.	65,764,917,111.00
10. Art, entertainment, and recreation.	17,299,755,589.00
11. Other service activities.	32,579,815,015.00

9.2.1.2 Annual Electricity Consumption

Annual electricity consumption of each commercial subsector is required to obtain CIC_{va} per each subcategory. However, value of electricity consumption per each subsector is not mentioned in the "Annual survey of trade & services" by Department of Census and Statistics, Sri Lanka. It only provides the total energy consumption of the commercial sector. In this work, we propose the following method to obtain an estimate for the annual electricity consumption of each subsector. However, if the annual electricity consumption is directly available for each subcategory, it should be directly utilized as it would yield more precise and reliable results.

This method assumes that the electricity consumption of a subcategory is nearly proportional to the number of establishments in that subcategory. With this assumption, this method calculates the annual electricity consumption of each subsector per year (e_s) as shown in (9.16)

$$\mathrm{e_s} = \frac{\mathrm{N_s}}{\mathrm{N_{total}}} \times \mathrm{e_{Total}} \times \rho_s \quad \textbf{(9.16)}$$

Where,

$\mathrm{e_s}$= Annual electricity consumption of the s subsector (kWh)

$\mathrm{N_s}$= Number of establishments in the subsector s

$\mathrm{N_{total}}$= Total number of establishments in the commercial sector

$\mathrm{e_{Total}}$= Total annual electricity consumption of the commercial category (kWh)

ρ_s = Correction factor for electricity intensity of subcategory s

Number of establishments in each subcategory are obtained from the Annual Survey of trade & services 2019 published by Department of Census and Statistics [36] and are shown in Table 9. 6. Total number of establishments in the commercial sector is calculated using (9.17).

$$\mathrm{N_{total}} = \sum_{s=1}^{11} \mathrm{N_s} \quad \textbf{(9.17)}$$

Table 9. 6 : Number of Establishments 2018

Commercial Subcategory	Number of Establishments
1. Wholesale and retail trade; repair of motor vehicles and motorcycles.	24,108
2. Transportation and storage.	3,266
3. Accommodation and food service activities.	6,918
4. Information and communication.	993
5. Real estate activities.	206
6. Professional, scientific, and technical activities.	1,188
7. Administrative and support service activities.	1,439
8. Education.	11,464
9. Human health and social work activities.	2,253
10. Art, entertainment, and recreation.	809
11. Other service activities.	4,994

Some subcategories exhibit higher electricity intensity. To account for these variations, a correction factor for electricity intensity of each sub category s, $\boldsymbol{\rho_s}$ is calculated using **(9.18)** This factor is calculated for each subsector based on the average electricity consumption values shown in Table 9. 7, sourced from our customer survey.

$$\rho_s = \frac{Es_{av,s}}{\left(\sum_{s=1}^{11} Es_{av,s} \big/ 11\right)} \tag{9.18}$$

Where, $Es_{av,s}$ = Average electricity consumption of subsector s obtained using survey data.

Table 9. 7 : Average electricity consumption of each subsector

Commercial Subcategory	Average Electricity Usage (kWh/month)
1. Wholesale and retail trade; repair of motor vehicles and motorcycles.	962.55
2. Transportation and storage.	366.33
3. Accommodation and food service activities.	230.83
4. Information and communication.	1,318.06
5. Real estate activities.	2,294.13
6. Professional, scientific, and technical activities.	1,435.95
7. Administrative and support service activities.	1,231.03
8. Education.	509.33
9. Human health and social work activities.	790.92
10. Art, entertainment, and recreation.	1,336.05
11. Other service activities.	617.53

Calculated correction factors for each subcategory are shown in Table 9. 8.

Table 9. 8 : Correction factors for each subcategory

Commercial Subcategory	Correction factor for consumption
1. Wholesale and retail trade; repair of motor vehicles and motorcycles.	0.69
2. Transportation and storage.	0.26
3. Accommodation and food service activities.	0.16
4. Information and communication.	0.94
5. Real estate activities.	1.63
6. Professional, scientific, and technical activities.	1.02
7. Administrative and support service activities.	0.88
8. Education.	0.36
9. Human health and social work activities.	0.56
10. Art, entertainment, and recreation.	0.95
11. Other service activities.	0.44

Calculated values for annual electricity usage of each subcategory by using (9.16) are shown in Table 9. 9.

Table 9. 9 : Annual Electricity Usage of Subsectors

Commercial Subcategory	Annual Electricity Usage (kWh)
12. Wholesale and retail trade; repair of motor vehicles and motorcycles.	1,156,508,162.09
13. Transportation and storage.	211,457,437.30
14. Accommodation and food service activities.	871,249,736.94
15. Information and communication.	245,523,678.13
16. Real estate activities.	13,716,834.78
17. Professional, scientific, and technical activities.	54,411,773.68
18. Administrative and support service activities.	487,177,428.01
19. Education.	291,006,725.85
20. Human health and social work activities.	266,716,881.57
21. Art, entertainment, and recreation.	19,975,561.61
22. Other service activities.	123,310,203.55

9.2.1.3 Cost of ENS Due to Unplanned Outages

In an unexpected power interruption case, a commercial entity can experience different types of losses such as:

- Spoilage of goods.
- Lost business or sales.
- Wages paid to staff who are unable to work during the interruption.
- Overtime payments to cover lost sales.
- Shutdown costs.
- Startup costs.
- Equipment damage.
- Other costs.

Total losses experienced by a commercial facility due to an unexpected power interruption can be calculated by adding all cost components as shown in (9. 19)

$$\begin{aligned}&\text{Total losses }(100\%)\\&= \text{Spoilage of goods} + \text{lost business or sales}\\&+ \text{wages paid to staff who are unable to work during the interruptioin}\\&+ \text{overtime payments to cover lost sales} + \text{shutdown costs}\\&+ \text{startup costs} + \text{equipment damages} + \text{other costs}\end{aligned} \quad \textbf{(9. 19)}$$

As discussed under section 9.2.1 when deriving (9. 13) it is reasonable to assume that the sales loss is linearly proportional to the value added. Hence, an average weighting factor is introduced for the unexpected outages in each subsector s (K_{us}) of the commercial sector as shown in (9. 20)

$$K_{u,s} = \frac{100\%}{\text{Lost business or sales in the subsector s as a percentage of its total losses}} \quad \textbf{(9. 20)}$$

The determination of specific $K_{u,s}$ values for commercial subsectors in Sri Lanka can be achieved through a comprehensive survey approach that involves gathering all necessary data across various subcategories, as outlined in section 9.1. In this work, (9. 21) is used to calculate $K_{u,s}$ values using survey data.

$$K_{u,s} = \frac{\sum_{i=1}^{N} K_{u,s,i}}{N_s} \qquad \textbf{(9. 21)}$$

Where,

$\mathbf{N_s}$ = Number of responses of the survey

$\mathbf{K_{u,s,i}}$ =Weighting factor of each i commercial establishment in s subsector

$K_{u,s,i}$ values are calculated from the survey data, using (9. 22)

$$K_{u,s,i} = \frac{100}{\text{Percentage of sales loss of } i^{th} \text{ response from survey for u}} \qquad \textbf{(9. 22)}$$

Calculated $K_{u,s}$ values are tabulated in Table 9. 14 for different subsectors in the commercial sector.

Table 9. 10 : $K_{u,s}$ Values

Type of the commercial sector	$K_{u,s}$
1. Wholesale and retail trade; repair of motor vehicles and motorcycles.	1.53
2. Transportation and storage.	1.07
3. Accommodation and food service activities.	1.30
4. Information and communication.	2.11
5. Real estate activities.	1.03
6. Professional, scientific, and technical activities.	1.70
7. Administrative and support service activities.	1.40
8. Education.	1.60
9. Human health and social work activities.	1.08
10. Art, entertainment, and recreation.	1.00
11. Other service activities.	1.40

As discussed in 9.2.1, interruption cost experienced by a commercial entity belongs to subsector s due to an unexpected power interruption ($CIC_{u,s}$) can be calculated as shown in (9.23).

$$CIC_{u,s} = K_{u,s} \times CIC_{va,s} \qquad \textbf{(9. 23)}$$

As discussed in 9.2.1, $CIC_{va,s}$ can be calculated using equation (9. 24) by using the data in Table 9. 5 and Table 9. 9.

$$\mathrm{CIC_{va,s}} = \frac{\text{Value added per one year in subsector s (LKR)}}{\text{Annual electricity consumption of subsector s (kWh)}} \quad \textbf{(9. 24)}$$

9.2.1.4 Cost of ENS Due to Planned Outages

The types of losses incurred by the commercial sector due to an expected power interruption can be slightly different from those of unexpected outages and may consist of the following.

- Lost business or sales.
- Overtime payments to cover lost sales.
- Startup cost.

Therefore, total losses experienced by a commercial entity due to an expected power interruption (L_p) can be calculated by adding lost business or sales, losses of restart and extra expenses incurred due to power interruptions as shown in (9. 25). These components can be considered as loss components that occur even when the interruption is anticipated. Importantly, these components do not decrease significantly even when the outage is known in advance. [35]

$$\begin{aligned}&\text{Percentage total losses considered under expected outges}\left(\mathrm{L_p}\right)\\ &\qquad = \text{Lost business or sales} + \text{Overtime payments to cover lost sales}\\ &\qquad + \text{startup costs}\end{aligned} \quad \textbf{(9. 25)}$$

As discussed under section 9.2.1 when deriving (9.13), it is reasonable to assume that the sales loss is linearly proportional to the value added. Hence, a weighting factor *($K_{p,s}$)* is introduced for planned outages in each service sector type i of the commercial sector as shown in (9. 26)

$$\mathrm{K_{p,s}} = \frac{\mathrm{L_p}}{\text{Lost business or sales as a percentage of total losses}} \quad \textbf{(9. 26)}$$

The determination of specific $\mathrm{K_{p,s}}$ values for commercial subsectors in Sri Lanka can be achieved through a comprehensive survey approach that involves gathering all necessary data across various subcategories, as outlined in section 9.1. In this work, (9. 27) is used to calculate $\mathrm{K_{p,s}}$ values using survey data.

$$\mathrm{K_{p,s}} = \frac{\sum_{i=1}^{N} \mathrm{K_{p,s,i}}}{\mathrm{N_s}} \quad \textbf{(9. 27)}$$

Where,

$\mathbf{N_s}$ = Number of responses of the survey

$\mathbf{K_{p,s,i}}$ =Weighting factor of each i commercial establishment in s subsector

$K_{p,s,i}$ values are calculated from the survey data, using (9.28).

$$K_{p,s,i} = \frac{\textit{Perecentage total losses considered under expected outges as per the } i^{th} \text{ response}}{\text{Percentage of business or sales loss of } i^{th} \text{ response}} \quad \textbf{(9. 28)}$$

Calculated $K_{p,s}$ values are tabulated in Table 9. 11 : $\mathbf{K_{p,s}}$ Values for different subsectors in the commercial sector.

Table 9. 11 : $\mathbf{K_{p,s}}$ Values

Type of the commercial sector	$K_{p,s}$
1. Wholesale and retail trade; repair of motor vehicles and motorcycles.	1.39
2. Transportation and storage.	1.00
3. Accommodation and food service activities.	1.00
4. Information and communication.	1.69
5. Real estate activities.	1.03
6. Professional, scientific, and technical activities.	1.00
7. Administrative and support service activities.	1.25
8. Education.	1.00
9. Human health and social work activities.	1.08
10. Art, entertainment, and recreation.	1.00
11. Other service activities.	1.40

As discussed in Research Methodology, interruption cost experienced by a commercial entity belongs to subsector s due to a planned power interruption ($CIC_{p,s}$) can be calculated as shown in (9. 29).

$$CIC_{p,s} = K_{p,s} \times CIC_{va,s} \quad \textbf{(9. 29)}$$

As discussed in 0, $CIC_{va,s}$ is calculated using equation (9. 24) by using the data Table 9. 5 and Table 9. 9.

9.2.1.5 Interruption Cost for Each Subsector and the Commercial Sector

Interruption cost for the each subsector in the industrial sector and the interruption cost for the commercial sector can be analytically calculated using a similar method explained in subsections 9.1.1.3 and 9.1.1.4

9.2.2 Unadjusted Results

9.2.2.1 Unadjusted Interruption Costs for Subcategories

Values estimated for interruption costs due to unplanned and planned outages i.e., $\mathrm{CIC}_{u,s}$ and $\mathrm{CIC}_{p,s}$ are shown in Table 9. 12 This report refers to these values as unadjusted values, as we intend to study the changes in these values upon introducing some adjustments considering practical scenarios in the coming subsections.

Table 9. 12 : Unadjusted CIC Values estimation

Commercial Subcategory	Unplanned $\mathrm{CIC}_{u,s}$	Planned $\mathrm{CIC}_{p,s}$	Combined $\mathrm{CIC}_{c,s}$
1. Wholesale and retail trade; repair of motor vehicles and motorcycles.	1,105.15	999.37	1,088.43
2. Transportation and storage.	1,247.03	1,165.69	1,234.18
3. Accommodation and food service activities.	366.88	282.21	353.50
4. Information and communication.	2,703.93	2,161.57	2,618.24
5. Real estate activities.	1,020.31	1,012.79	1,019.12
6. Professional, scientific, and technical activities.	1,454.01	855.30	1,359.41
7. Administrative and support service activities.	276.13	245.95	271.36
8. Education.	548.98	343.11	516.46
9. Human health and social work activities.	266.30	265.48	266.17
10. Art, entertainment, and recreation.	866.05	855.65	864.40
11. Other service activities.	371.01	369.89	370.84

9.2.3 Correction Factors

In the customer interruption cost (CIC_{va}) method, annual value added is taken as the main input to obtain an estimation for the damage due to the electricity interruptions. Even though annual value-added gives an overall economical estimation about a given subsector it is not directly related to the usage of electricity. It is observed that in some sub sectors electricity is a crucial factor for their output hence the value added is highly dependent on usage of electricity while value added in some subcategories is barely affected by electricity usage. Therefore, some corrections factors should be introduced to get more accurate value to customer interruption cost.

9.2.3.1 Critical Electricity Consumption Correction

It is important to consider the end use of the electricity in each subsector. In some subsectors electricity is used in more critical scenarios while some subsectors may use more electricity for lighting and air conditioning. Therefore, criticality of each end use for different subsector are defined as follows,

Table 9. 13 : Critical Consumption Percentages

Commercial Subcategory	Lighting (%)	Power (%)	Hot Water (%)	Other Process Heat (%)	Process Cold (%)	AC (%)	ICT (%)	Space Heating (%)
1. Wholesale and retail trade; repair of motor vehicles and motorcycles.	10	25	5	20	5	15	20	5
2. Transportation and storage.	5	40	5	15	5	20	5	5
3. Accommodation and food service activities.	10	20	25	15	5	20	5	10
4. Information and communication.	5	15	5	15	5	45	10	5
5. Real estate activities.	5	15	5	20	5	45	5	5
6. Professional, scientific, and technical activities.	10	25	5	15	5	30	10	5
7. Administrative and support service activities.	10	25	5	20	5	25	10	5
8. Education.	10	20	5	20	5	35	5	5
9. Human health and social work activities.	10	20	25	10	5	25	5	5
10. Art, entertainment, and recreation.	10	20	5	20	5	35	5	5
11. Other service activities.	10	20	5	20	5	35	5	5

Adjustments done according to following scenarios for Sri Lankan market from base values taken from [43],[44] ,[45], [42] and as for following criteria.

- Review of industry standards and best practices.
- Analysis of sector-specific operational needs.
- Validation through survey results.
- Adjustments based on industrial expert feedback.

Table 9. 14 : Critical Electricity Consumption Factor

	Commercial Subcategory	Critical Electricity Consumption Factor (CEF)
1.	Wholesale and retail trade; repair of motor vehicles and motorcycles.	75%
2.	Transportation and storage.	65%
3.	Accommodation and food service activities.	85%
4.	Information and communication.	80%
5.	Real estate activities.	80%
6.	Professional, scientific, and technical activities.	75%
7.	Administrative and support service activities.	75%
8.	Education.	75%
9.	Human health and social work activities.	60%
10.	Art, entertainment, and recreation.	80%
11.	Other service activities.	70%

9.2.4 Adjusted Results

9.2.4.1 Adjusted Interruption Costs for Subcategories

Table 9. 15 : Adjusted Cost of ENS Values

Subsector of the commercial sector	Unplanned $CIC_{u,s}$	Planned $CIC_{p,s}$	Combined $CIC_{c,s}$
1. Wholesale and retail trade; repair of motor vehicles and motorcycles.	828.86	749.53	816.33
2. Transportation and storage.	810.57	757.70	802.22
3. Accommodation and food service activities.	311.85	239.88	300.48
4. Information and communication.	2,163.15	1,729.25	2,094.59
5. Real estate activities.	816.25	810.23	815.30
6. Professional, scientific, and technical activities.	1,090.50	641.47	1,019.56
7. Administrative and support service activities.	207.10	184.46	203.52
8. Education.	411.74	257.34	387.34
9. Human health and social work activities.	159.78	159.29	159.70
10. Art, entertainment, and recreation.	692.84	684.52	691.52
11. Other service activities.	259.71	258.93	259.59

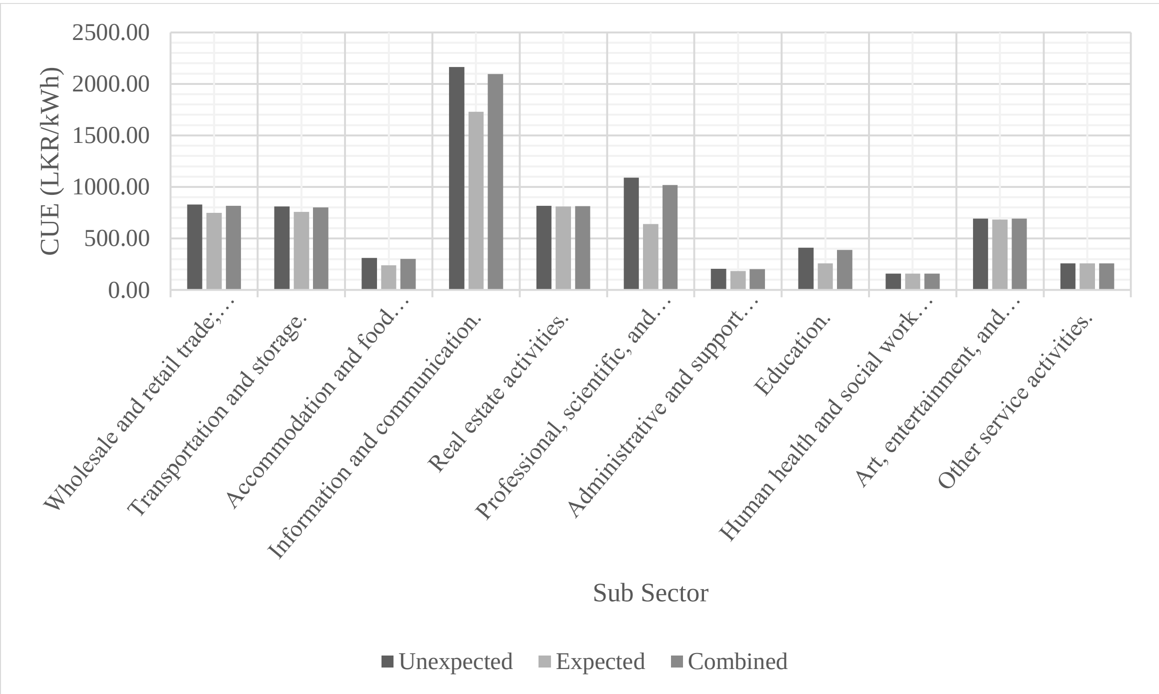


Fig. 9. 4 Adjusted Cost of ENS values for sub-sectors.

9.2.4.2 Adjusted Interruption Costs for the commercial sector

Table 9. 16 : Analytically calculated and adjusted Cost of ENS values

Unexpected Outages	528.95 LKR/kWh
Expected Outages	477.29 LKR/kWh
Combined	517.92 LKR/kWh

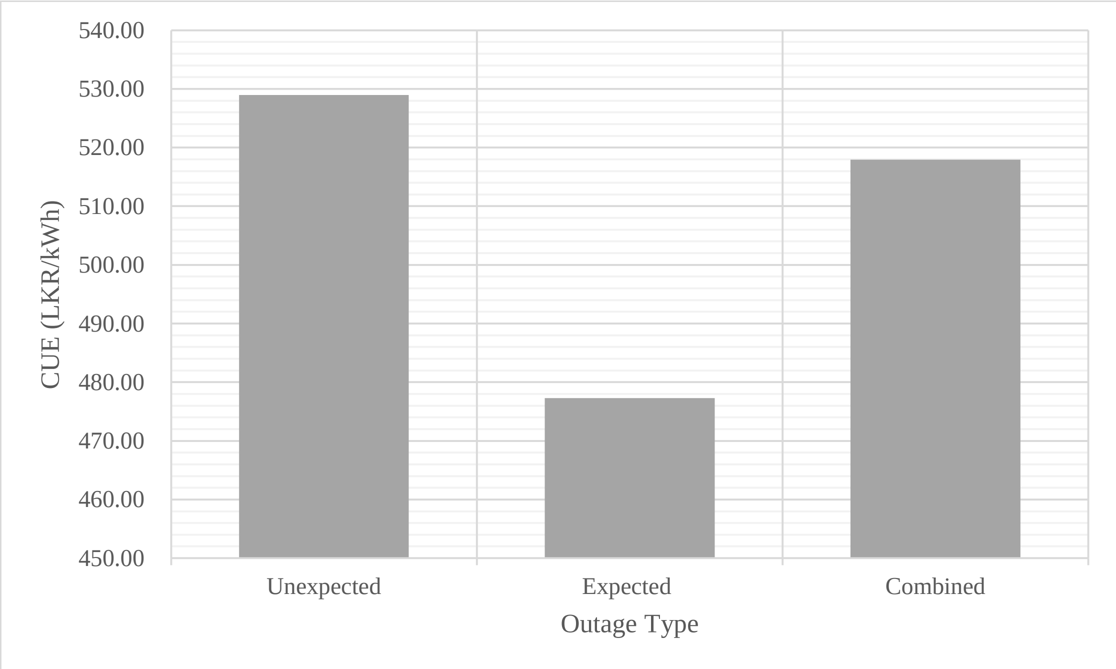


Fig. 9. 5 :Analytically calculated and adjusted Cost of ENS values

9.2.5 Discussion

9.2.5.1 Comparison of Cost of ENS with survey-based Cost of ENS estimations for Subcategories

Calculations were performed using input data from Sri Lanka for the year 2018. As a result, the customer interruption cost/expected energy not served values will be valid in 2018. However, there is insufficient past related work that matches to that precise year on estimating method calculations. Despite the lack of data, we compare the survey-based results published in [2] for the corresponding year. [2] calculated the values for the following subcategories,

- Wholesale and Retail
- Hotels & Restaurants
- Transport & communication

- Government Services
- Privet Services

However, it is not specified what type of subcategories are included in the categories mentioned above. As a result, comparing two studies together is difficult.

9.2.5.1.1 Possible aggregation bias and different categorization.

As previously stated, each study's subcategorization is different. In addition, several categories are grouped together. In a 2018 survey study, for example, "Transport & communication" is aggregated as one category, whereas [7] presents "Transportation and storage" as one category and "Information and communication" as another, with storages category aggregated with transport and information sector aggregated with communication. This makes effectively comparing either category with the "Transport & communication" category in the prior study extremely difficult.

Different categorization also make comparing result less accurate such as where transport category in [42] comprises of following sub categories,

- Land transport and transport via pipelines.
- Water transport.
- Air transport.
- Warehousing and support activities for transportation.
- Postal and courier activities.

All the above subcategories ultimately contribute to the total value-added figure for the "Transport" category, which is used as input for the proposed estimating method. While it is listed under the same name category as transport in the previous survey-based method, it is highly unlikely that the survey had responses representing sub sections such as air transport and water transport, therefore even though the name category is transport, it will only represent land-based transport, whereas the estimation method represents all other transport sections as well.

It can be observed when analyzing the result as follows,

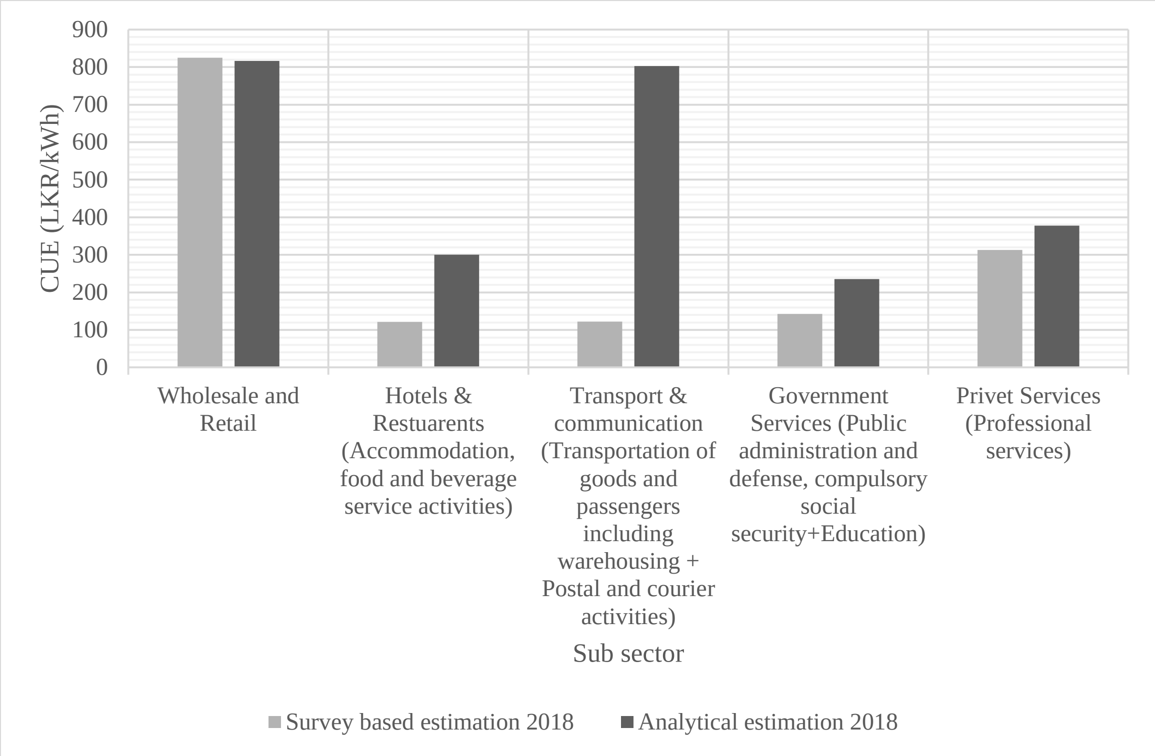


Fig. 9. 6 : Adjusted Cost of ENS for combined outages considering complete Value Added for Transport Sector

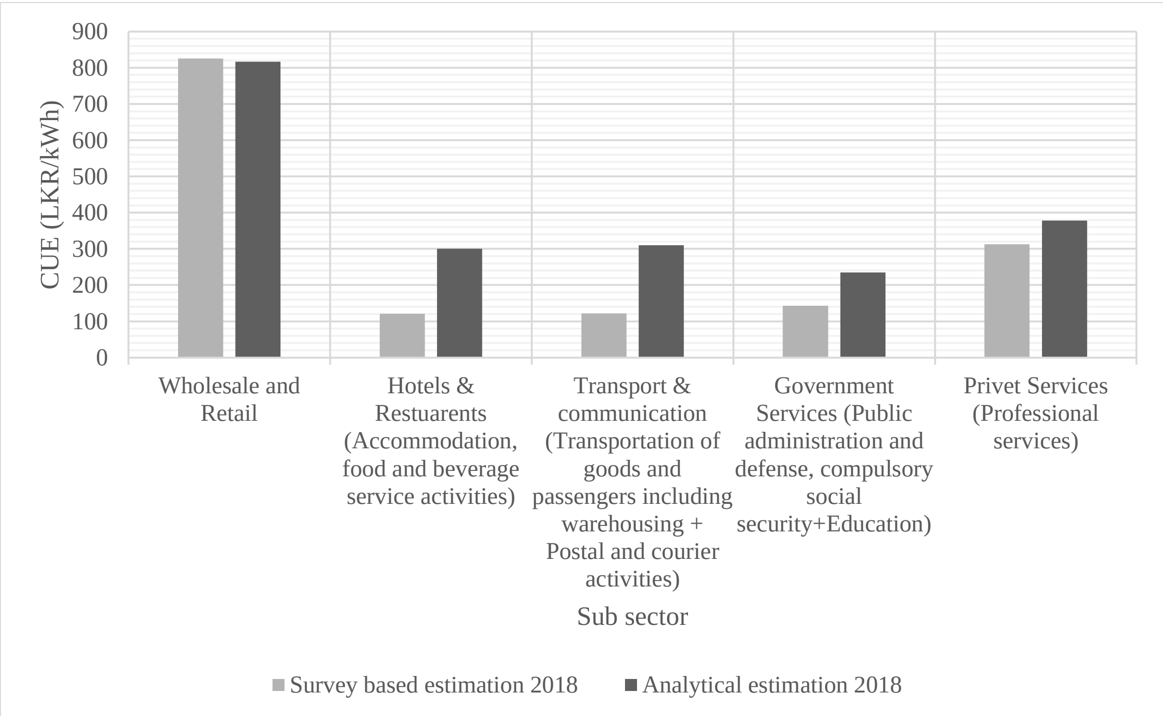


Fig. 9. 7 : Adjusted Cost of ENS for combined outages considering only land-based Transport Value Added for Transport Sector

Fig. 9. 6 compares the value of the transport sector when calculated with the total value added for the entire sector, revealing a significant difference from the prior study. Whereas Fig. 9. 7 provides computed values using just land-based transportation, the results are like the prior study. Fig. 9. 8 shows the total combined value different when Transport category correction.

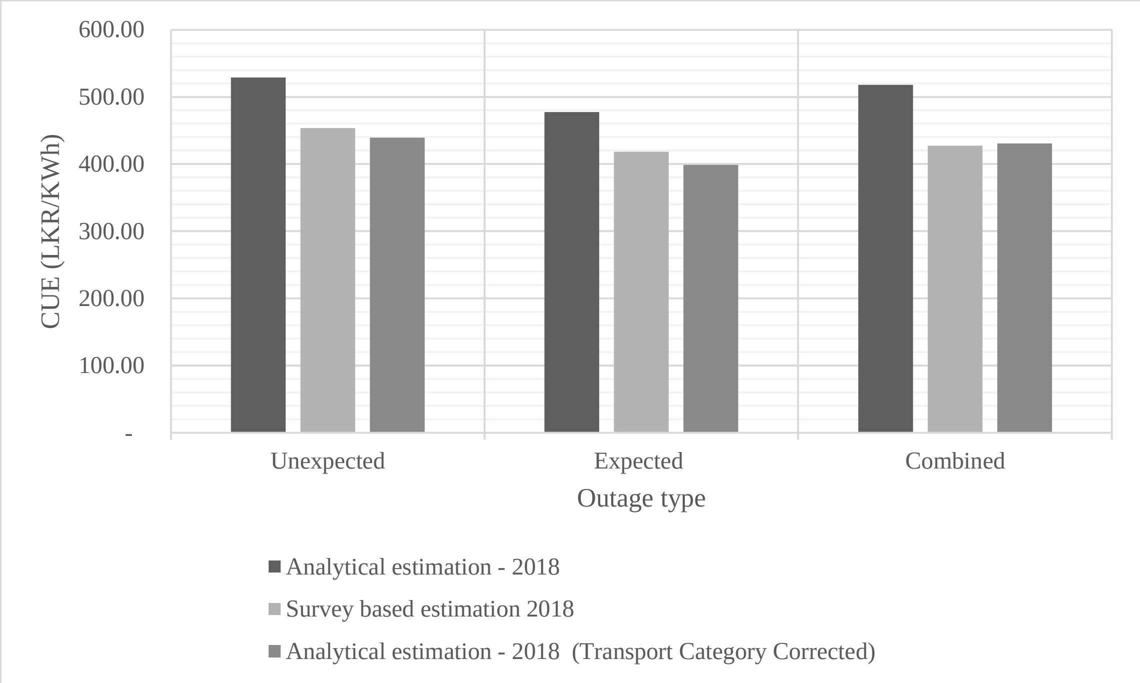


Fig. 9. 8 : Cost of ENS for Combined Outages (Compared Categories Only)

9.2.5.1.2 Comparison of Cost of ENS with survey-based Cost of ENS estimations considering comparable subcategories

Despite the above-mentioned difficulties some of relatively matching categories are compared here,

- Wholesale and Retail
- Hotels & Restaurants (Accommodation, food, and beverage service activities)
- Transport & communication (Transportation of goods and passengers including warehousing + Postal and courier activities)
- Government Services (Public administration and defense, compulsory social security Education)
- Privet Services (Professional services)

However, the corresponding categories may not exactly match with each other.

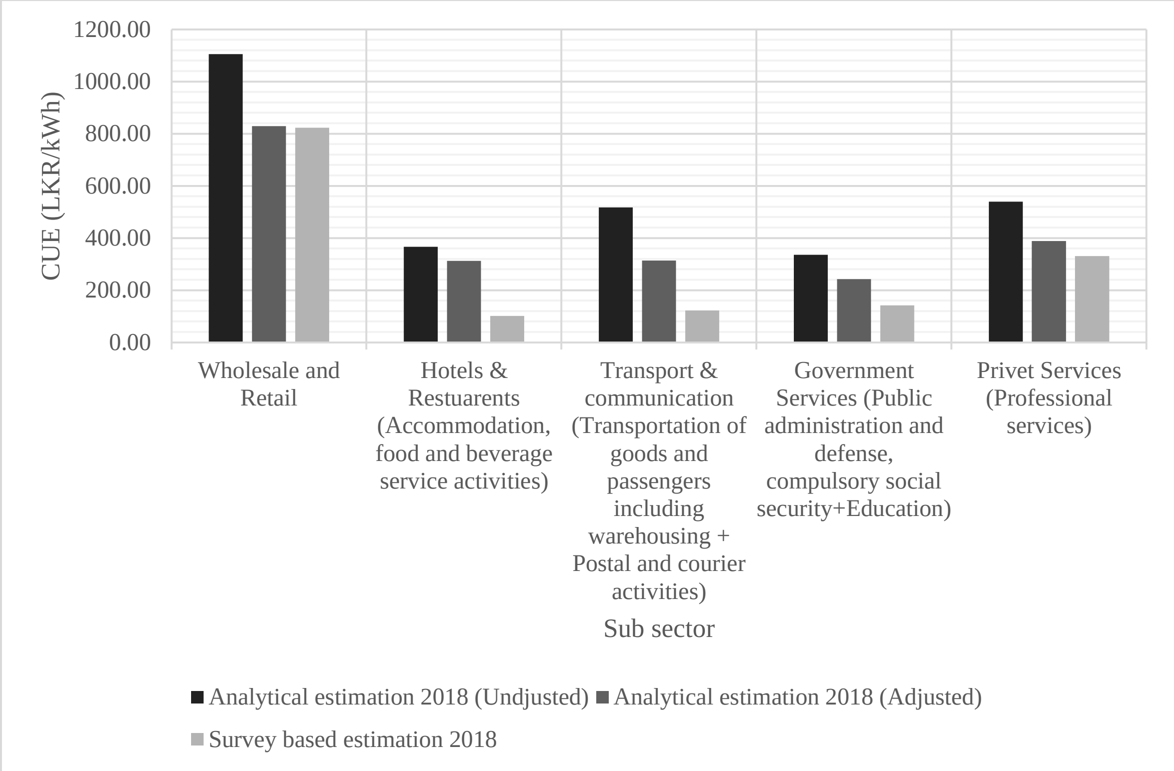


Fig. 9. 9 : Analytically estimated values for unexpected outages with survey-based estimation for 2018 considering comparable categories only.

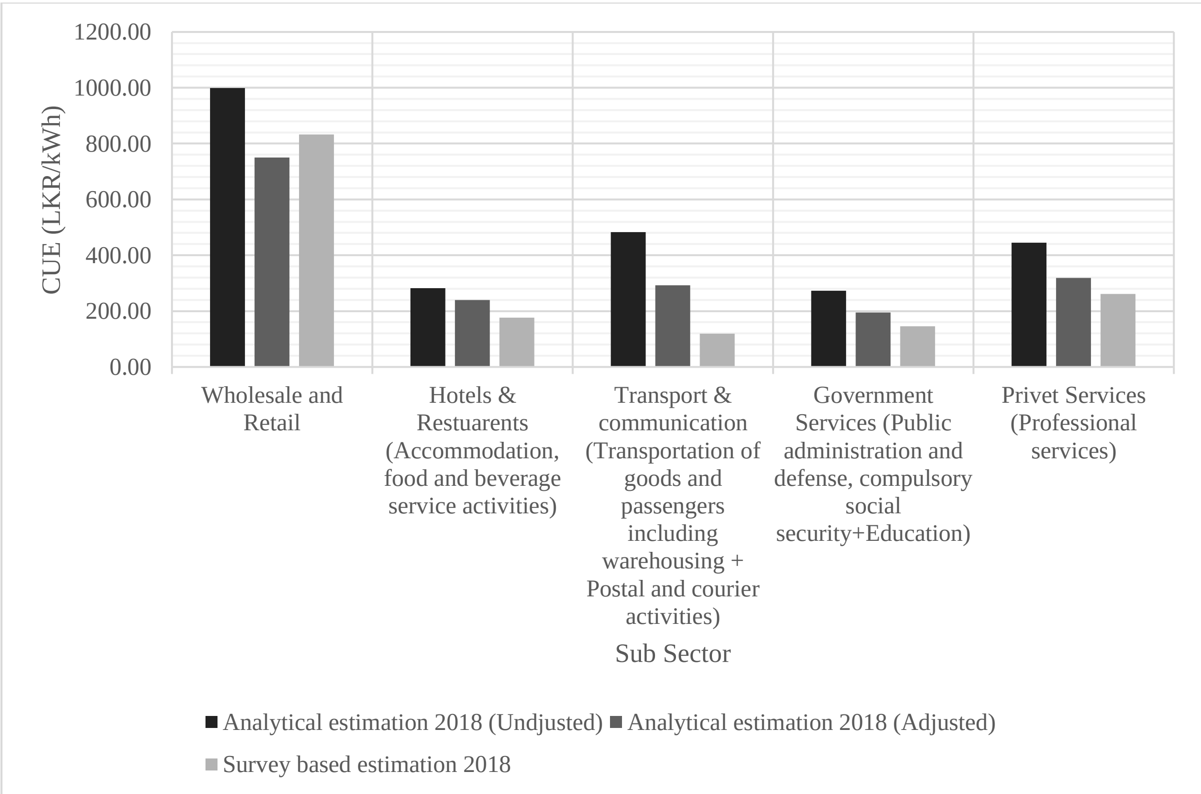


Fig. 9. 10 : Analytically estimated values for expected outages with survey-based estimation for 2018 considering comparable categories only.

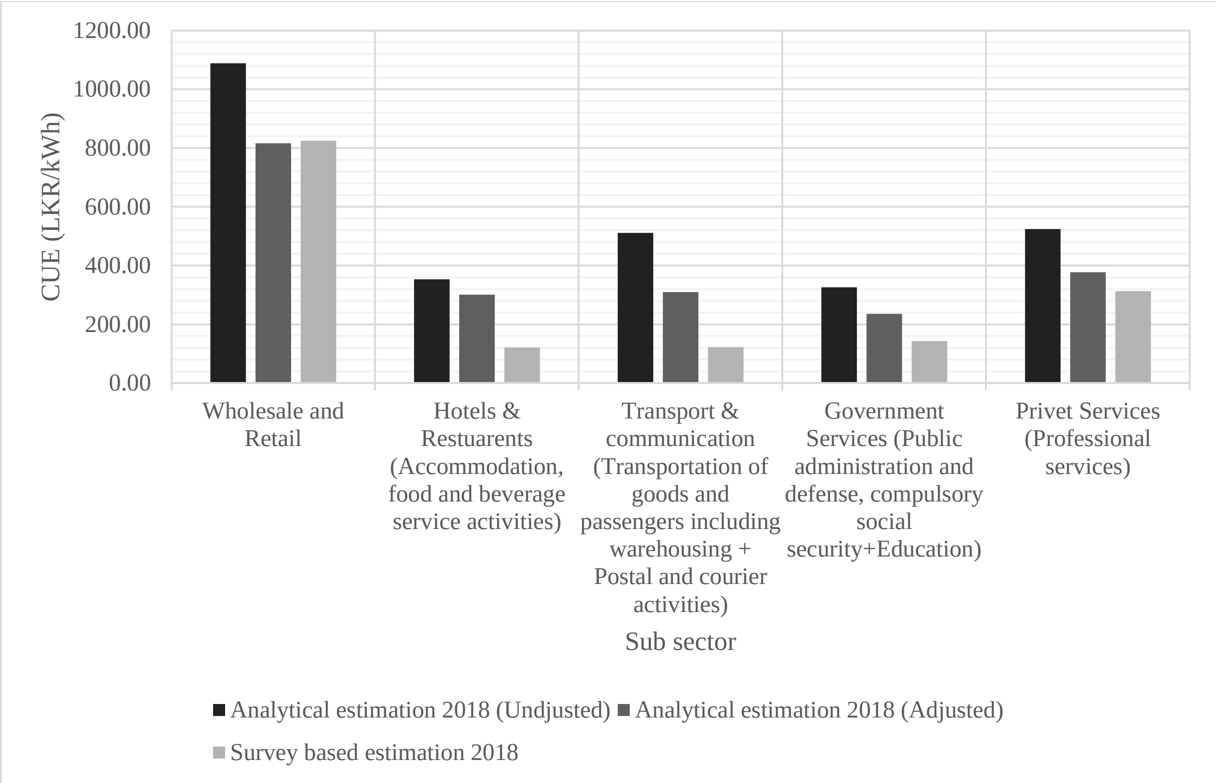


Fig. 9. 11 : Analytically estimated values of sub sectors for combined outages with survey-based estimation for 2018 considering comparable categories only.

9.2.5.2 Comparison of Cost of ENS with survey-based Cost of ENS estimations for the commercial sector

We've provided analytical estimates for unadjusted and adjusted Cost of ENS values using 2018 data in Table 9. 17, and the corresponding survey-based estimates for 2018 are also found in Table 9. 18. These values are visually represented in Fig. 9. 12.

It's apparent that unadjusted values deviate significantly from the survey-based estimates for 2018 in the case of both planned and unplanned outages. However, after adjustment, the analytically estimated values align more closely with the survey-based estimates, although they still exhibit slightly higher values.

Table 9. 17 : Analytically calculated Cost of ENS for the Commercial Sector using 2018 data.

	Unadjusted (LKR/kWh)	Adjusted (LKR/kWh)
Unexpected Outages	731.94	528.95
Expected Outages	661.73	477.29
Combined	716.88	517.92

Table 9. 18 : Survey based estimation 2018.

Unexpected Outages	453.49 LKR/kWh
Expected Outages	418.19 LKR/kWh
Combined	427.37 LKR/kWh

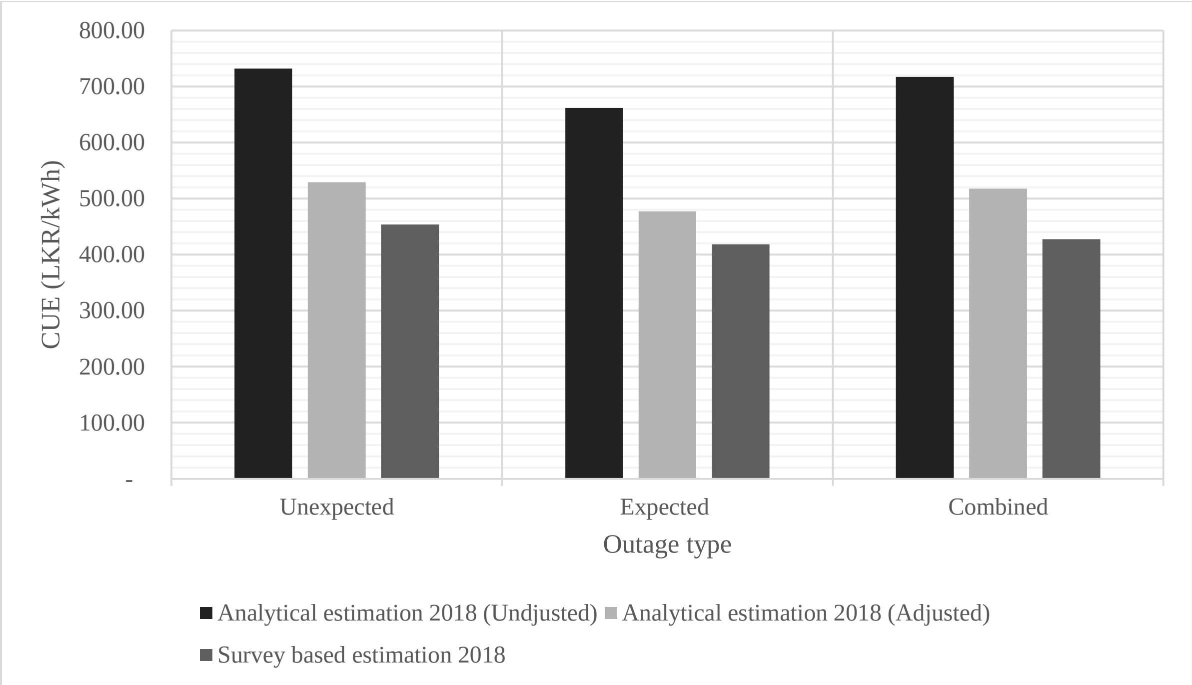


Fig. 9. 12 : Analytically estimated Cost of ENS values with 2018 data and survey-based estimation for 2018

Considering the challenges mentioned in section 9.2.5.1 regarding the comparison of two different studies, it may not be entirely fair to contrast combined values for the entire commercial sector when calculated using dissimilar subsectors. To ensure a more equitable comparison, we have computed combined values for the commercial sector using only comparable subsectors. The outcomes of this approach are documented in Table 9. 19, Table 9. 20 and visualized in Fig. 9. 13

Table 9. 19 : Analytically calculated Cost of ENS for the Commercial Sector using 2018 data by only considering comparable subsectors.

	Unadjusted (LKR/kWh)	Adjusted (LKR/kWh)
Unexpected Outages	776.99	447.68
Expected Outages	621.59	346.76
Combined	748.71	429.66

Table 9. 20 : Survey based estimation 2018 considering only comparable subsector.

Unexpected Outages	453.49 LKR/kWh
Expected Outages	418.19 LKR/kWh
Combined	427.37 LKR/kWh

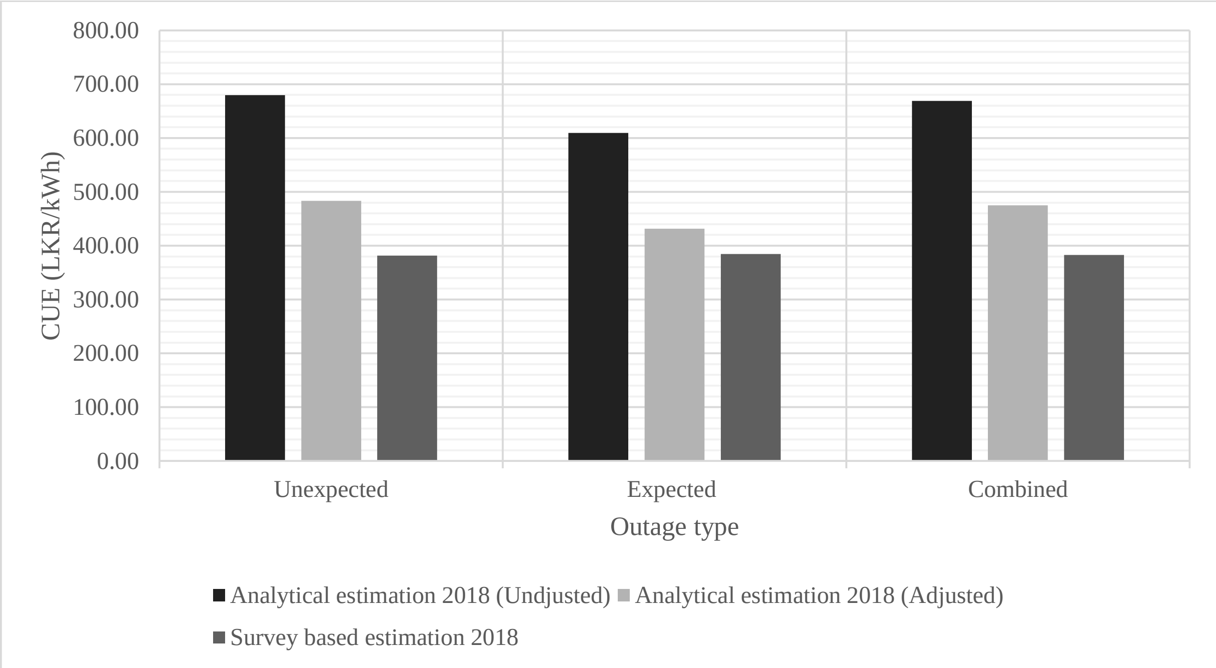


Fig. 9. 13 : Analytically estimated Cost of ENS values with 2018 data and survey-based estimation for 2018 considering comparable categories only.

Similar as the previous section, we notice that adjusted values exhibit a minor deviation from the survey-based values for 2018 when focusing exclusively on comparable subsectors. However, analytically estimated values still tend to be slightly higher than the survey-based values.

As outlined in Section 9.2.5.1, the comparison of results from distinct studies, particularly when they involve varying subsector levels, poses a challenge. The values can fluctuate based on how subsectors are defined. Additionally, the contrast between survey-based and estimation methods is inherently complex. Notably, across various categories, estimated values often exhibit a slight elevation compared to survey-based values.

Furthermore, despite variations at the subsector level, when we aggregate these values to represent the entire commercial sector, it becomes evident that the estimation approach converges closely with the prior survey-based method values.

10. Cost of Energy Not Served for Sri Lanka

10.1 Methodology

It is assumed that the contribution of each sector to the overall Cost of ENS is proportional to its GDP contribution. Then, the values for Cost of ENS due to unplanned outages and planned outages are obtained for Sri Lanka using (10.1) and (10.2), respectively, by combining the values obtained for domestic, commercial, and industrial sectors. Similarly, a combined value is calculated for the Cost of ENS for Sri Lanka, using (10.3).

$$C_{Tot,u} = \frac{\sum_{S=1}^{3}\left(C_{S,u} \times GDP_S\right)}{\sum_{S=1}^{3} GDP_S} \tag{10. 1}$$

Where,

$C_{Tot,u}$ = Cost of ENS due to unexpected outages in Sri Lanka

$C_{S,u}$ = Cost of ENS due to unexpected outages in the sector S

GDP_S = GDP contribution of the sector S (%)

$$C_{Tot,p} = \frac{\sum_{S=1}^{3}\left(C_{S,p} \times GDP_S\right)}{\sum_{S=1}^{3} GDP_S} \tag{10. 2}$$

Where,

$C_{Tot,p}$ = Cost of ENS due to planned outages in Sri Lanka

$C_{S,p}$ = Cost of ENS due to planned outages in the sector S

$$C_{TOT} = \frac{\sum_{S=1}^{3}(C_S \times GDP_S)}{\sum_{S=1}^{3} GDP_S} \tag{10. 3}$$

Where,

C_{TOT} = Cost of ENS for Sri Lanka

C_S = Cost of ENS for sector S in Sri Lanka

10.2 Results

Even though the survey is being conducted for the year 2022, the Department of Census and Statistics has not published the GDP contribution of each sector for the year 2022. Since the most recent available data corresponding to year 2020 are used in this study for a sample calculation. Furthermore, the Department of Census and Statistics does not publish direct contribution from the domestic sector, hence the percentage value are obtained by referring to [1]. The GDP percentages used in this study are shown in table 10.1.

Table 10. 1 : GDP Contribution from each Sector (2020)

Commercial Sector	60 %
Industrial Sector	26 %
Domestic Sector	3%

Table 10. 2 : Cost of ENS Values for the Industrial Sector (All Sub-Categories)

Unexpected Outages	1,007.98 LKR/kWh
Expected Outages	692.94 LKR/kWh
Combined	888.78 LKR/kWh

Table 10. 3 : Cost of ENS Values for the Commercial Sector (All Sub-Categories)

Unexpected Outages	657.67 LKR/kWh
Expected Outages	596.18 LKR/kWh
Combined	612.74 LKR/kWh

Table 10. 4 : Cost of ENS Values for the Domestic Sector

Unexpected Outages	528.45 LKR/kWh
Expected Outages	480.47 LKR/kWh
Combined	516.97 LKR/kWh

Following values are obtained by using the (10. 1), (10.) and (10.).

Table 10. 5 : Cost of ENS Values for Sri Lanka

Unexpected Outages	755.65 LKR/kWh
Expected Outages	620.55 LKR/kWh
Combined	690.15 LKR/kWh

10.3 Discussion

The GDP contributions used in this study to combine the Cost of ENS values obtained for the three sectors may differ from actual GDP contributions of the three sectors in the year in which the study was conducted. It should be noted that more accurate values can be obtained by utilizing GDP data of the relevant year, if data is available.

The Cost of ENS values obtained for unexpected and expected outages using the survey conducted in 2022 show about 457% and 311% increase, respectively when compared to those values estimated by a previous survey-based study conducted in 2018 [1] which are tabulated in tables 10.6. Possible reasons for such increases are discussed in sub sections 9.2.5.1.1 & 9.2.5.1.2 of this report.

It is important to note that the direct comparison of the Cost of ENS values obtained from this study with the findings of a previous study may not be accurate due to various reasons outlined in sub sections 8.1.3 and 9.1.3. For better comparison, the adjusted values obtained in sub sections 8.2.5 and 9.2.5 by only using the subcategories considered in both survey based studies can be used. These adjusted values estimated by a previous survey-based study conducted in 2018 [1] and the adjusted values of the survey-based estimation conducted in 2022 in this study are tabulated in tables 10.7 and 10.8, respectively. Results reveal that the adjusted Cost of ENS values estimated for both unexpected and expected outages show about 103% and 90% increase, respectively. Possible reasons for such increases are discussed in sub sections 8.1.3 & 9.1.3 of this report.

Table 10. 6 : Previous survey-based estimation 2018

Unexpected Outages	135.59 LKR/kWh
Expected Outages	151.02 LKR/kWh
Combined	120.67 LKR/kWh

Table 10. 7 : Previous survey-based estimation 2018 (Compared Categories Only)

Unexpected Outages	388.87 LKR/kWh
Expected Outages	348.33 LKR/kWh
Combined	382.13 LKR/kWh

Table 10. 8 : Survey based estimation 2022 (Compared Categories Only)

Unexpected Outages	788.15 LKR/kWh
Expected Outages	663.33 LKR/kWh
Combined	740.27 LKR/kWh

11. Software Implementation

11.1 Introduction

In this chapter, we introduce a simple software solution designed to easily calculate the 'Cost of Energy Not Served' using predefined values and input economical parameters, following the methodologies outlined in the report. The software offers a user-friendly platform for efficiently computing the Cost of Energy Not Served. This chapter provides a brief explanation of the software's features and usage.

11.2 Features

The current key features of the software can be listed as follows which is designed to simplify and enhance the estimation process of the Cost of ENS.

- Calculation of Cost of ENS: The software can efficiently calculate the Cost of ENS, aligning with the methods detailed in the report's section on "Estimate Cost of Energy Not Served using Analytical Data." This calculation can be performed for either the entire island, sector, or individual subsectors.
- Local Value Storage: Users can save their calculated values locally, allowing for easy retrieval and reference to prior computations.
- Input Data Storage: The software includes the capability to store input data for various years. This feature facilitates the comparison and analysis of energy-related data across different timeframes.

11.3 Process

The software's process is initiated following the last calculation, where it calculates the combined Cost of Energy Not Served (ENS) value using sectors (Domestic, Commercial, and Industrial) as follows:

1. Start Point: The process begins with the last calculation, which calculates the combined Cost of ENS value.
2. Input Sector Data: Users are required to input data related to the sectors, including Domestic, Commercial, and Industrial. This data serves as the basis for calculating combined values. Users can input this sector data manually.
3. Subsector Level Calculation: For sector data, users have the option to calculate values at the subsector level. At the subsector level, users can input required specific economical parameters, which can either be previously saved or new values.

4. Saving Calculated Values: Following the calculation of sector parameters using subsectors, users have the capability to save these calculated values. This feature allows for the preservation of data for future reference and analysis.
5. Reuse of Saved Values: The saved values can be reused in previous steps to calculate combined values, streamlining the process for future calculations.
6. Adding and Saving Parameters: Users also have the option to add and save parameters required for calculations such as corrections factors.

This process empowers users to perform calculations at both sector and subsector levels, while also providing the flexibility to save, reuse, and customize parameters, ensuring accurate and efficient estimation of the Cost of Energy Not Served. Process is also illustrated in Fig. 11. 1 as well.

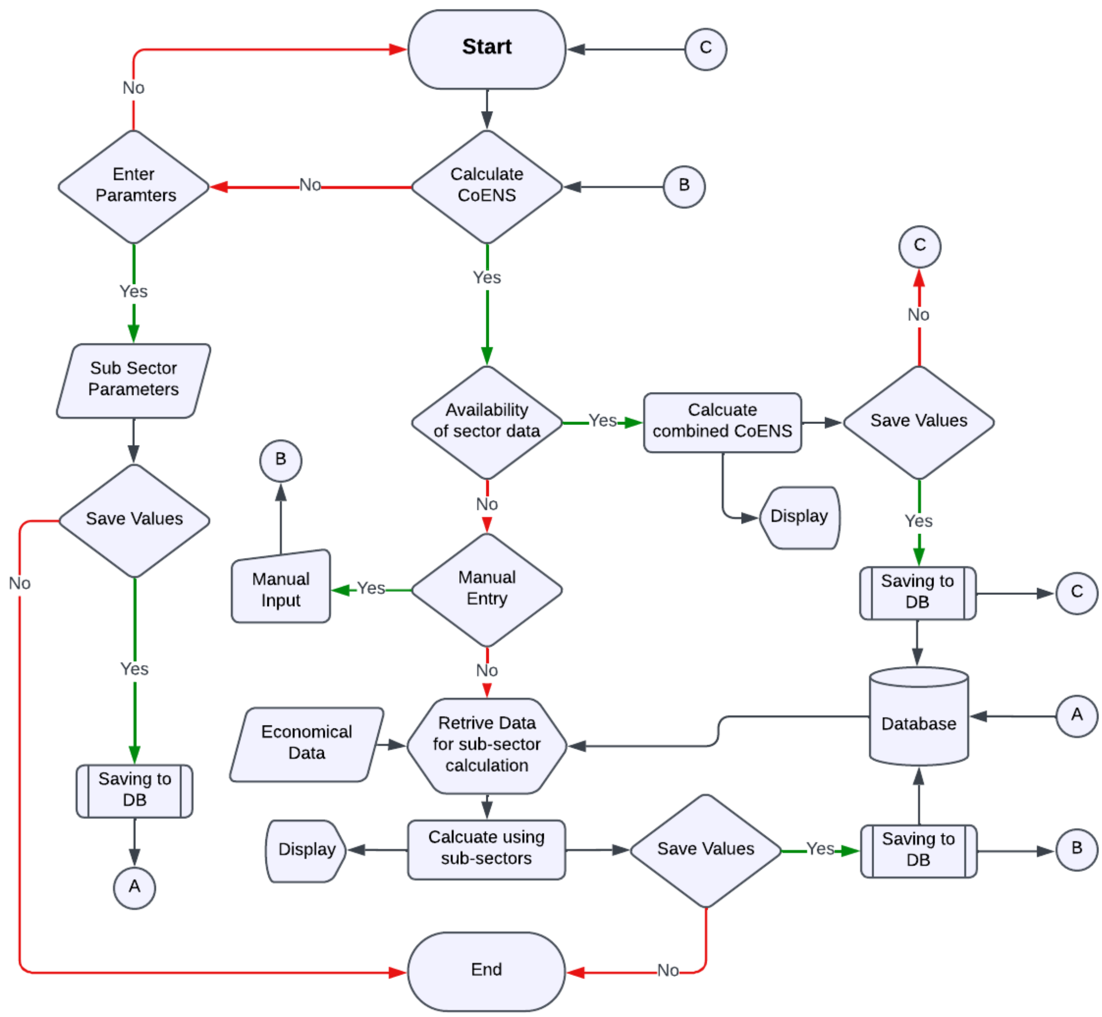
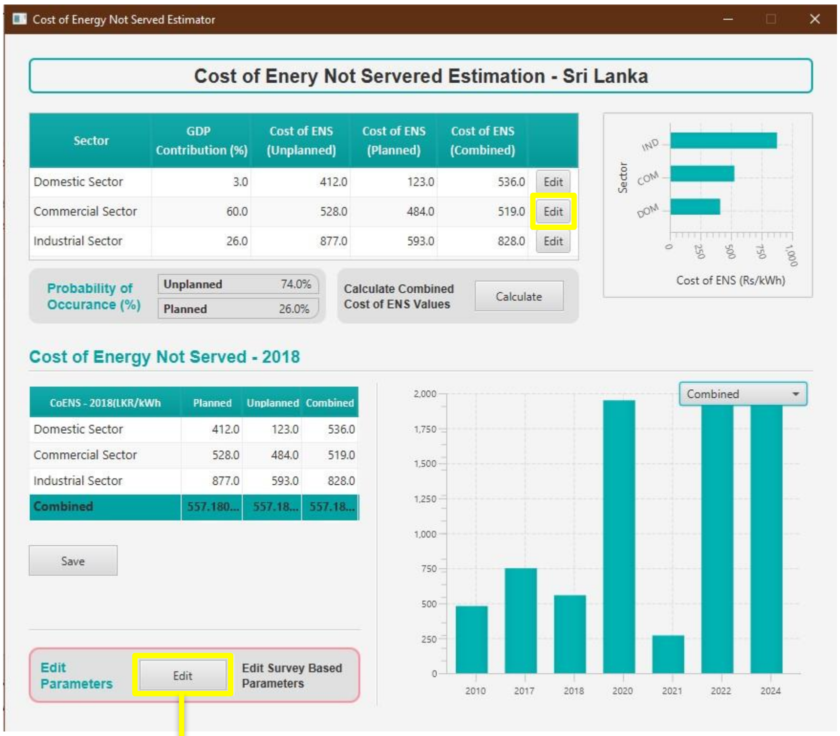


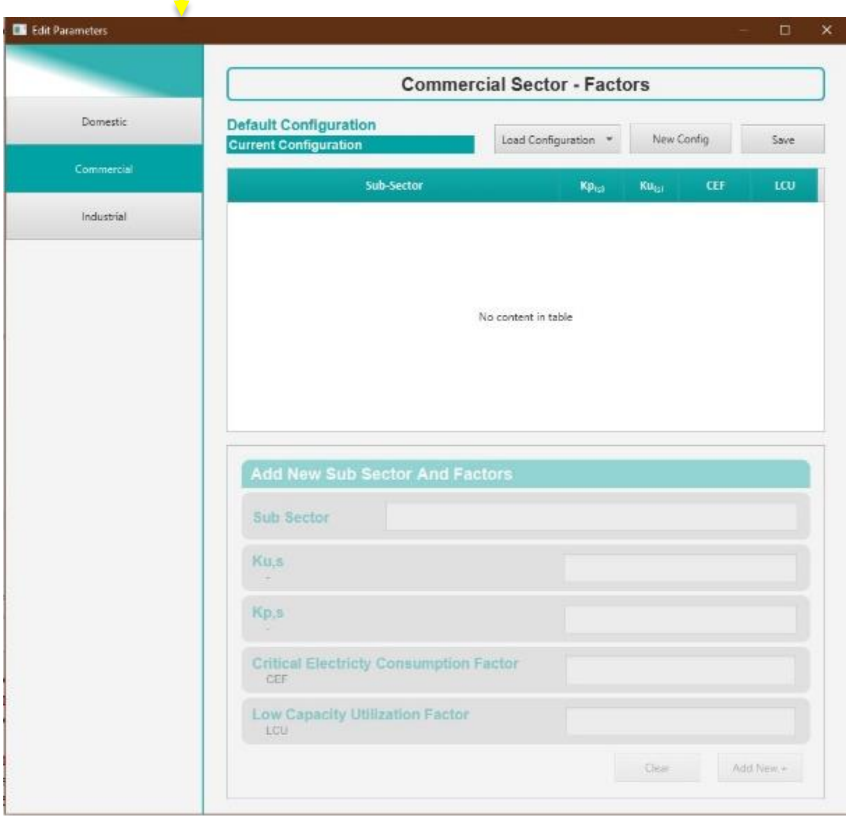
Fig. 11. 1 : Flow chart

11.4 User Interface



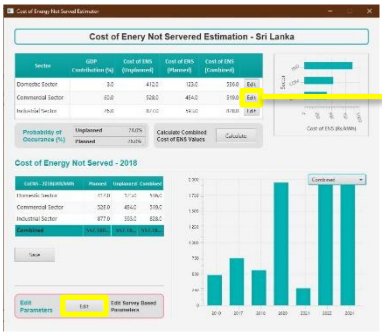
Combined values for each sector can be observed and combined value for Sri Lanka can be calculated from

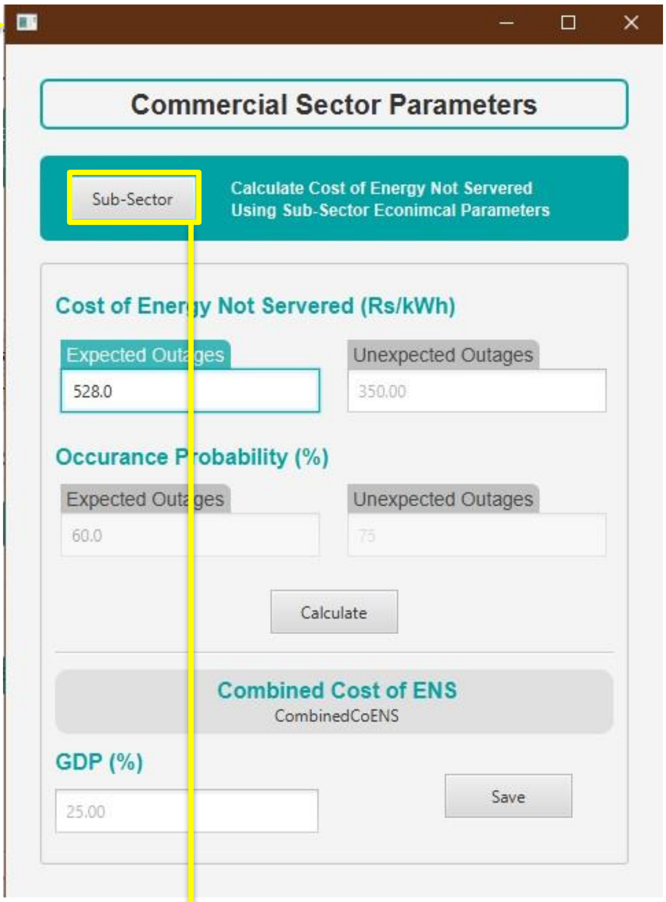
Main Menu



Survey based factors can be entered/edited in

Edit Parameter Menu



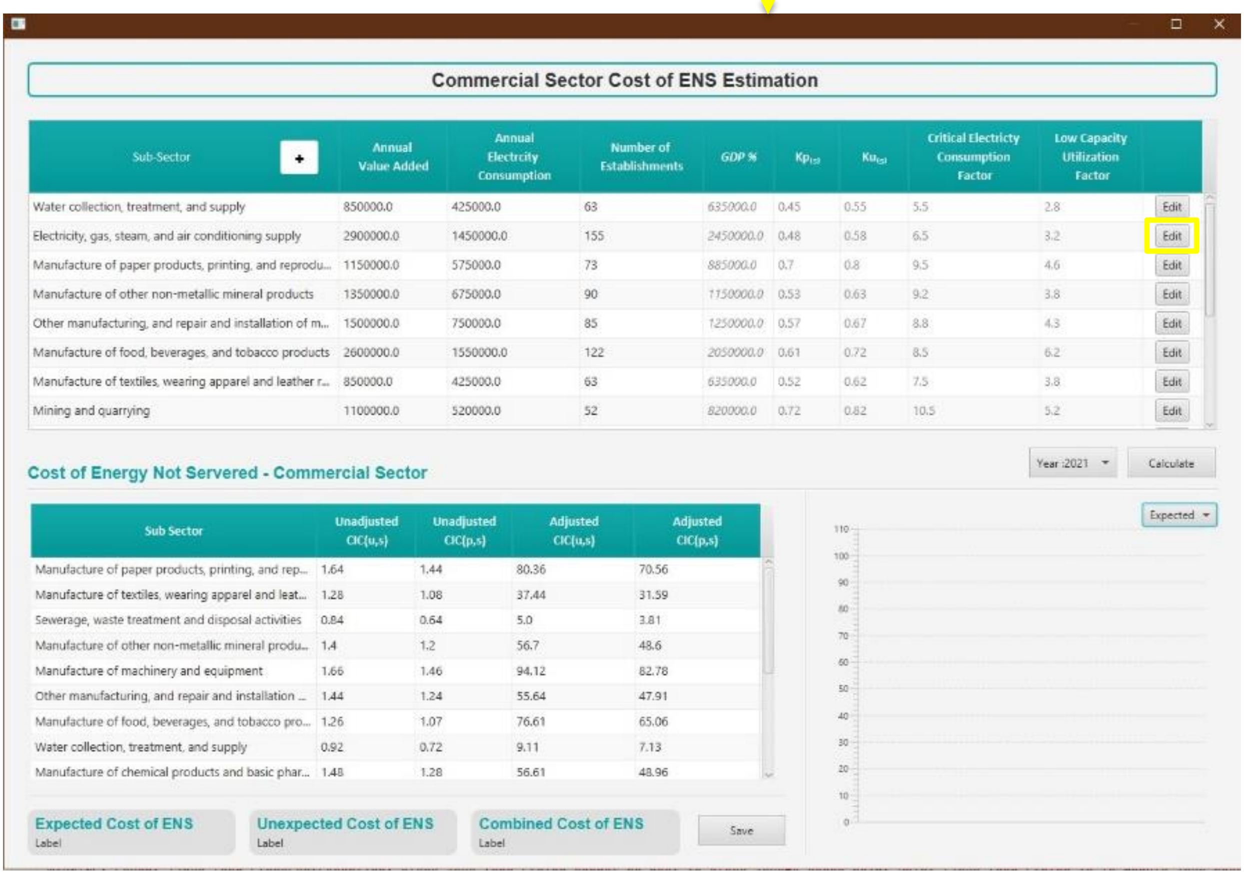


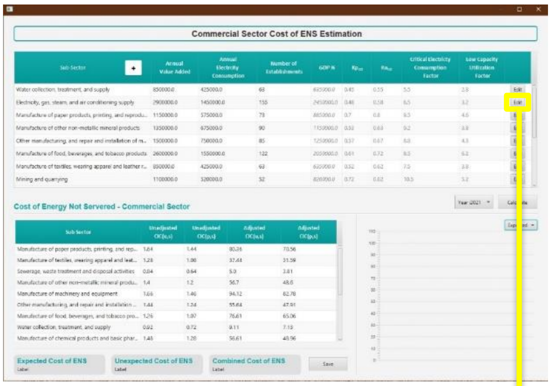
Sector parameters can be entered using,

Sector Parameter Menu

Sector parameters can be calculated using

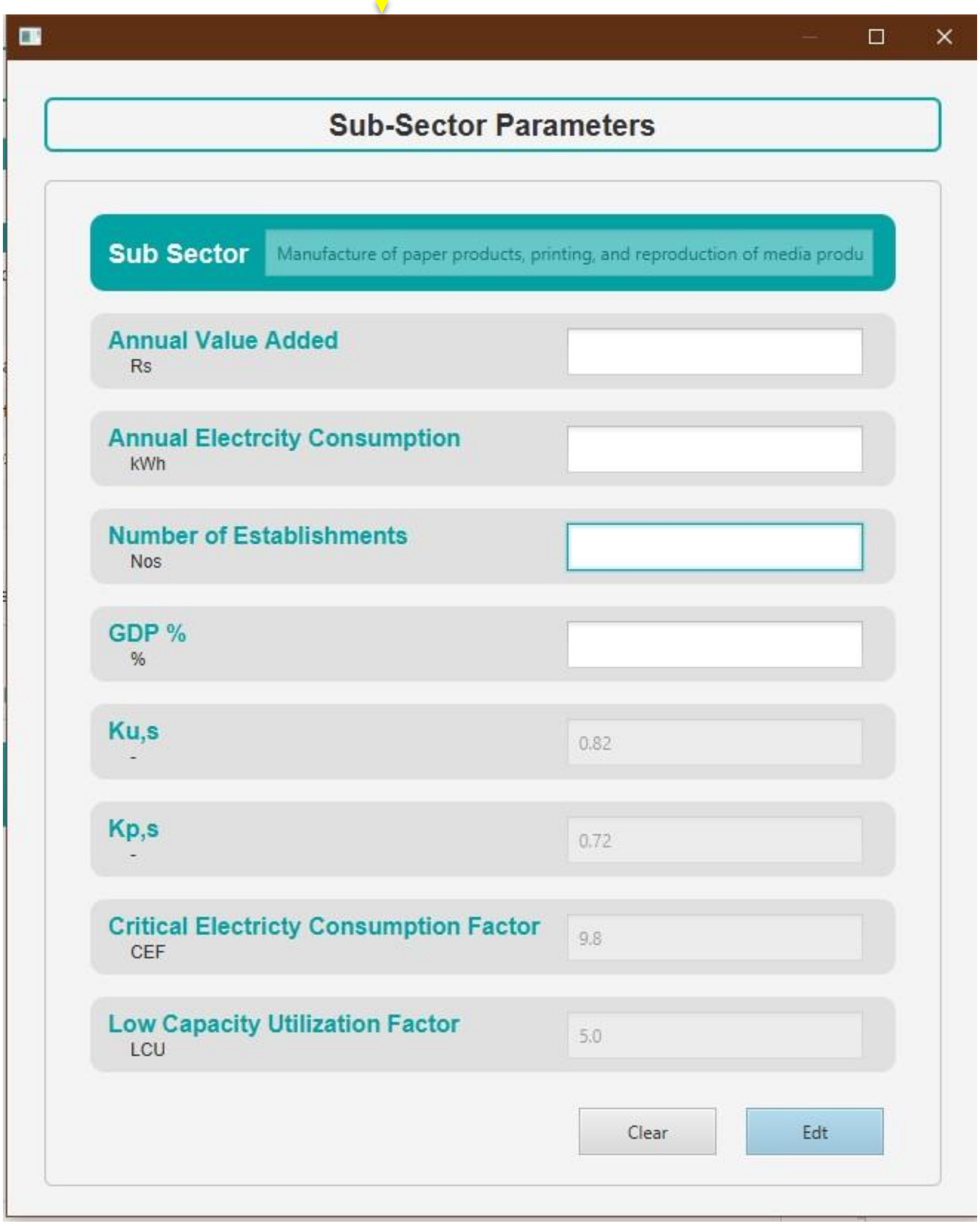
Sub Sector Menu





Sub sector parameters can be entered using,

Sub Sector Parameter Menu



11.5 Limitations

The software has certain limitations, including:

- Predefined Calculation Methods: Calculations can only be performed using the predefined methods described in this report. The software is not adaptable to custom calculation methods.
- Fixed Sectors: The software relies on data for three predefined sectors, namely Domestic, Commercial, and Industrial, to derive the final combined values. Users cannot introduce new sectors beyond these predefined categories.
- Data Requirement: To perform calculations, all required data, including sector-specific information, must be provided. There is no option to skip or bypass the input of essential data. Incomplete or missing data may result in inaccurate calculations.

These limitations define the boundaries within which the software operates and highlight the importance of adhering to the specified calculation methods and data requirements for accurate results.

12. Conclusion

In this study, the Cost of Energy Not Served (CENS) is estimated for three primary electricity consumer sectors in Sri Lanka, namely the residential, commercial, and industrial sectors. A survey-based approach is employed to obtain these estimates. Subsequently, analytical methods are applied to develop a methodology for updating the CENS, drawing insights from the survey results. It is important to note that both the survey approaches and the updating methods derived from analytical approaches are tailored to each sector's unique characteristics and the accessibility of publicly available analytical data. This report presents a comparative analysis and discussion of the survey-based estimates and the updating methods.

For the residential sector, the estimate of the CENS is obtained using a contingent valuation approach. The data collected in this process exhibits congruence with findings from similar studies conducted globally. However, it is worth mentioning that the results reveal significantly higher values compared to a previous study conducted in Sri Lanka. This variance is discussed with a focus on socio-economic factors that may contribute to the increase.

The updating method for the residential sector is derived from a production function approach. This method offers valuable insights into the economic factors driving recent trends in the CENS observed in the survey-based study. Given the limited availability of past data required for model derivation, it is recommended to update the equation whenever new survey-based CENS values for the residential sector become available.

The Cost of ENS is calculated for both the industrial and commercial sectors using a survey-based method as well as an analytical method. Cost of ENS of both expected and unexpected outages for 15 subcategories in the industrial sector and 11 for in commercial sector. Furthermore, each result from different methods is compared and thoroughly discussed. However, comparing different types of methods and studies can be a tedious task because of different reasons which are also discussed in this report.

Survey-based methods for both commercial and industrial sectors follow a similar methodology which is to collect data about the damages occurred during interruptions in both industrial and commercial customers. Both sectors collected damage due to interruption in 9 different loss categories in 5 different time durations. Following that using different factors such as probability of occurrence of an outage, GDP contribution of subsectors and electricity usage of customers the Cost of ENS is calculated for different sub sectors and ultimately combined values for commercial and industrial categories as well.

Analytical methods for both industrial and commercial categories are based on the annual value of each subsector and the average electricity consumption of those subcategories. These parameters are used to calculate the customer interruption cost functions. However, directly deriving the Cost of ENS from annual value added may result in inaccurate estimates. As a result, distinct sets of correction factors are applied in both industrial and commercial sector analytical calculations to obtain more precise Cost of ENS statistics at the end.

A combined value for the cost of unserved energy for Sri Lanka is calculated by considering the GDP contribution and calculated Cost of ENS values of each sector. However, the survey-based results are highly sensitive to customer replies to the survey questions. During the period of this study, there were planned power outages to manage the electricity demand and lockdowns due to the COVID19 pandemic. The impact of those rare circumstances may be reflected in the survey based findings.

Table 12. 1 : Summary of Survey Based Method2022 Cost of ENS Values – 2022

Industrial Sector	
Unexpected Outages	1,007.98 LKR/kWh
Expected Outages	692.94 LKR/kWh
Combined	888.78 LKR/kWh
Commercial Sector	
Unexpected Outages	657.67 LKR/kWh
Expected Outages	596.18 LKR/kWh
Combined	612.74 LKR/kWh
Domestic Sector	
Unexpected Outages	528.45 LKR/kWh
Expected Outages	480.47 LKR/kWh
Combined	516.97 LKR/kWh
Combined Cost of ENS for Sri Lanka	
Unexpected Outages	755.65 LKR/kWh
Expected Outages	620.55 LKR/kWh
Combined	690.15 LKR/kWh

References

[1] P. D. C. Wijayatunga and M. S. Jayalath, "Assessment of economic impact of electricity supply interruptions in the Sri Lanka industrial sector," *Energy Convers. Manag.*, vol. 45, no. 2, pp. 235–247, Jan. 2004, doi: 10.1016/S0196-8904(03)00132-8.

[2] D. Punsara Colambage, H. Y. Ranjit Perera, D. P. Colambage, H. Y. R. Perera, D. Punsara Colambage, and H. Y. Ranjit Perera, "Assessment of cost of unserved energy for Sri Lankan commercial sector," *MERCon 2018 - 4th Int. Multidiscip. Moratuwa Eng. Res. Conf.*, vol. 19, no. 1, pp. 253–258, 2018, doi: 10.1109/MERCon.2018.8421892.

[3] D. P. Colambage, W. H. Eranga, K. M. V. J. Senaratne, H. W. M. K. Vithanage, and H. Y. R. Perera, "Assessment of cost of Unserved Energy for Sri Lankan Industries," *SLEMA J.*, vol. 19, no. 1, p. 8, 2016, doi: 10.4038/slemaj.v19i1.13.

[4] H. Y. . Colambage, D. Punsara, Perera, "Variation of Cost of Unserved Energy depending on Interruption Duration: A Case Study for Sri Lanka," *2019 IEEE 2nd International Conference on Renewable Energy and Power Engineering, REPE 2019*. 2019.

[5] S. Kufeoglu, "Economic Impacts of Electric Power Outages and Evaluation of Customer Interruption Costs," Aalto University, 2015.

[6] J. Reichl, "Power Outage Cost Evaluation: Reasoning, Methods and an Application," *J. Sci. Res. Reports*, vol. 2, no. 1, pp. 249–276, Jan. 2013, doi: 10.9734/jsrr/2013/3167.

[7] D. Chattopadhyay, "Investigation of the value of unserved energy," 2008.

[8] ACER/ CEPA, "Study on the estimation of the Value of Lost Load of electricity supply in Europe," no. July, pp. 1–116, 2018.

[9] K. Akpeji *et al.*, "A conceptual framework for assessing the economic cost of electricity disruptions," 2018.

[10] Royal Academy of Engineering, "Counting the cost : the economic and social costs of electricity shortfalls in the UK A report for the Council for Science and Technology," 2014.

[11] S. Kufeoglu and M. Lehtonen, "A review on the theory of electric power reliability worth and customer interruption costs assessment techniques," in *International Conference on the European Energy Market, EEM*, 2016, vol. 2016-July. doi: 10.1109/EEM.2016.7521239.

[12] A. Ratha, E. Iggland, and G. Andersson, "Value of Lost Load: How much is supply security worth?," *IEEE Power Energy Soc. Gen. Meet.*, 2013, doi: 10.1109/PESMG.2013.6672826.

[13] B. E. Baarsma and J. P. Hop, "Pricing power outages in the Netherlands," *Energy*, vol. 34, no. 9, pp. 1378–1386, 2009, doi: 10.1016/j.energy.2009.06.016.

[14] A. Shivakumar, M. Welsch, C. Taliotis, M. Howells, D. Jakšić, and T. Baričević, "Estimating the socio-economic costs of electricity supply interruptions," *Rapid Response Energy Br.*, no. November, pp. 1–10, 2014.

[15] R. Castro, S. Faias, and J. Esteves, "The cost of electricity interruptions in Portugal: Valuing lost load by applying the production-function approach," *Util. Policy*, vol. 40, pp. 48–57, 2016, doi: 10.1016/j.jup.2016.04.003.

[16] G. Tollefson, E. Chan, J. Aweya, R. Billinton, and G. Wacker, "A CANADIAN CUSTOMER SURVEY TO ASSESS POWER SYSTEM RELIABILITY WORTH," *IEEE Trans. Power Syst.*, vol. 9, no. 1, pp. 443–450, 1994.

[17] K. Kivikko, A. Mäkinen, P. Järventausta, A. Silvast, P. Heine, and M. Lehtonen, "Comparison of reliability worth analysis methods: Data analysis and elimination methods," *IET Gener. Transm. Distrib.*, vol. 2, no. 3, pp. 321–329, 2008, doi: 10.1049/iet-gtd:20060532.

[18] M. Farber-Deanda, L. A. Greening, and T. Kim, "Estimates of the Value of Uninterrupted Service for The Mid-West Independent System Operator Paul Centolella SAIC Project Team."

[19] F. Carlsson and P. Martinsson, "Does it matter when a power outage occurs? - A choice experiment study on the willingness to pay to avoid power outages," *Energy Econ.*, vol. 30, no. 3, pp. 1232–1245, 2008, doi: 10.1016/j.eneco.2007.04.001.

[20] London Economics, "The Value of Lost Load (VoLL) for Electricity in Great Britain: Final report for OFGEM and DECC," 2013.

[21] G. Wacker, E. Wojczynski, and R. Billinton, "COST METHODOLOGY AND RESULTS-A CANADIAN RESIDENTIAL SURVEY," 1983.

[22] T. Schröder and W. Kuckshinrichs, "Value of lost load: An efficient economic indicator for power supply security? A literature review," *Front. Energy Res.*, vol. 3, no. DEC, pp. 1–12, 2015, doi: 10.3389/fenrg.2015.00055.

[23] C. Growitsch, R. Malischek, S. Nick, and H. Wetzel, "The Costs of Power Interruptions in Germany: A Regional and Sectoral Analysis," *Ger. Econ. Rev.*, vol. 16, no. 3, pp. 307–323, 2015, doi: 10.1111/geer.12054.

[24] M. de Nooij, C. Koopmans, and C. Bijvoet, "The value of supply security. The costs of power interruptions: Economic input for damage reduction and investment in networks," *Energy Econ.*, vol. 29, no. 2, pp. 277–295, 2007, doi: 10.1016/j.eneco.2006.05.022.

[25] M. Munasinghe and M. Gellerson, "ECONOMIC CRITERIA FOR OPTIMIZING POWER SYSTEM RELIABILITY LEVELS.," *Bell Journal of Economics*, vol. 10, no. 1. pp. 353–365, 1979. doi: 10.2307/3003337.

[26] M. Munasinghe, "Costs Incurred by Residential Electricity Consumers Due to Power Failures," *J. Consum. Res.*, vol. 6, no. 4, p. 361, 1980, doi: 10.1086/208779.

[27] Dimuthu Punsara Colambage, "ASSESSMENT OF COST OF UNSERVED ENERGY FOR SRI LANKA," University of Moratuwa ,Sri Lanka, 2018.

[28] CEB, *Statistical Digest 2019*. 2019.

[29] S. Singh, Ajay and M. B. Masuku, "Sampling Techniques & Dertermining Sample Size in Applied Statistics Research: an Overview," *Int. J. Econ. Commer. Manag.*, vol. II,

no. 11, pp. 1–22, 2014.

[30] F. Carlsson and P. Martinsson, “Willingness to Pay among Swedish Households to Avoid Power Outages: A Random Parameter Tobit Model Approach,” *Energy J.*, vol. 28, no. 1, pp. 75–89, 2015.

[31] P. Teansri, P. Bhasaputra, and W. Pattaraprakorn, “Development composite customer damage function using the customer survey based method for power system reliability planning,” *ECTI Trans. Electr. Eng. Electron. Commun.*, vol. 10, no. 1, pp. 42–50, 2012.

[32] P. D. C. Wijayatunga and M. S. Jayalath, “Economic impact of electricity supply interruptions on the industrial sector of Bangladesh,” *Energy Sustain. Dev.*, vol. 12, no. 3, pp. 5–12, 2008, doi: 10.1016/S0973-0826(08)60433-0.

[33] K. Kim and Y. Cho, “Estimation of power outage costs in the industrial sector of South Korea,” *Energy Policy*, vol. 101, no. December 2016, pp. 236–245, 2017, doi: 10.1016/j.enpol.2016.11.048.

[34] J. E. Bartlett II, J. W. Kotrlik, and C. C. Higgins, “Determining appropriate sample size in survey research,” *Inf. Technol. Learn. Perform. J.*, vol. 19, no. 1, pp. 43–50, 2001.

[35] S. Kufeoglu and M. Lehtonen, “A comparison of direct worth and relative worth studies for outage cost estimations in industry sectors,” *Proc. 2015 IEEE Innov. Smart Grid Technol. - Asia, ISGT ASIA 2015*, 2016, doi: 10.1109/ISGT-Asia.2015.7386998.

[36] Department of Census & Statistics, *2019 ANNUAL SURVEY OF INDUSTRIES*. 2019.

[37] Sri Lanka Sustainable Energy Authority, “Energy Balance 2018,” 2018.

[38] Ceylon Electricity Board, “Ceylon Electricity Board SALES AND GENERATION DATA BOOK 2017,” *Www.Ceb.Lk*, 2017.

[39] Lanka Electricity Company (Private) Limited, “Statistical Digest 2018,” 2018.

[40] S. Kufeoglu and M. Lehtonen, “A Novel Hybrid Approach to Estimate Customer Interruption Costs for Industry Sectors,” *Engineering*, vol. 05, no. 10, pp. 34–40, 2013, doi: 10.4236/eng.2013.510a006.

[41] CENTRAL BANK OF SRI LANKA, “CENTRAL BANK OF SRI LANKA ANNUAL REPORT 2019,” 2019.

[42] Department of Census and Statistics, *Trade & services 2019*. 2019.

[43] F. Report, “Energy consumption of the tertiary sector (trade, commerce and services) in Germany for the years 2011 to 2013,” no. February 2015, 2013.

[44] International Energy Agency, “Energy Efficiency Indicators Database,” *Energy Efficiency Indicators Database*, 2021. https://www.iea.org/reports/energy-efficiency-indicators-database

[45] M. A. Wilson, E. J., & Brown, “American Council for an Energy-Efficient Economy,” *Energy efficiency policy progress across the United States in 2020*. https://www.aceee.org/research-report/a211