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RESEARCH ARTICLE

Transmission Outage Cost Analysis Using Value of Loss Load Approach Based on Macro-Economic Data

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Abstract

Value of Loss Load (VoLL) is a crucial parameter used in economic evaluations of electric power systems. VoLL represents the value of losses incurred by customers in the event of electricity service interruption. The size of the VoLL has a significant influence on investment decisions for policymakers and electricity management. A low VoLL necessitates a low level of reliability, while a high VoLL requires a high level of reliability. However, there has been no quantitative measurement of the impact of electricity disturbances on the macroeconomic in West Nusa Tenggara, which includes the Lombok System and the Sumbawa-Bima System. West Nusa Tenggara plays a vital role in supporting the national economy, particularly in the tourism industry segment. Hence, the aim of this research is to analyze West Nusa Tenggara transmission outage costs using the VoLL approach and predict VoLL for 2024 – 2030 by trend analysis. VoLL calculations using a macroeconomic approach are derived from the GRDP ratio of sectors influenced by electricity to the electrical energy consumption of industrial and business customers. The research results reveal that the VoLL of the Lombok System is lower than that of the BimaSumbawa System. Outage costs resulting from disruptions on the Transmission System side impact GRDP by 0.001% per year. The VoLL trend for 2024 – 2030 is projected to experience an average decline of 2.29% per year, indicating high growth in electricity demand, proportional to the increase in GRDP. These results should be taken into consideration in the execution of the 2021 - 2030 Electricity Supply Business Plan, especially in West Nusa Tenggara.

Keywords: value of loss load, outage cost, macroeconomic

1. Introduction

Electricity has become an important part of modern society [1]. Indeed, modern industrial society is so reliant on electricity that electricity can be considered a crucial input factor for all economic activities [2]. In [3] it is stated that interruptions of electricity services disrupts business operations in all sectors simultaneously. Indeed, power outage accidents will cause huge economic losses to the social economy [4]. Therefore it is very clear that both the security of electricity and the sufficiency of electricity infrastructure have become fundamental needs for modern society. However, currently, the electricity security system is facing serious threats due to natural disasters, network cyber attacks, and climate change [5].

From an economic perspective, it can be said that all economic activities stop when there is no electricity. To find out how much influence the availability of electrical energy has on the economy, quantity parameters are needed. Value of Lost Load (VOLL) is a useful quantity parameter in the economic evaluation of electric power systems. VoLL can be represented as the value of losses borne by customers in case of electricity service interruptions [6] or the average value of electricity consumers' willingness to pay to avoid additional time without electricity.

In several countries, VoLL is also a useful concept when designing energy markets, as it allows economic evaluation of security measures and quality of electricity distribution [7]. Moreover, VoLL is an electricity industry metric intended to capture the social benefits of reduced power outages in fiscal terms [8].

For policymakers and electricity management, the size of the VoLL would affect decisions regarding investment in new generating capacity and closing older, less efficient power plants [9]. It is a useful value for planning the total cost of electricity supply capacity [10]. Furthermore, VoLL is also a necessary criterion for transmission systems reliability management which represents the cost of energy that has not been served due to electrical disturbances [11]. Hence, VoLL can be used as a benchmark or parameter that defines reliability and a financial measure to justify any investment that meets higher expectations [12].

In this research, the outage cost analysis only focuses on transmission system disruptions and VoLL for industrial-business customers in West Nusa Tenggara. The choice of research location was because the West Nusa Tenggara Electricity System, especially the transmission system, was increasingly developing. Even though it is said to be a much smaller system than the Jamali System, the system in Nusa Tenggara has an important role in supporting the country's economy in the tourism segment where there is one of the five Super Priority Destinations, namely Mandalika. Moreover, regularly there are annual Moto GP and World Super Bike agenda. In this paper, air transportation and the Information & Communication sector of GRDP and priority consumers are taken into account, which is previous research [12] [13] was not taken into account.

The goals of this research is to provide information on transmission outage costs and their impact on GRDP. Secondly, it measures VoLL which can then be taken into consideration in planning to improve the reliability and continuity of the Transmission System in West Nusa Tenggara.

2. Value of Loss Load and Trend Analysis

2.1 Value of Loss Load

VoLL is a financial indicator expressing the costs identical with an electricity supply interruption. A high VOLL may be used as an indicator that a particular sector should be equipped with an emergency backup system due to the potentially very high disruption costs [14]. Based on [8] the VoLL could be measured by three main approaches :

2.1.1 Proxy / Macroeconomic Modeling

This method involves taking the ratio of the gross economic product of a geographic area (e.g. Gross Domestic Product ("GDP") or Gross Value Added ("GVA")) and the electricity consumption of industrial and commercial consumers in that region. While it is generally believed that the GVA method is a good starting point for VoLL estimation for I&C consumers, the method has identified drawbacks as it can often give curiously high VoLL estimates for some industries with low electricity usage [15].

2.1.2 Survey-based Strategies Survey

This method is carried out by direct or indirect interviews with individuals or businesses to provide subjective estimates of specific VoLL according to them. The most frequent approach for the housing sector is stated preferences methodology (also known as contingent valuation) in which researchers develop hypothetical power outage scenarios and ask survey participants to provide how much they are willing to pay in an effort to avoid a power outage.

2.1.3 Revealed preferences

The two approaches above are hypothetical and/or too aggregated in calculating outage costs, then the revealed preference strategy aims to analyze decisions of market behavior by electricity consumers to conclude VoLL. This method uses an approach based at least on actual consumer choices that takes into account internalized outage costs and associated budget constraints that may limit the procurement of a more reliable electricity supply. There are three mechanisms used, namely : Interruptible contracts, Mitigation investments, and Demand-curve estimation.

The research specifically selected the macroeconomic approach method for its simplicity in providing benchmarks and points of comparison. Most of the necessary administrative data can be collected at a low cost by researchers and decision-makers in the electricity industry. Additionally, having aggregate and social estimates of VoLL is crucial for electricity system planning due to its network nature. The results derived from this macroeconomic approach are broadly applicable to the entire electricity grid given its extensive geographic coverage.

2.2 Trend Analysis

Trend analysis is a method of statistical analysis that is often applied to identify and analyze patterns, trends, or changes in data over time. This method requires examining historical data to reveal trends in a particular phenomenon. Several fields applied trend analysis, including science, marketing, finance, and economics, to make an outlook as a reference for considering decisions based on past data.

Trend analysis techniques include:

(a) Time Series Data or data collected and recorded from observation or measurement activities over consecutive time intervals. It can be daily, monthly, yearly, and so on.
(b) Data Visualization such as line charts or graphs to describe patterns and over time trends
(c) Identify trend patterns, or recurring cycles, whether they show increases, decreases, or are cyclical.
(d) Statistical methods are used to measure and analyze trends. This may include moving averages, regression analysis, or other time series analysis techniques.
(e) Extrapolate and make potential future value or outcomes predictions.

A trend model can be expressed as follows :

$$T_t = g\left(Time_t\right) \quad (1)$$

Where Timet is the time index. Most common models of trend analysis are : Linear Trend, Quadratic Trend Exponential Trend, and Trends with Changing Slope.

3. Value of Loss Load Based on Macro-Economic

There are several data used in this research: West Nusa Tenggara Gross Regional Domestic Product (GRDP) data for 2020 - 2024 which was taken directly from the official BPS website, Electrical Energy Sales data, and Energy Not Served (ENS) from the national electricity company along the 2021 - 2030 Electricity Supply Business Plan (RUPTL) document. Figure 1 is the research flowchart employed in this paper.

3.1 VoLL Calculation 2020 – 2023

In this research, VoLL calculation uses an indirect measurement techniques framework with a macroeconomic approach, where the data used is GDP and energy consumption. This method is a production function approach that considers the macroeconomic value-added and electricity consumption as a ratio representing VoLL:

$$VOLL_{ic} = \frac{GDP_{ic}}{EC_{ic}} \quad (2)$$

where *GDP* represents the annual Gross Value Added (in Rp) of sector i in a province/-country c and *EC* is the annual electricity consumption in kilowatt-hours (kWh).

Not all GDP data is calculated. GDP data is used only for sectors that are affected by electricity availability. Generally, GDP is divided into 17 categories [16]. Study [13] used the categories manufacturing, electricity, gas, clean water, commerce, accommodation, finance, rentals, and services as industrial–business customers. In this paper, air transportation and the Information & Communication sector are added. The GRDP grouping results are displayed in Table 1. Industrial - business consumers

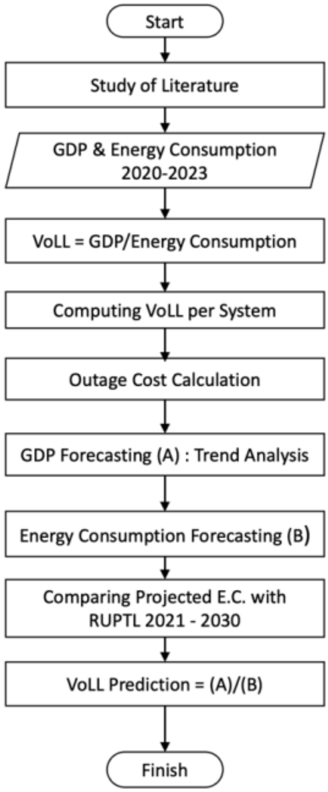

Figure 1. Research Flowchart

electrical energy consumption in 2020 – 2023 in West Nusa Tenggara can be seen in Table 2.

Table 1. GRDP Constant Price Affected by Electricity

No	Sector	2020	2021	2022	2023
1	Industry	4,351.56	4,442.86	4.530,84	4.644,52
2	Electricity and gas	85.80	103.21	112,97	118,67
3	Water	76.03	76.41	78,95	80,41
4	Commerce	12,908.89	13,131.49	13.781,64	14.737,70
5	Acco & Trans.	6,101.14	6,198.10	6.978,85	7.418,60
6	Finance	3,688.04	3,849.76	3.865,08	3.818,83
7	Information	2,655.52	2,787.64	2.874,68	3.014,95
8	Business	167.69	168.25	182,37	195,86
9	Education	4,609.53	4,686.35	4.832,86	5.080,27
10	Health	2,041.56	2,202.13	2.256,48	2.392,52
11	Other Service	2,076.40	2,110.63	2.333,13	2.484,71
		38,762.16	**39,756.83**	**41.827,85**	**43.987,04**

Table 2. Energy Consumption for Industry and Business

No	Consumer	Energy Consumption for Industry and Business (GWh)			
		2020	2021	2022	2023
1	Business	337.15	349.39	409.67	458.79
2	Industry	193.57	230.67	237.56	272.78
		530.72	**580.06**	**647.23**	**731.57**

3.2 VoLL Calculation Per System

West Nusa Tenggara Province has 2 large islands, each of which has a high voltage system, namely the Lombok System and the Sumbawa – Bima System. The two systems are not interconnected. GRDP calculation per system based on government administrative areas. Meanwhile, energy consumption data, especially for business and industrial consumers, is based on Consumer Service Unit data. This data will be used to compute VoLL per system.

Table 3. GRDP and Energy Consumption per System 2023

System	GRDP (Billion Rp)	Energy Consumption (GWh)
Lombok	31,246.04	520.65
Sumbawa - Bima	12,741.00	210.91
	43,987.04	**731.57**

3.3 Outage Cost 2021 – 2023

Next, after obtaining the VoLL and ENS, the costs incurred due to transmission system outage (O_{ict}) are calculated using the following equation:

$$O_{ic} = VOLL_{ic} \bullet INS_{ict} \tag{3}$$

The results of O_{ict} will be analyzed regarding the impact of disturbances on GRDP through a linear regression equation where GRDP and EC are the dependent variable and independent variable, respectively.

3.4 VoLL Forecasting 2024 -2030

In carrying out VoLL predictions, the method used is trend analysis which is determined by calculating 3 forecast error parameters, namely, Mean Absolute Deviation (MAD), Mean Square Deviation (MSD) dan Mean Absolute Percentage Error (MAPE).

$$MAD = \frac{1}{n} \sum \Sigma_n^t \left| Y_t - Y_t' \right| \tag{4}$$

$$MSD = \frac{\sum_{t=1}^{n} |Y_t - Y_t'|^2}{n} \quad (5)$$

$$MAPE = \frac{1}{n}\sum_{t=1}^{n} \frac{|Y_t - Y_t'|}{Y_t} \quad (6)$$

where y_t is real value of t period, Y_t' is forecast for $_t$ period and n is the number of periods of data. After obtaining the best analysis method based on the 3 (three) parameters above, forecasting of GRDP and Electricity Consumption is carried out until 2030.

Subsequently, refer to [13] demand forecast is computed based on the number of consumers and energy intensity. Equation (7) represents the energy intensity variable and its growth average is formulated in (8). The number of consumers variable contains data on the number of consumers in a certain period and the average consumer growth can be expressed in (9), where n is the amount of data.

$$Energy\ Intensity\ (EI) = \frac{Energy\ Consumption}{Customer} \quad (7)$$

$$Energy\ Intensity\ (EI) = \frac{\sum_{t=1}^{n} EI}{n} \quad (8)$$

$$Energy\ Intensity\ (EI) = \frac{\sum_{t=1}^{n} Customer}{n} \quad (9)$$

Based on data on energy consumption 2020 – 2023, Table 4 is the result the growth.

Table 4. Growth of Energy Intensity and Consumer

	Social	Resident	Business	Industry	Government
EI	7.76%	-3.25%	9.66%	27.04%	-2.94%
Consumer	5.65%	6.43%	1.73%	-7.20%	3.38%

The result of this forecasting would be compared to RUPTL 2021 – 2023 prediction [17], which is it forecasting energy consumption using the capacitive balance method.

4. Result and Discussion

4.1 VOLL Calculation for 2020 – 2023

Table 5 is the result of VoLL calculations for 2020 – 2023. From year to year, VoLL can be seen decreasing with an average decrease of 6.28 % /year. This is due to the increase in electrical energy consumption being higher (11.3% / year on average) than the increase in GRDP (4.31% / year). This also indicates an improvement in the quality of electricity services in NTB, both generator and transmission readiness.

Further, from Table 5 a linear regression is carried out, which is GRDP is Y and Energy Consumption is X with the following linear equation as follow :

$$Y = 24.53\ x\ 10^{12} + 26.59\ x\ 10^{3}\ X \quad (10)$$

with R^2 = 0.99 and Significance < 0.00189.

Table 5. VoLL Calculation Result for 2020 - 2023

Year	GRDP (Billion Rp)	Energy Consumption (GWh)	VoLL (Rp/kWh)
2020	38,762.16	530.72	73,036.99
2021	39,756.83	580.06	68,538.84
2022	41,827.85	647.23	64,625.93
2023	43,987.04	731.57	60,127.15

4.2 VOLL Calculation per System

The VoLL calculation results for each system in Table 6 show that the VoLL for the Lombok System is smaller than the Sumbawa Bima System. This is clear because Lombok Island is the location of the provincial capital with higher economic activity. Meanwhile, the high VoLL of the Sumbawa-Bima system indicates that electrical energy consumption and GRDP are not as large as Lombok Island. On the reliability side, the level of system reliability is also below the Lombok System where the transmission sections in the Sumbawa-Bima System are still radial (N-2 condition is not met). However, the VoLL of the Lombok System in 2022 will increase by 0.34%, whereas in this period the Lombok System is on standby because the minimum reserve generator capacity is not met.

Table 6. VoLL Calculation Result for each System in 2023

System	VoLL (Rp/kWh)		
	2021	2022	2023
Lombok	63,90512	64,125.14	60,013.23
Bima - Sumbawa	79,961.85	65,860.47	60,408.35

4.3 Outage Cost

Using equation (2), table 7 shows the costs of outages due to system disruptions from 2021 – 2023. The total costs for this period reached IDR 37,57 billion or IDR 12,52 billion / year.

Table 7. Outage Cost Calculation Result for 2021 - 2023

Tahun	ENS (kWh)	Outage Cost (Rp. Million)
2021	142,481	9,765.48
2022	146,522	9,469.12
2023	304,968	18,336.85

By using the (10) where X is the sum of actual energy consumption and ENS, then potential GRDP without transmission interruption is obtained. Then, from deviation between Potential GRDP and actual GRDP signifies that the ENS had a decreasing impact of 0.0011% on GRDP. Even though the impact is relatively very low, it still shows that electricity reliability affects the economy

4.4 NTB VoLL Prediction for 2024 – 2030

Because GRDP data is clustered as long-term data had a trend pattern, the periodic series method used for future outlook is a trend analysis. Moreover, several models are resolved by error prediction criterion's evaluation which is mentioned in (3.4) i.e. MAD, MSD, and MAPE. The smallest value of each criterion of the simulation results in Table 8 is the quadratic model a which is then selected. Minitab 18 simulation results The GRDP prediction using a quadratic model is depicted in Figure 2.

Table 8. Outage Cost Calculation Result for 2021 - 2023

Parameter	Linear	Quadratic	Exponential
MAD	291.1	98.8	253.2
MSD	96,962.9	12,206.2	76,464.5
MAPE	0.7	0.2	0.6

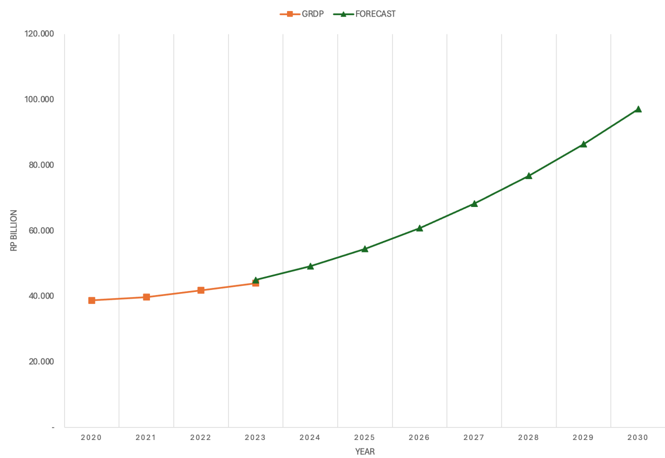

Figure 2. GRDP prediction with a quadratic trend model

To obtain energy consumption predictions, energy consumption data and the consumer number per sector are needed. The variables used in this forecasting are the percentage of consumer growth and energy intensity in Table 4. Further, energy consumption predictions were calculated using Excel, and the results are shown in Figure 3.

From the comparison of Table 9, the energy consumption prediction results show that it does not exceed the prediction number of [17], so this data can be used. The deviation from these two data is because RUPTL uses an optimistic scenario, namely an average growth in energy consumption of 9%. Hereinafter, sequentially, prediction

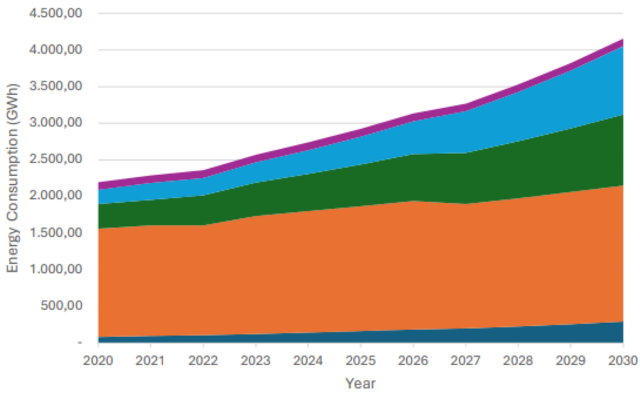

Figure 3. Total Energy Consumption prediction

Table 9. Outage Cost Calculation Result for 2021 - 2023

Data	Total Energy Consumption (GWh)						
	2024	2025	2026	2027	2028	2029	2030
RUPTL [17]	3,028.3	3,277.2	3,544.4	3,818.4	4,113.6	4,427.6	4,745.1
Forecasting Result	2,740.0	2,926.1	3,133.5	3,270.1	3,530.9	3,824.6	4,156.0

data of 2024 – 2030 industrial – business sectors' energy consumption and VoLL are shown in Table 10 and Table 11.

Table 10. Industry and Business Energy Consumption Prediction for 2024 - 2030

No	Consumer	Energy Consumption for Industry and Business (GWh)						
		2024	2025	2026	2027	2028	2029	2030
1	Business	511,81	570,96	636,94	698,47	779,19	869,24	969,70
2	Industry	321,59	379,12	446,96	567,80	669,39	789,16	930,35

Table 11. VoLL Prediction Result for 2024 - 2030

Year	GRDP (Billion Rp)	%	Energy Consumption (GWh)	%	VOLL (Rp/kWh)
2024	49,198.94	11.8	833.39	13.9	59,034.40
2025	54,499.01	10.8	950.08	14.0	57,362.44
2026	60,875.43	11.7	1,083.90	14.1	56,163.35
2027	68,328.20	12.2	1,266.27	16.8	53,960.16
2028	76,857.32	12.5	1,448.58	14.4	53,056.87
2029	86,462.79	12.5	1,658.40	14.5	52,136.22
2030	97,144.61	12.4	1,900.05	14.6	51,127.27

Table 11 shows that the increase in GRDP is in line with the increase in electricity use, even though the GRDP average growth is lower than the energy consumption average growth. This has an impact on decreasing VoLL. As stated in [11] a high VOLL calls for a high reliability level and a low VOLL for a low reliability level. The estimated trend for the Value of Lost Load (VoLL) from 2024 to 2030 shows a projected average annual decrease of 2.29%. This indicates a consistent growth in demand each year, emphasizing the importance of planning for electricity infrastructure development to improve the quality and reliability of electricity supply.

5. Conclusion

The research drew three conclusions. First, the VoLL (Value of Lost Load) in the Lombok System is lower than in the Bima-Sumbawa System. This is due to higher electricity consumption in the Lombok System, particularly for industry and business, and the reliability of the Transmission System. Currently, the Sumbawa-Bima transmission system is still radial. Second, the total outage costs due to disruptions on the Transmission System amounted to IDR 12.52 billion per year and had a side effect on the GRDP of 0.001% per year. Outage costs are affected by the ENS (Energy Not Supplied), where the determining factor for the magnitude of the ENS is the duration and frequency of outages. Third, the trend of the VoLL from 2024 to 2030 is estimated to decrease by an average of 2.29% per year. This indicates a potential continuous growth in demand every year, highlighting the need for electricity infrastructure development planning to enhance the quality and reliability of electricity availability.

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