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RESEARCH ARTICLE

Application of Spatial Methods in Predicting Electricity Demand Based on Small Islands in Sebatik Island Divided by Two Countries

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Abstract

Indonesia, as the largest archipelagic country in the world, also has several outer islands. Sebatik Island is one of the 92 outer small islands of Indonesia, located in a strategic position as it borders Malaysia. Various needs of society, one of which is electricity, are very important for people's lives and economic development. Thus, the goal is for all households in Indonesia to have access to electricity by 2024, with both the electrification rate and the ratio of electrified villages reaching 100%. An electricity plan is also necessary to help ensure that electricity is distributed fairly and equitably throughout Indonesia. Load prediction is an essential aspect of the load side of the electric power system that requires careful planning. Machine learning methods are not suitable for application in load prediction analysis in remote areas of small islands, which have limited space. Therefore, this research presents an alternative approach, specifically the spatial method utilizing (RTRW) documents. The application of this spatial method is intended to offer an overview of electricity load predictions that are more aligned with the actual situation. This spatial method analyzes the area size with land use development patterns according to local policies, multiplied by the standard definition of an activity in each spatial unit. Thus, an estimate of the peak load for each year is obtained, even up to ultimate conditions. The load prediction model follows the Gompertz equation, where the ultimate condition obtained is 63.55 MW, which may occur 118 years from the starting point in 2022. Choosing a 90% confidence level in the Monte Carlo simulation provides a reasonable range of predicted values. Based on this new knowledge, a country's electric utility will be able to build infrastructure and generate electricity in a more efficient manner.

Keywords: Small Outer Islands, Load Prediction, Electricity, Spatial Method, Monte Carlo Simulation.

1. Introduction

Indonesia is the largest archipelago in the world with more than 17,000 islands. There are 5 main islands including Sumatra, Java, Kalimantan, Sulawesi and Papua. Indonesia also has outer island regions such as Sebatik Island. Sebatik Island is in the province of North Kalimantan. It is one of Indonesia's 92 small outer islands and is strategically located as it borders Malaysia to the north. From the illustration above, we can see that Indonesia has a large population of people. The large population also illustrates the community's diverse needs. One of these is the need for electricity, which is very important for community life and economic growth. Based on the press release from the Ministry of Energy and Mineral Resources regarding the electrification program, it was noted that the electrification rate in 2023 will increase from 99.67% in 2022 to 99.78%, while the rate of electrified villages was recorded at 99.83%. Thus, the target is that all households in Indonesia will have access to electricity by 2024, with both the electrification rate and the ratio of electrified villages reaching 100%.

Based on the above report, a special strategy was developed to solve various problems caused by the number of islands and communities. Indonesia's plan is related to economic development, which is a priority for the Indonesian government, one of which in this case is to guarantee the reliability of electricity supply and the source of economic life is very important (Sihombing and Suwarno, 2021). Sufficient electricity is one of the key issues in the Indonesian strategy together with PT PLN (Maidin et al., 2022). This is related to the distribution of electricity evenly throughout different parts of Indonesia. The distribution of electrical energy should be designed considering economic and rational principles, especially in the next load operation. This can refer to the process of load planning, considering other components such as voltage and frequency stability. However, this component is also strongly influenced by transmission system losses (PLN, 2015).

The government, together with PT PLN, must therefore regulate electricity. One more regulation that regulates and mentions the urgency of electricity in Indonesia is the Minister of Energy and Mineral Resources Regulation Number 38 of 2016 on the Acceleration of Electrification in Undeveloped Rural, Remote, Border and Small Island Populations through the Implementation of Small-Scale Electricity Supply Business (The Ministry Of Energy And Mineral Resources, 2016). The above scheme illustrates the urgent need to accelerate electrification in the outlying small island regions of Indonesia. An Electricity Plan is also needed to help ensure that electricity becomes distributed and equitable across Indonesia.

According to X. Wang and J.R. McDonald, there are 3 important components in modern electricity planning, namely load prediction, generation, and transmission and distribution (X, Wang and McDonald, 1994). In general, electricity has 2 systems with different sides, namely the load side and also the generation side (Jabir et al., 2018). This corresponds to the modern electricity components, where load prediction is part of the load side of the power system, which is closely related to the high and low needs of the community. Another case is on the power side, which focuses on the generation/production of electricity. So, the government's efforts to provide electricity must follow the projected needs of the community and be supported by strategic plans by executing and making electricity load prediction schemes (Fadilah et al., 2021). Optimal and economical electricity load is what the community needs, especially the people in the outermost regions based on small islands in Indonesia with the support of a rational distribution system with a proven scheme (Muchtar et al., 2023). Prediction error can lead to incorrect planning; if it is too high, it will result in more electricity plants than needed, resulting in unneeded capital expenditures. Meanwhile, if it is too low, it can constrain economic growth, resulting in the installation of many expensive generators to cover the electricity shortfall, at the expense of consumers (Moon et al., 2024).

This research has gained important insights from several previous studies. Based on (Barokah and Harahap, 2024) carried out electricity load forecasting for 2022, obtained a value of 4,169.223135 (MWh) and 2023 of 4,246.966856 (MWh) using machine learning method, namely Artificial Neural Network (ANN). However, this method requires a lot of data to learn. In addition, there is another machine learning method, namely Autoregressive Integrated Moving Average (ARIMA). Meanwhile (Prastyo et al., 2021) concluded that the ARIMA method can predict large data on electricity consumption in PLN Lumajang Regency and ARIMA gets a low accuracy value. Other research by (Rohman et al., 2022) state that the results of training the Artificial Neural Network backpropagation method require an improved pattern, increasing training data (learning) and inputting as many parameter combinations as possible. Therefore, from some of the above-mentioned research, it can be concluded that this machine learning method is not adapted when applied to the analysis of the load prediction in the outer areas of small islands, where the data that can be used as a database is also limited. By reference, small islands also have limited areas with limited loads. Therefore, this research offers another method, namely the spatial method using data in the form of Spatial Planning Plan (RTRW) documents (Government Regulation of the Republic of Indonesia Number 21 of 2021, 2021; The governor of northern kalimantan, 2017), which considers land use development as a driver (Nurdin et al., 2023). The application of this spatial method is supposed to provide an overview of electricity load predictions that are more relevant to the actual situation.

The structure of this research consists of four different parts to present the results of the research properly. Firstly, the problem behind this research is described. This is followed by a detailed discussion of the methodology used to predict the existing electricity load in Indonesia, focusing on the small island outer regions. Next, the third section explains the technicalities and explores in detail the analysis of the prediction results of the proposed spatial method, supported by validation with real data in load prediction. The fourth section discusses the analysis of the results compared to other methods in case studies in small island outer regions. Finally, a closing section summarises the findings of the study and provides a detailed summary to identify potential future research.

2. Methods and Materials

2.1 Prediction of Electricity Demand in the Planning of Modern Electricity Systems

Modern electricity system planning is a complex and dynamic process that aims to ensure the availability of reliable, efficient and sustainable electricity supply (Abdin and Zio, 2019). In the digital era and globalization, this planning not only depends on traditional methods such as deterministic, but also involves the use of advanced technologies such as machine learning and artificial intelligence. These methods enable more informed decision making through historical data analysis, load prediction, and risk analysis. The modern electricity planning structure was introduced by (X, Wang and McDonald, 1994) and used as a basic concept for understanding modern electricity planning. The basis of electricity planning is the national planning document and national energy policy, then the energy policy is derived into national energy planning. Electricity planning consists of 3 aspects, namely electricity load prediction, electricity generation planning, and electricity transmission or grid planning (X, Wang and McDonald, 1994). Power plant planning is based on the results of the prediction of electricity demand. The accuracy of the load prediction or forecasting is crucial in terms of determining the optimal capacity of power plants and power grids.

One relevant approach is the spatial prediction of electricity load, which considers the geographic distribution of load and potential regional growth. In the electricity planning trilemma, three aspects of electricity planning are of concern: load, generation, and primary energy (resources) (Kalpikajati and Hermawan, 2022), (Sugiyono, 2017). .

2.2 Development of Geospatial-based Electricity Demand Prediction

The electricity load forecast is an important process in power system planning and management. Using advanced technology and extensive data, electricity load demand prediction assists electricity system operators in planning generation capacity, managing energy distribution, and ensuring the reliability of electricity supply to support future demand. In general, electricity load prediction methods are classified into 2 main approaches, namely subjective approaches and objective approaches (Flores and White, 1989; Homar and Stensrud, 2008). The objective approach is a load prediction approach based on multiple drivers that form a mathematical model of load prediction. This approach can be further divided into 2 methods, namely time series method and causality method (Syofian and Sanjaya, 2022). Geospatial-based electricity load prediction in this study uses the causality method, which is a load prediction method based on a mathematical model that shows the load relationship with a certain independent variable known as the spatial method. Changes in the value of these variables will have an impact on changes in the value of load, which is the independent variable in the mathematical model formed.

Spatial load prediction is based on a paper written by Van Wormer around 1954 (Van Wormer, 1954). In the paper, Van Wormer proposed load prediction or electricity load prediction that considers the location where the load is located. The load prediction model that considers the location where the load is located was further developed by Lee Wilis to predict the electricity load in the distribution system (Willis, 2002). The load prediction model was introduced as a spatial load prediction model. Spatial load prediction is objective load prediction with land use change as the driving force. Lee Wilis proposed a spatial model in which the load distribution area is divided into regular (based on power system service area) and irregular (based on utility service area) spatial units. In small spatial units, load growth characteristics will tend to follow a growth pattern according to the Gompertz function or sigmoid curve. The general Gompertz equation is shown in equation (1) below.

$$P"(t) = a.e^{b.e^{c.t}} \quad (1)$$

Where $P"$ is the load in year t, a is the asymptote, b is the constant that controls the shift of the graph along the x-axis (left or right), c is the growth rate constant that controls the y-axis, and e is the Euler number ($e = 2.71828...$). Load growth patterns that follow the Gompertz equation, as shown in Fig. 1, tend to grow intensively in a few years. The rate of load growth in this small spatial area tends to decrease as nearby areas or other parts of the region begin to grow until a saturation point is reached.

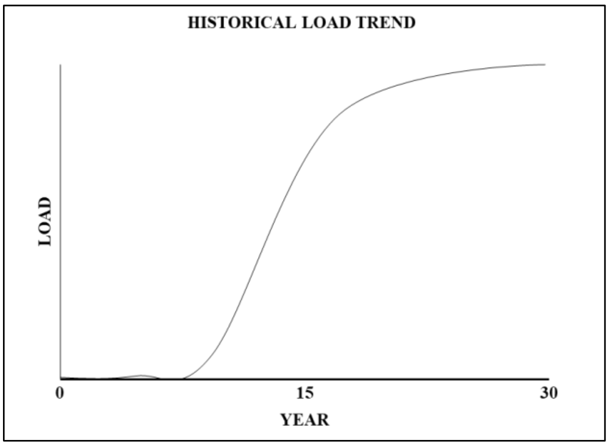

Fig. 1. Patterns of load increase according to the Gompertz Equation.

2.3 Uncertainty and Variability in Electricity Demand Prediction

Load prediction is a projection where there is always a possibility that the projection will not match the real conditions. The probability that the prediction does not match the real conditions increases as the prediction year is further away from the validated prediction year of real data. Such uncertainty needs to be considered in load prediction or electricity load forecasting. A projection model that accounts for uncertainty in load prediction or forecasting can be developed by adding a Monte Carlo simulation to a previously developed projection model.

Monte Carlo simulation is a stochastic technique based on the use of random numbers and probability statistics to solve various problems. In general, it can be assumed that Monte Carlo simulation is a simulation used to solve non-probabilistic problems with probabilistic methods. The basic principle of this simulation is to develop an analytical model based on a probabilistic approach that can predict the behaviour of the observed system. Each system behaviour is evaluated to obtain the distribution of the system behaviour. Based on this distribution, the future behaviour of the system can be predicted. Monte Carlo simulation can be defined as a simulation that uses random numbers as a tool to calculate something that is not *a* random number. Suppose X is *a* random number whose expected value is defined as $A = E[x]$. If the numbers $X1, X2, ..., Xn$ can be generated, where n is a free random number with a similar distribution, the following approach can be made (Adnan Fadjar, 2008; Hasugian et al., 2022; Hénon, 1971; Liu and Fotouhi, 2020; N. Metropolis and S Ulam, 1949; Raychaudhuri, 2008; Urbanucci and Testi, 2018). Equation (2) shows the Monte Carlo simulation equation.

$$A \approx \tilde{A} = \frac{1}{n}\sum_{k=1}^{n} X_k \quad (2)$$

Where,

X_k is the k-th random number
$\tilde{A}$ is the average value of A
$n \rightarrow \sim$
A is not a random number

The error value using Monte Carlo simulation is close to equation (3).

$$\varepsilon = \frac{3\sigma}{\sqrt{n}} \quad (3)$$

Where n is the number of random variables generated and σ is the standard deviation of the random variable. Based on the equation, it can be concluded that a small error is obtained with many random variables. The standard deviation can be calculated based on the entire population of data, which in the simulation the members are only the minimum value and the maximum value. In this research, Monte Carlo equation is implemented using Crystal Ball software. In engineering cases, Monte Carlo equation is used when experiments (direct measurement and observation) are difficult or costly to perform (Ceperley and Alder, 1986; Gruber et al., 2023).

2.4 Secondary Data

The secondary data used in this study include the following:

1. Nunukan Regency Regional Regulation Document No. 19/2013 concerning Nunukan Regency Spatial Plan and Area 2013 – 2033 (Regent of Nunukan, 2013).
2. Sebatik System daily load data recorded by the Sebatik Diesel Power Plant (DPP) System, PLN Nunukan Region.
3. Statistical population census data by sub-district (people) for Nunukan Regency, year 2020-2021, compiled by the Central Statistics Agency (Badan Pusat Statistik/BPS) of Nunukan Regency (Central Statistics Agency, 2020).
4. Sebatik Island ArcGIS map data sourced from the Indonesian Geospatial Agency (Indonesian Geospatial Agency, 2022).
5. Sebatik Island satellite map data in 2022 sourced from the Google Earth satellite map.

2.5 Standard Definition

The standard load demand per area is prepared based on a number of references as follows:

1. Document "Assessment of Ability to Pay, Mechanism for Gradually Implementing Economic Electricity Tariffs and the Impact of Inflation for 450 VA and 900 VA Electricity Customers", prepared by the Directorate General of Electricity, Ministry of Energy and Mineral Resources in 2014.
2. Glenn Hawkins, "Rules of Thumb", BSRIA, 2011 (Hawkins, 2011).

Determine the standard that will be used as the reference for determining the load amount according to regional characteristics, as shown in Table 1. This standard is important to ensure consistency and quality in data analysis.

The crucial stage in this methodology is the definition of the standard load requirement per unit area according to the characteristics of the island or area. The standard load requirement per unit area is developed based on existing standards, which can be specific to certain areas or general (Hawkins, 2011). Subsequently, based on the standard load requirement per unit area, the maximum load limit that may occur in the spatial area of the island can be determined using the following equation:

$$L_M = \sum_{i=1}^{N} \mathrm{l}_i . s_i \quad (4)$$

where,

- L_M = The maximum possible load that may occur (kW)
- l_i = The maximum built-up area for the ultimate condition for each spatial area i (m^2)

- s_i = The standard load requirement for each spatial area characteristics i (kW/m^2)

Once the maximum load requirement (kW) in the 3T area is determined, the load projection for each year t is carried out using the equation:

$$L_i(t) = l_i(t).\, s_i \tag{5}$$

where,

- $Li(t)$ = The load that may occur in spatial area i in year t (kW)
- $li(t)$ = The built-up area in year t for each spatial area i (m^2)
- s_i = The standard load requirement for each spatial area characteristics i (kW/m^2)

Table 1. Standard Load Demands per Area.

Code	Information	Load (W/m^2)
0	Conservation Area/no activity	0.0
1	Settlements with low density (population density of 1 – 59 people per km^2)	1.5
2	Settlements with medium density (population density 60 – 499 people per km^2)	2.0
3	Settlements with high density (population density 500 - > 1000 people per km^2)	3.0
4	Business area with low activity density	4.0
5	Business area with medium activity density	5.0
6	Business area with high activity density	6.8
7	Transportation Infrastructure Area with low activity density	1.0
8	Transportation Infrastructure Area with medium activity density	2.9
9	Transportation Infrastructure Area with high activity density	7.1
10	Industrial area with low activity density	5.0
11	Industrial area with medium activity density	10.0
12	Industrial area with high activity density	15.0
13	Tourist Destination Area with low activity density	1.5
14	Tourist Destination Area with medium activity density	2.5
15	Tourist Destination Area with high activity density	4.6

3. Result and Analysis

3.1 Case Study: Sebatik Island

Sebatik Island is an island located in North Kalimantan Province. This island lies on the border between Indonesia and Malaysia. In the 1891 London Convention, where all the territories of Sebatik controlled by the Dutch were taken by Indonesia, and all the areas of Sebatik controlled by the British were taken by Malaysia. The origin of the name "Sebatik" comes from the Dutch Expedition's giving of the name, which, during their dominion, researched in Sebatik and discovered a large snake resembling a Python (Husain, 2017). The people who followed the expedition referred to the snake they found as the "Sawa Batik" snake, and at that time, the Dutch referred to it as "Sebettik," gradually changing its pronunciation until it became "Sebatik". The island's position is shown in Fig. 2, Sebatik Island is a location divided into two regions, Indonesia and Malaysia, thus its economy is driven by cross-border trade activities. Therefore, the distinctive characteristic guiding the analysis of land use changes in Pulau Sebatik is its economic nature propelled by across national borders trade activities.

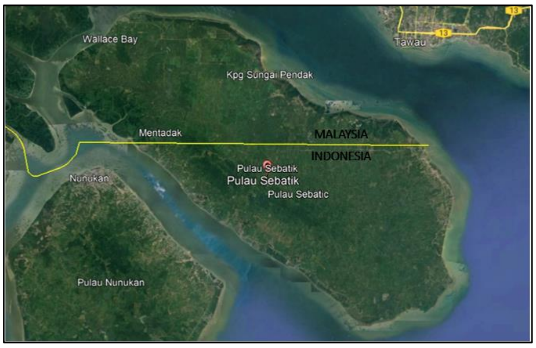

Fig 2. The location of Sebatik Island is on the border between Indonesia and Malaysia.

Fig 3. Land use on Sebatik Island 2022.

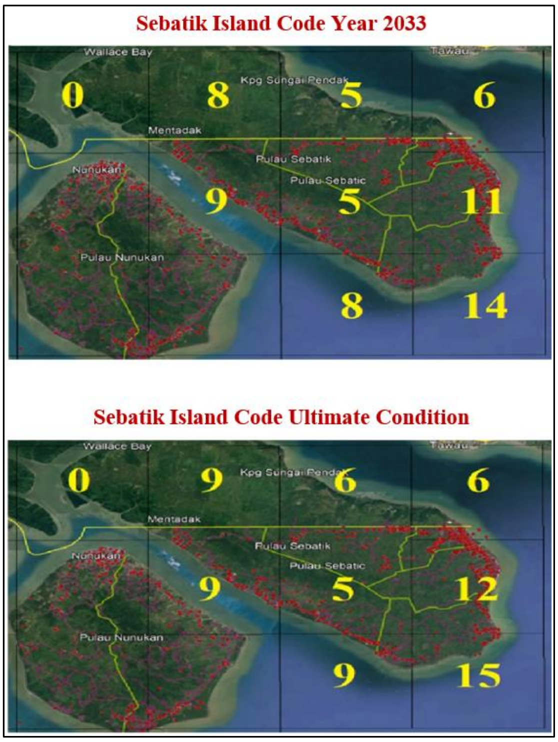

Fig 4. Land use changes on Sebatik Island 2033, and ultimate.

3.2 Analysis of Land Use Development

Utilizing ArcGIS software, the Sebatik island chosen as a case study was mapped and divided into regular spatial units based on the electrical grid service region. The units were 10 km x 10 km because this size is sufficiently accurate to allow for projections. Results are better when the spatial unit size is lower, but data collection and verification are quite laborintensive. As shown in Fig. 3, in the year 2022, spatial unit 1 is an area where there are no activities. Meanwhile, spatial unit 6, generally covering most of the area in Sebatik Barat District, is a residential area with a medium population density, with a significant portion of its territory being used for irrigation and agriculture. Spatial unit 4 is a high-density residential area, with a population density ranging from 500 - > 1000 people per square kilometer. Other spatial units, apart from units 1, 4, and 6, are residential areas with a medium population density, ranging from 60 - 499 people per square kilometer. According to the Nunukan Regency Spatial Plan Document 2013-2033, periodic changes in land use on Sebatik Island are shown in Fig. 4.

As shown in Fig. 3 and Fig. 4, during the period 2023-2033, spatial unit 1 is still an area without any activities. Meanwhile, spatial unit 2, the Bambangan Village in the Sebatik Barat Sub-district, will be developed as an Inter-Island Ferry Terminal Development Area & Type C Terminal Development Area. Spatial unit 3, the Aji Kuning Village in the Central Sebatik Sub-district, serves as a Local Environmental Service Center designed to serve inter-village scale activities. Spatial unit 6, covering a large portion of the Sebatik Barat Sub-district, is a residential area with medium population density, where a significant portion of the territory is used for irrigation and agriculture, as well as mining area development. Spatial unit 7, an urban area in Sebatik Island, consists of the Sebatik Timur Sub-district and parts of the Sebatik Sub-district, where there are Diesel Power Plants, medium-scale agro-industrial development, integrated fisheries industrial zones, regional seaport infrastructure & Type C Terminal Development Area. Spatial unit 8, covering a large portion of the Sebatik Sub-district, is a residential area with medium population density, featuring the development of a Type C Terminal, a pier, and several office buildings. Spatial unit 9, to be developed as a Regional Service Center, is the Tanjung Karang Village in the Sebatik Sub-district, containing a Tourism Area located at Batu Lamampu Beach, which is a residential area with a medium population density, ranging from 60 - 499 people per square kilometer. Spatial unit 5, also to be developed as a Regional Service Center, serves activities at the sub-district or multiple village scales, namely the Binalawan Village in the West Sebatik Sub-district, where three port infrastructures are located. Finally, spatial unit 4, to be developed as a Regional Service Center, is the Seipancang Village in the Sebatik Utara Sub-district, containing fishing port facilities and having a high population density residential area, with a population density ranging from 500 -> 1000 people per square kilometer.

Basically, there is no document that can provide a basis for assessing the development and ultimate changes in land use on Sebatik Island. However, analysis with the researcher's subjectivity can be conducted by observing the patterns of land use changes during the period mentioned in the Regency Spatial Planning Document of Nunukan Regency regarding Sebatik Island. This analysis serves as the foundation for creating an ultimate land use representation of Sebatik Island, as follows:

1. Spatial Units 2, 5, and 8, which are in Sebatik Barat Sub-district and Sebatik Sub-district, will be developed into regional port infrastructure areas with high activity density towards the city center of Nunukan Regency.
2. Spatial Units 3 and 4, located around high population density areas and directly bordering Malaysia, which promotes cross-border trade activities, will develop into business areas comprising government offices, schools, markets, hospitals, and other facilities with high-density activity levels.
3. Meanwhile, in spatial unit 6, it will still develop into a business area with a medium-density activity level due to the majority of its area being used for the management of irrigation and agriculture areas, as well as the development of mining zones.
4. The eastern area of Sebatik Island, in spatial unit 7, will become the center of industrial and infrastructure activities on the island with high population density.
5. Spatial unit 9 will develop into a high-activity tourist destination area, supported by its proximity to the urban center of Sebatik Timur District, which serves as the main economic hub on Sebatik Island. Additionally, spatial unit 9 features a tourism area located at Batu Lamampu Beach.

Furthermore, the land use changes are accompanied by annual changes in the built-up area within each spatial unit. The expansion of the built-up area is primarily based on the annual land use change map provided in the appendix of the RTRW Document for Nunukan Regency 2013-2033. However, in the absence of the specified map in the RTRW Document, planners or researchers can use a subjective approach based on the existing built-up area. The evolution of changes in the built-up area during the period 2022-2033 is shown in Fig. 5. The built-up area in the ultimate condition is depicted in Fig. 6. The calculation of the built-up area can be done using ArcGIS maps overlaid with Google Earth (Aziz et al., 2024; Joleha et al., 2024). The results of the calculation are presented in Table 2.

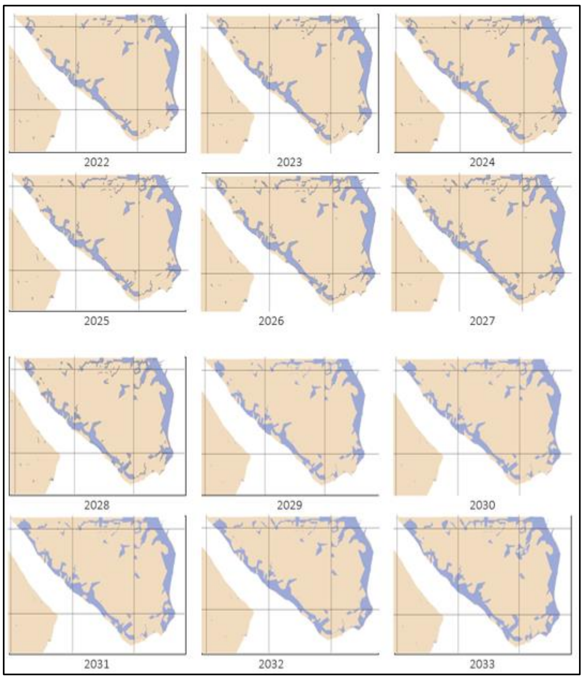

Fig 5. Evolution of the increase in area built on Sebatik Island 2022 – 2033.

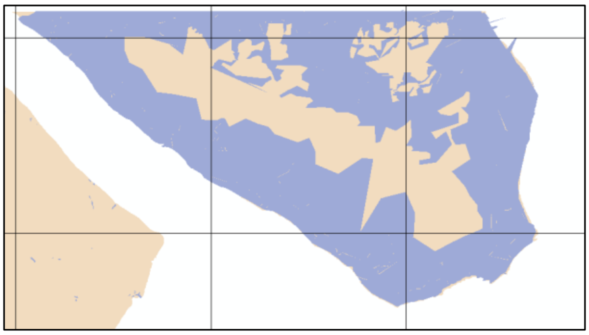

Fig 6. The area built on Sebatik Island is in ultimate condition.

Table 2. The area of the built-up area in each spatial unit on Sebatik Island.

Spatial units	Area (Hectares)											
	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	Ultimate
1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	48,57	62,92	69.08	88	103.14	119.09	141.05	169.07	202.99	241.59	263	303.9	1255.83
3	234,82	242,42	250.38	262.38	280.95	301.25	315.8	335.63	359.16	393.79	419.59	442.9	1204.88
4	265,88	282,53	284.42	303.96	314.71	333.87	350.8	359.19	372.05	392.8	414.98	423	470.92
5	502,91	511.57	521.17	540.86	560.54	580.05	599.4	616.89	656.41	691.55	723.88	797.52	2273.34
6	720,08	724.68	728.31	747.08	765.4	787.8	814.25	849.03	874.58	913.98	950.54	1077.63	5743.81
7	1398,13	1402.25	1406.64	1432.77	1459.84	1479.83	1499.1	1525.16	1546.01	1577.68	1622.68	1729.37	4340.01
8	268,03	278.32	280.76	300.31	314.48	334.44	356.26	376.82	407.7	427.19	473.33	525.59	1135.4
9	119,45	124.57	129.02	143.94	162.94	186.92	205.83	228.14	266.18	330.26	369.25	416.23	1436.66
Total	3557,87	3629.26	3669.78	3819.3	3962	4123.25	4282.49	4459.93	4685.08	4968.84	5327.25	5716.14	17860.65

3.3 Load Prediction and Validation

The results for predictions of peak load demands on Sebatik Island can be observed even though there are no land use change codes for the years 2023-2032. So that the load growth in that year is given by adding the average of the margin between the projected total peak loads of 2022 and 2033 for each year. Validation is performed by comparing the projection data for the existing year, which is 2022, with the actual peak load data from the Sebatik DPP System sourced from the PLN Nunukan Region. The load data used is the highest peak load recorded in October 2022, which is considered a relatively normal condition post the Covid-19 pandemic. The highest peak load in October 2022 is 3233 kW. The validation ratio of the projected peak load to the actual recorded load in the Sebatik DPP System is 0.044. By incorporating the validation ratio into the spatial peak load projection of the Sebatik System obtained in the previous stage, the spatial peak load projection of the Sebatik System is obtained, as shown in Table 3.

Table 3. The projected peak load on Sebatik Island for 2022-2033 has been validated.

Description	Year											
	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Maximum Load (MW)	63,55	63,55	63,55	63,55	63,55	63,55	63,55	63,55	63,55	63,55	63,55	63,55
Projected Load (MW)	3,23	4,41	5,58	6,76	7,93	9,10	10,28	11,45	12,63	13,80	14,97	16,15

The Gompertz equation that comes closest to the projected peak load on Sebatik Island for 2022-2033 according to Equation (1) is as follows:

$$f(t) = ke^{-\ln\left(\frac{k}{P_0}\right)e^{-ct}} = 63.55e^{-\ln 19.66e^{-0.09t}} \quad (6)$$

Where k is the validated maximum peak load on Sebatik Island of 63.55 MW, e is the Euler number (e = 2.71828...), P_0 is the initial validated load on Sebatik Island of 3.23 MW, c is the growth rate on Sebatik Island of 0.09, and t is the projection year. Calibration of the projected peak load on Sebatik Island for 2022-2033 according to the Gompertz equation produces a projected peak load for Sebatik Island for 2022-2033 as shown in Fig. 7.

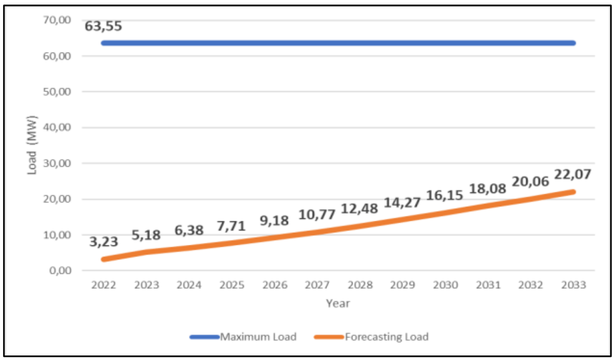

Fig 7. Sebatik Island peak load projection for 2022-2033 according to the Gompertz Equation.

If Equation (6) is extended to obtain the peak load projection profile of Sebatik Island according to the Gompertz Equation, the peak load projection profile of Sebatik Island will be obtained, as shown in Figure 8. From the figure, it can be seen that it will take more than 100 years from the year 2022 for the peak load in Sebatik Island to approach the maximum peak load according to the spatial development of the island. In other words, the development of Sebatik Island, even though its economy is driven by cross-border trade activities with the potential for industrial areas, transportation infrastructure, business, and rapid tourism development. Electrical planners can formulate power generation and capacity planning, as well as power lines and capacity planning, based on this spatial peak load projection, considering the spatial development on Sebatik Island.

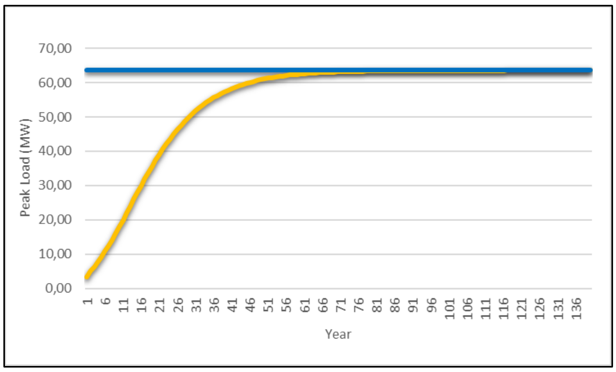

Fig 8. Sebatik Island peak load projection according to the Gompertz Equation.

3.4 Aspects of Uncertainty and Variability

A projection model of electricity demand in Sebatik Island which takes uncertainty aspects into consideration. In this model, a Monte Carlo simulation is conducted with the assistance of the Crystal Ball software. The assumption of the distribution is formed from all the electricity demand projection data on Sebatik Island according to the Gompertz Equation shown in Fig. 8. Based on the distribution determination simulation using Crystal Ball, the assumption of the distribution for the electricity demand projection on Sebatik Island follows a Logistic Distribution with a mean value of 61.82 and a scale value of 5.45.

Monte Carlo simulation was conducted to assess the sensitivity of the electricity demand projection for Sebatik

Island from 2022 to 2033. The results of the Monte Carlo simulation in the form of a trend graph are shown in Fig. 9. From the graph, it can be observed that the further away from the initial projection point, the wider the range of uncertainty in the projection. The results of the Monte Carlo simulation in the form of values at a 90% confidence level are presented in Table 4.

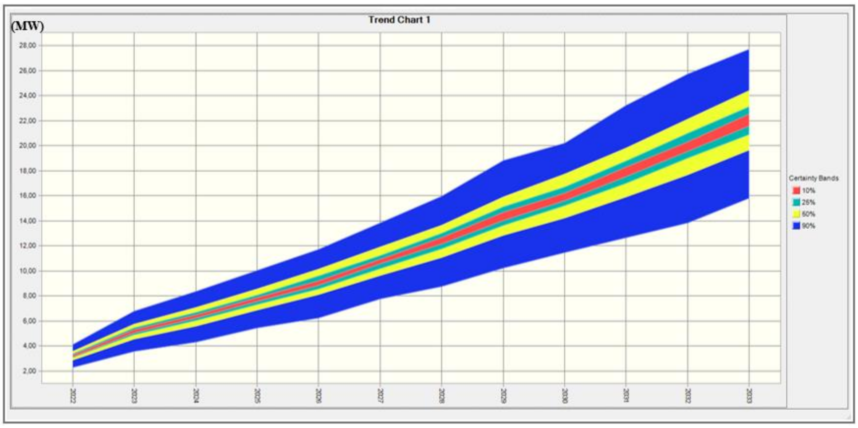

Fig 9. The sensitivity of the projected peak load on Sebatik Island according to the Gompertz Equation.

Table 4. Monte Carlo simulation results on Sebatik Island in the form of values

Year	Minimum (MW)	Maximum (MW)	Mean (MW)
2022	2.32	4.27	3.24
2023	3.53	6.76	5.17
2024	4.57	8.14	6.34
2025	5.51	10.09	7.70
2026	6.20	11.80	9.16
2027	7.74	14.10	10.80
2028	8.74	16.67	12.51
2029	10.24	18.52	14.25
2030	11.55	20.88	16.15
2031	12.49	23.41	18.03
2032	14.55	26.09	20.15
2033	16.04	27.83	22.08

4. Discussion

For a detailed discussion of the relevance of this spatial method, it is also compared with other methods for the prediction of load demand for small islands. M. T. Sarker et al. conducted research on energy consumption prediction methods for a case study of Bhashan Char Island in Bangladesh. To effectively prediction energy consumption in such a neglected area, the study proposed a new method that combines the Inverse Matrix Method (IMM) with the Linear Regression Method (LRM). The combined model produces accurate estimates using historical data on energy consumption and relevant factors such as weather patterns, population dynamics, economic indicators, and seasonal trends (Sarker et al., 2024). In this case, only short-term prediction can be applied.

In the spatial method, other factors are considered, such as the direction of land use development according to the local RTRW document, load standards according to people's lifestyles, and boundaries as a characteristic of a small island. Furthermore, the spatial method is satisfied with Monte Carlo equation, which provides a range of values based on the level of confidence in the prediction results. Thus, this result will make the prediction results of the spatial method more accurate and precise. Since it is also validated with real load data recorded by PLN Nunukan Region, the load prediction by this study is very reasonable.

The Gompertz equation makes it possible to extend the prediction results, originally limited to the year of expiration of the RTRW document, to the maximum load of the island (ultimate) if there is no significant change in regional policy. Based on this new knowledge, a country's electric utility will be able to build infrastructure and generate electricity in a more optimal way. This mathematical model is particularly applicable to remote or off-grid island environments. This study can also help the Sebatik Island community integrate renewable energy sources such as wind, solar, and tidal power into the energy mix.

5. Conclusions

This study shows that spatial methods for prediction of electricity load on the island of Sebatik are more accurate than other methods, such as machine learning. This method is more applicable to small island outer regions because it takes into consideration the development of land use, borders and distribution of population activities according to local policies. In this case, short- and long-term predictions can be applied.

The results of the electricity load prediction using the spatial method show the development of the electricity load demanded on the island of Sebatik up to the year 2033, which is 22.07 MW. It can even be drawn to reach the final load of 63.55 MW in the 185th year because this prediction uses the Gompertz equation, which is validated with real data from PLN. This study also uses Monte Carlo simulation to consider the uncertainty aspect of the prediction. Electricity planners can choose a 90% confidence level, which results in a more reasonable range of predicted values.

This study shows that Sebatik Island has a high potential for the integration of renewable energy sources, which can be used to support sustainable economic growth. The findings provide important new insights for electricity planners in Indonesia, particularly in the Outermost Regions, to design efficient electricity infrastructure that is adapted to the demands of local communities, and to ensure equitable and sustainable electricity distribution in the future.

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