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Optimization of Double Exponential Smoothing Model for Daily Earth Temperature Forecasting in Dayeuhluhur, Cilacap

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Abstract

Global warming has caused an increase in the Earth's surface temperature, which has a significant impact on the environment and human life. This study aims to predict the daily surface temperature in Dayeuhluhur District, Cilacap, for the next one year using the Double Exponential Smoothing (DES) method. The data used comes from the NASA POWER platform with a time span of 2015 to 2025, including three main variables: earth surface temperature (TS), solar radiation (ALLSKY_SFC_SW_DWN), and maximum 10-meter wind speed (WS10M_MAX). Preprocessing was done by removing February 29 in leap years and applying annual differencing (lag 365) to stabilize the seasonal pattern. Smoothing parameters α and β were optimized based on Mean Absolute Percentage Error (MAPE) values. Results show a moderate and consistent increasing trend in temperature, with the best accuracy in the temperature variable (MAPE 2.41%), followed by solar radiation (21.56%) and wind speed (30.18%). This method proves effective in forecasting temperature with clear seasonal patterns and contributes to supporting data-driven climate change mitigation policies.
Keywords: Forecasting, Temperature, Dayeuhluhur, Double Exponential Smoothing, MAPE.

Abstrak

Pemanasan global telah menyebabkan peningkatan suhu permukaan bumi, yang berdampak signifikan terhadap lingkungan dan kehidupan manusia. Penelitian ini bertujuan untuk memprediksi suhu permukaan harian di Kecamatan Dayeuhluhur, Cilacap, selama satu tahun ke depan menggunakan metode Double Exponential Smoothing (DES). Data yang digunakan berasal dari platform NASA POWER dengan rentang waktu 2015 hingga 2025, mencakup tiga variabel utama: suhu permukaan bumi (TS), radiasi surya (ALLSKY_SFC_SW_DWN), dan kecepatan angin maksimum 10 meter (WS10M_MAX). Preprocessing dilakukan dengan menghapus tanggal 29 Februari pada tahun kabisat dan menerapkan differencing tahunan (lag 365) untuk menstabilkan pola musiman. Parameter smoothing α dan β dioptimalkan berdasarkan nilai Mean Absolute Percentage Error (MAPE). Hasil menunjukkan tren peningkatan suhu yang moderat dan konsisten, dengan akurasi terbaik pada variabel suhu (MAPE 2.41%), diikuti oleh radiasi surya (21.56%) dan kecepatan angin (30.18%). Metode ini terbukti efektif dalam meramalkan suhu dengan pola musiman yang jelas dan berkontribusi dalam mendukung kebijakan mitigasi perubahan iklim berbasis data.
Kata-kata kunci*: Peramalan, Suhu, Dayeuhluhur, Double Exponential Smoothing, MAPE.*

1. Introduction

Currently, the world is facing serious threats, one of which is caused by climate change. Human activities that continue to produce greenhouse gas emissions, such as carbon dioxide, accelerate the process of global warming, which, without being realized, is causing air temperatures to become increasingly hotter over time [1]. People are unaware that global warming has led to serious environmental problems, such as natural disasters, various diseases, and many others [2]. Climate change, marked by temperature trend changes, will have widespread impacts on both humans and the environment [3]. Changes in the Earth's surface temperature trends also affect sectors such as agriculture, water resource management, and local ecosystems, especially in tropical regions like Dayeuhluhur District, Cilacap. However, the lack of accurate data and effective prediction methods remains a major challenge in understanding and anticipating the impacts of temperature changes.

Changes in surface temperature trends have had direct consequences on rural communities, particularly in tropical and highland regions such as Dayeuhluhur District, Cilacap. Rising temperatures and prolonged dry seasons have disrupted agricultural patterns, leading to a decline in productivity and water availability. In 2023, thousands of hectares of rice fields in Cilacap were reported to be at risk of planting failure due to drought and a lack of irrigation water, illustrating the vulnerability of local farming systems to climate anomalies [4]. These conditions not only threaten food security but also have broader socio-economic implications for communities that rely heavily on agriculture as their primary livelihood. The Earth's surface temperature not only reflects global atmospheric conditions but also affects local weather patterns, such as changes in wind speed and rainfall distribution. In rural areas like Dayeuhluhur, temperatures tend to be lower compared to urban areas due to the urban heat island phenomenon [5]. Dayeuhluhur was chosen as the study location due to its topographical uniqueness, dependence on climate-sensitive agriculture, and limited availability of detailed climatological data, which underscores the need for accurate localized forecasting models. This temperature variation has a significant impact on local sustainability, making mitigation efforts supported by accurate predictive data crucial.

The time series approach is one of the most widely used methods for projecting temperature data based on historical patterns to predict future temperature values. Moreover, time series modeling serves as a rational, effective, and efficient basis for forecasting [6]. Various time series methods, such as the additive and multiplicative Holt-Winters models, have been applied to predict economic and environmental trends [7]. Double Exponential Smoothing has become one of the main choices in analyzing data with consistent trends, especially for data showing seasonal patterns or linear trends. Methods like Brown and Holt are commonly used to forecast demand based on historical data. Results have shown that the Holt method is more accurate due to its lower forecasting error value [8].

Several previous studies have compared two forecasting methods for air temperature in Cilacap [9], showing that while both are effective, the results can be improved through parameter optimization to enhance the accuracy of daily temperature trend predictions. In addition, a hybrid machine learning model combining Double Exponential Smoothing, particle optimization, and extreme learning machines has successfully predicted landslide shifts with high accuracy and demonstrated a reduced impact of reservoir cycles on landslide stability [10].

This study utilizes secondary data obtained from the NASA POWER platform, consisting of three key environmental parameters: surface temperature (TS), surface solar radiation (ALLSKY_SFC_SW_DWN), and maximum wind speed at a 10-meter height (WS10M_MAX). These variables are initially visualized to identify seasonal patterns and overall trends, although the forecasting analysis specifically focuses on surface temperature. This study aims to predict the Earth's surface temperature in Dayeuhluhur District using the Double Exponential Smoothing (DES) method, based on monthly historical data from 2015 to 2023. The model is optimized using the Mean Absolute Percentage Error (MAPE) to determine the most accurate parameter combination.

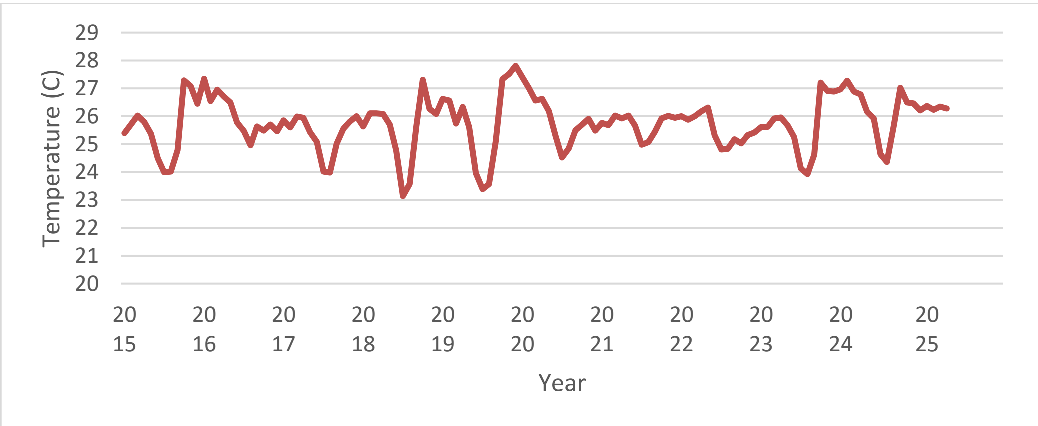

Figure 1. Temperature Trend Graph for 2015–2023

As shown in Figure 1, the surface temperature trend in Dayeuhluhur District exhibits recurring seasonal fluctuations with a subtle upward tendency, suggesting potential long-term warming in the region. Model performance will be evaluated by calculating MAPE and by comparing forecast results against historical temperature patterns. The expected outcome of this study is a high-accuracy forecasting model that can serve as a scientific basis for climate change adaptation and mitigation strategies. The findings may support the development of early warning systems, inform climate-sensitive spatial planning, and guide local agricultural calendars to reduce vulnerability. This model is anticipated to assist both local governments and rural communities in strengthening their resilience to ongoing climate challenges.

2. Method

This study uses a quantitative approach with the Double Exponential method to analyze time series data of earth's surface temperature in Dayeuhluhur District, Cilacap. The main focus of the study is to ensure the quality of the data used, optimize the Double Exponential Smoothing model, and produce findings that are relevant to the research objectives. The research process includes a series of interrelated steps, starting from data collection and processing to determine the optimal values of alpha and beta with the smallest MAPE, to evaluation of results, validation, and visualization of findings. The flow of the applied research methodology can be seen in Figure 2.

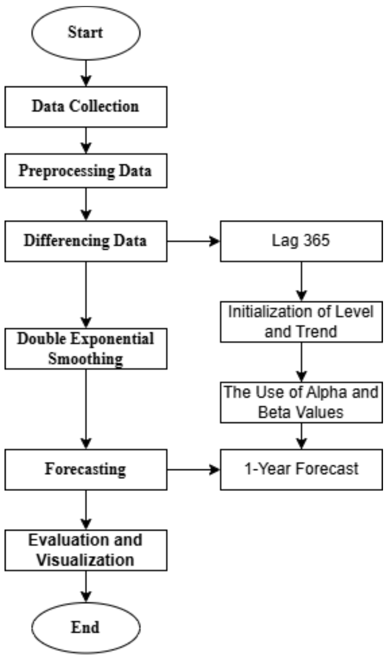

Figure 2. Double Exponential Smoothing Forecasting Flowchart

2.1 Data Mining

Data mining has been widely used in various studies. Data mining functions to extract added value from data using pattern recognition technology, statistics, and mathematics [11]. Various data mining methods, ranging from classification to prediction, have been applied according to research needs, with each method offering its own advantages. In this study, the method applied focuses on forecasting techniques, because this method is widely known and often used in data analysis studies.

2.2 Time Series

Time series is a quantitative method used to analyze data based on patterns that form over time. By utilizing previous data history, this method allows accurate prediction of future information [12]. Identification of patterns and trends in ordered data makes time series effective for various applications, such as temperature forecasting using the Double Exponential Smoothing approach.

2.3 Preprocessing Data

The data for this study were collected through secondary data collection techniques. The main data source for this study came from the NASA Prediction of Worldwide Energy Resources (POWER) platform, which provides solar and meteorological data sets from NASA research to support renewable energy, build energy efficiency, and agricultural needs [13]. Data is taken via API from NASA POWER website in CSV format and processed using Excel software. This study uses three main variables, namely: ALLSKY_SFC_SW_DWN (CERES SYN1deg All Sky Surface Shortwave Downward Irradiance in $MJ/m^2/day$), TS (MERRA-2 Earth Skin Temperature in °C), and WS10M_MAX (MERRA-2 Wind Speed at 10 Meters Maximum in m/s).

The main focus of the analysis is on the surface temperature (TS) variable for the Dayeuhluhur District area, with a data time span from January 1, 2015 to February 28, 2025. Before further analysis using the Double Exponential Smoothing (DES) method, the data undergoes a preprocessing stage to ensure consistency. One important step is the removal of February 29 in leap years (2016, 2020, and 2024), so that all years in the dataset have the same number of days, namely 365 days. This removal is necessary because the DES method used involves a differencing process with an annual lag, so that the presence of the 366th day can cause a discrepancy in the calculation pattern. Thus, the data used becomes more uniform and ready for further analysis.

2.4 Differentiating (Data Transformation)

In time series analysis, differencing is a technique used to eliminate seasonal trends or patterns by calculating the difference between the current value and the value in the previous period. In this study, annual differencing (lag 365) is applied to overcome seasonal patterns in surface temperature data so that the data becomes more stationary and suitable for the Double Exponential Smoothing (DES) method. This step has proven effective in increasing forecasting accuracy as explained by Hansun (2016) in his research related to the application of DES to data that has been differencing [14].

2.5 Double Exponential Smoothing

Double Exponential Smoothing is a time series forecasting method that combines two main components, namely level and trend, to identify data patterns with linear trends. Trend is a smoothed estimate of the average growth at the end of each period [15]. Double Exponential Smoothing is divided into two types, namely Brown's and Holt's Exponential Smoothing. The difference between the two is that Brown uses one constant value, namely α, which plays a role in smoothing the data as a whole by smoothing it twice, while Holt uses two constant values, namely α and β [16]. In this process, the smoothing parameters α (alpha) and β (beta) are determined by testing various combinations of values to minimize prediction errors.

$$L_t = \alpha Y_t + (1 - \alpha)(L_{t-1} + T_{t-1}) \quad (1)$$

$$T_t = \beta(L_t - L_{t-1}) + (1 - \beta)T_{t-1} \quad (2)$$

$$F_{t+m} = L_t + mT_t \quad (3)$$

Explanation :

- L_t: Level at period t
- T_t: Trend at period t
- Y_t: Actual value at period t
- F_{t+m}: Forecasted value for period (t+m)
- α : Alpha/Parameter value for level (value between 0 and 1)
- β : Beta/Parameter value for trend (value between 0 and 1)
- L_{t-1} : Level at previous period (t-1)
- T_{t-1} : Trend at previous period (t-1)
- m : Number of future periods to forecast

2.6 Forecasting

Forecasting is the science of estimating future events using data or information obtained from the past through quantitative analysis **[17]**. The process can be carried out using mathematical models to project past data [18]. In statistics, techniques such as moving averages, regression, and exponential smoothing are often used to estimate future values, such as temperature or market conditions. Forecasting provides valuable insights for decision-making, such as predicting temperatures based on historical data to support better planning.

2.7 Evaluation and Visualization

The selected combination of parameters α and β is the one that produces the smallest MAPE (Mean Absolute Percentage Error) value for the level, trend, and forecast, in order to ensure the highest accuracy in data prediction. Once the α and β parameters are determined, the level component (L_t) and the trend component (T_t) are calculated using the established formulas. The level component represents the current data value, while the trend component describes the pattern of data change over time. These two components are then used to make future period predictions by combining the level and trend values to generate a more accurate projection of surface temperature. The formula for calculating MAPE is as follows **[19]**:

$$\text{MAPE} = \sum 100\% \,|\, (Xt - Ft)\; n \,| \quad (4)$$

Explaanation:

- Xt : Original data value for period t
- Ft : Forecasted value for period t
- n : Number of forecasting periods

The MAPE calculation allows for the assessment of the model's accuracy in predicting surface temperature, with a smaller MAPE value indicating more accurate forecasting results. To provide an interpretation of the MAPE value, criteria are used to indicate the level of forecasting accuracy. These criteria are presented in Table 1.

Table 1. MAPE Value Criteria

MAPE Value	Interpretation
<10%	The forecasting results are very accurate
10-20%	Accurate forecasting results
20-50%	The forecasting results are quite accurate
>50%	Inaccurate forecasting results

3. Results and Discussion

In the Double Exponential Smoothing (DES) method, an analysis is conducted on the secondary data obtained from the NASA POWER platform, which includes three main variables: surface solar radiation (ALLSKY_SFC_SW_DWN), earth surface temperature (TS), and maximum wind speed at 10 meters height (WS10M_MAX). The analysis begins with the visualization of these three variables to identify seasonal patterns and trends over the observation period. The focus is then directed toward forecasting surface temperature using the Double Exponential Smoothing (DES) method, which has undergone annual differencing. The predicted surface temperatures for the upcoming year are presented in tabular form and compared with historical patterns to assess the accuracy of the applied model.

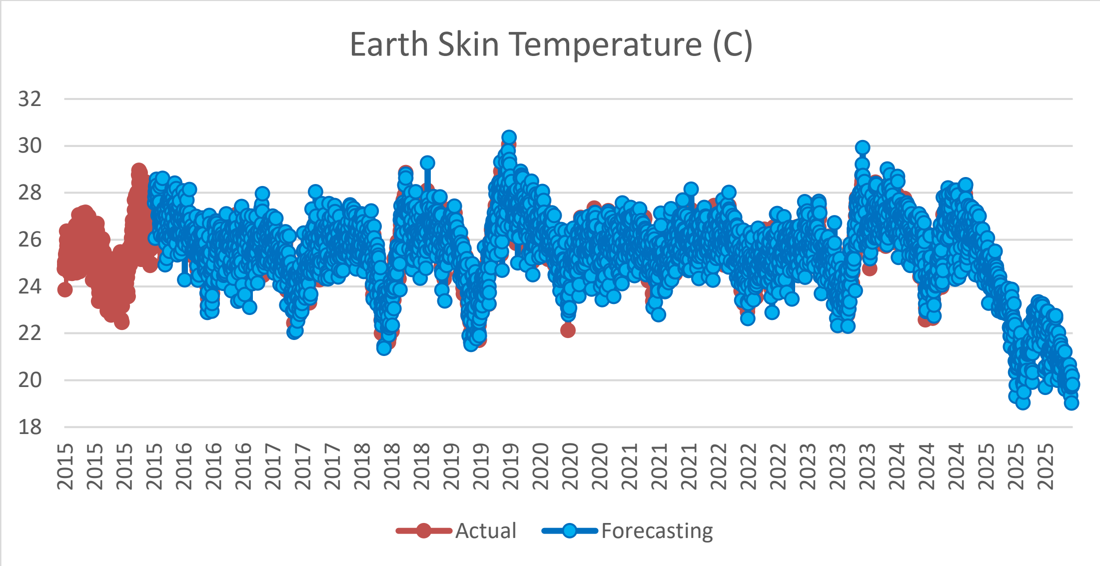

Figure 3. Earth Surface Temperature Forecast Graph

Figure 3 shows Earth Skin Temperature data from early 2015 to February 2025, consisting of actual data (in orange) and forecast results (in blue) using the Double Exponential Smoothing method. There is a consistent seasonal fluctuation pattern every year, where temperatures tend to increase in the middle of the year and decrease at the beginning and end of the year.

In general, the temperature trend between early 2015 and February 2025 shows relative stability, without drastic spikes or decreases in the long term. However, the forecast results for one year ahead indicate a notable decrease in the surface temperature trend. This could potentially reflect localized cooling effects, such as prolonged rainfall, reduced solar radiation, or microclimate shifts in the region. On a broader scale, it may also relate to regional climate variability influenced by phenomena such as La Niña. If such a cooling trend continues, it could disrupt agricultural cycles that are sensitive to temperature thresholds, delay planting seasons, or increase the risk of crop disease due to excess moisture. For communities in Dayeuhluhur that rely heavily on traditional farming, this shift represents a critical challenge in adapting to climate uncertainty. Therefore, continuous monitoring and integrated early warning systems are essential to anticipate these impacts.

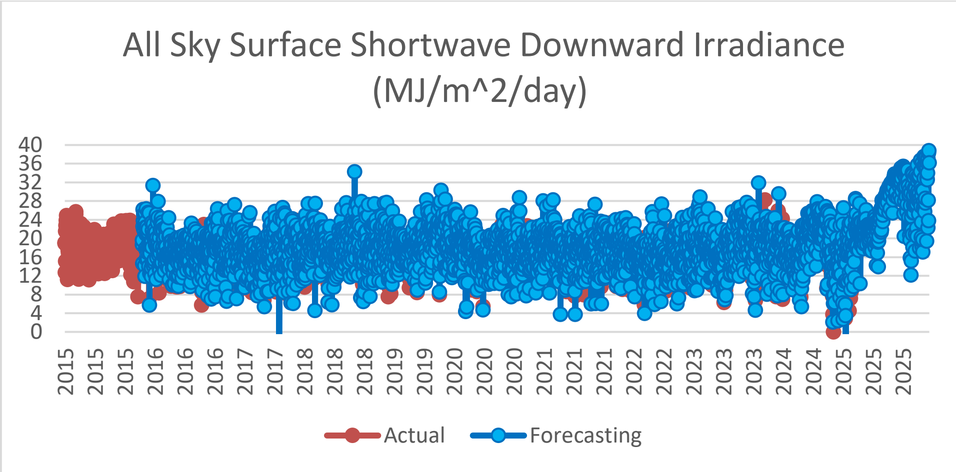

Figure 4. Surface Solar Radiation Forecasting Graph

Figure 4 shows the All Sky Surface Shortwave Downward Irradiance (MJ/m²/day) graph from early 2015 to February 2025, which includes actual data and forecast results. A consistent seasonal pattern is seen each year, with radiation intensity increasing in the middle of the year and decreasing at the beginning and end of the year. This pattern reflects the influence of the apparent position of the sun and atmospheric conditions in the Dayeuhluhur area. The forecast results using the Double Exponential Smoothing method are able to follow the seasonal pattern well, although there are some extreme fluctuations that are likely caused by weather anomalies or model limitations in capturing short-term variability.

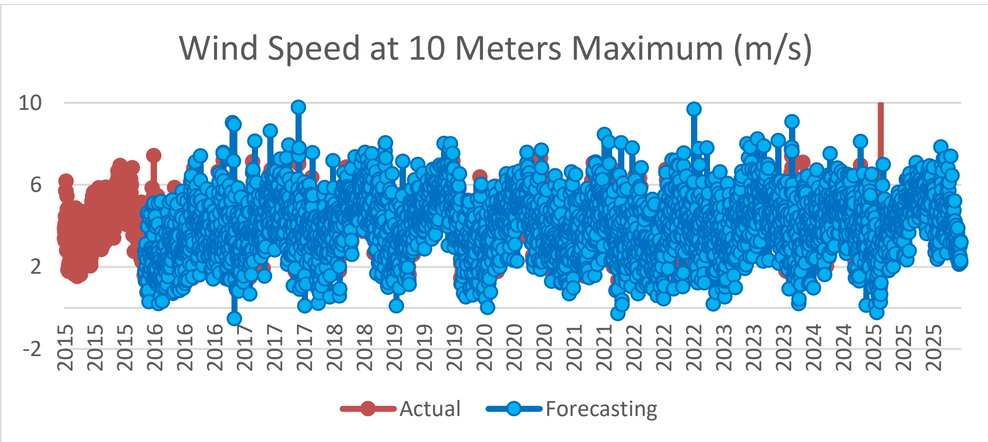

Figure 5. Maximum Wind Speed Forecasting Graph at 10 M Height

Figure 5 displays the WS10M_MAX variable, which represents the maximum wind speed at a height of 10 meters. The graph shows more dynamic wind variations that do not always follow a strict seasonal pattern. However, some annual patterns can still be identified, particularly an increase in wind speed during certain seasons, which may be related to extreme weather conditions.

After applying annual differencing and implementing the Double Exponential Smoothing (DES) method to the surface temperature data, a one-year forecast was generated for the period from March 1, 2025, to February 28, 2026. This process used smoothing parameters $\alpha = 0.65$ and $\beta = 0.1$, selected based on the stability of the level and trend components after differencing. Table 2 presents the monthly forecast results, including surface temperature, solar radiation, and maximum wind speed. These values represent monthly averages derived from daily estimates, aimed at illustrating broader seasonal patterns.

Table 2. Earth Surface Temperature Forecast Results in Dayeuhluhur

Year	Month	Forecast Results		
		Earth Skin Temperature (C)	All Sky Surface Shortwave Downward Irradiance (MJ/m^2/day)	Wind Speed at 10 Meters Maximum (m/s)
2025	March	25.06	19.63	4.04
2025	April	24.59	21.03	3.57
2025	May	23.61	21.92	4.38
2025	June	23.00	21.06	4.36
2025	July	21.35	24.17	5.09
2025	August	20.70	29.27	5.60
2025	September	21.61	31.70	5.29
2025	October	22.62	32.94	5.74
2025	November	21.73	29.97	4.18
2025	December	21.33	25.86	5.00
2026	January	20.87	27.75	4.67
2026	February	20.04	32.12	2.90

The DES model successfully captures the seasonal pattern in surface temperature, with higher predicted values during the middle of the year and lower values at the beginning and end. Similarly, solar radiation shows a peak in September–October and a trough in March and June, aligning with the sun's apparent position and atmospheric clarity. Wind speed predictions, though more erratic, also reflect seasonal variation with a noticeable increase between August and October.

To evaluate model accuracy, the Mean Absolute Percentage Error (MAPE) was used across all three variables. The surface temperature forecast achieved the lowest MAPE of 2.41%, indicating a high degree of reliability. In contrast, the MAPE for solar radiation was 21.56%, and for wind speed, 30.18%, revealing the model's reduced effectiveness in handling variables with higher volatility and irregular seasonality.

Despite the strong performance for surface temperature, the DES model has notable limitations. It is sensitive to the selection of smoothing parameters and lacks responsiveness to abrupt changes or nonlinear climate phenomena such as El Niño or La Niña. These constraints are especially relevant in microclimate regions like Dayeuhluhur, where local anomalies may not be fully captured by simple exponential models.

The relatively high error rates in solar radiation and wind speed forecasting also raise concerns. Inaccurate solar radiation data can affect calculations of evapotranspiration, crop productivity, and energy planning. Similarly, poor wind predictions may compromise early warning systems for storms or drought-related wind hazards. Therefore, while DES provides a useful baseline for forecasting surface temperature, integrating it with hybrid or exogenous models is recommended for future research to improve accuracy in multi-variable climate analysis.

From a policy and mitigation standpoint, the findings of this study can support local governments in climate-informed decision-making. Forecasted temperature patterns can inform agricultural calendars, adaptive irrigation scheduling, and climate-resilient spatial planning. Accurate forecasts also enable communities in Dayeuhluhur to better anticipate environmental risks and develop localized response strategies, thereby enhancing regional resilience to climate change.

4. Conclusion

This study demonstrates that the Double Exponential Smoothing (DES) method effectively predicts surface temperature in Dayeuhluhur District, with a high level of accuracy indicated by a low MAPE value of 2.41%. Compared to other variables solar radiation and wind speed—which produced higher error rates, surface temperature forecasts were more stable and reliable. The results confirm the model’s potential as a preliminary tool for data-driven decision-making in climate-sensitive sectors. Temperature forecasting using DES can support agricultural planning, climate change adaptation strategies, and local natural resource management. By anticipating temperature trends, local governments and rural communities can enhance their preparedness for climate-induced risks such as drought, crop failure, or weather anomalies.

Nevertheless, the DES model has limitations, particularly its sensitivity to parameter selection and its inability to capture complex or abrupt climate anomalies. Some deviations in the forecast suggest that external factors such as regional climate shifts or extreme weather events may not be fully reflected in the model. In conclusion, this study contributes to the development of accurate and practical forecasting tools for climate adaptation. Future research is encouraged to explore hybrid models or integrate external variables to improve accuracy, especially for highly volatile indicators such as wind speed and solar radiation.

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