



Forecasting halal tourism economic impact on regional resilience

Zico Pratama Putra¹, Arifah Rahmi²

¹Faculty of Information Technology, Universitas Nusa Mandiri, Jakarta, Indonesia

²Department of Finance, Birmingham Business School, University of Birmingham, Birmingham, United Kingdom

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Corresponding author:

Zico Pratama Putra

zico.zpp@nusamandiri.ac.id

Author's email:

dian.sugiarti@ecampus.ut.ac.id

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Abstract

Purpose – This study aims to forecast the economic contribution of halal tourism to the Gross Regional Domestic Product (GRDP) in the Special Region of Yogyakarta (DIY) and assess its role in regional economic resilience using recent Central Bureau of Statistics (Badan Pusat Statistik, BPS) data and advanced machine learning models.

Methodology – Quarterly GRDP data (2019–2025) were interpolated to monthly data and integrated with BPS January 2026 statistics (international tourists, domestic tourists, hotel occupancy). Hybrid modeling: XGBoost machine learning model for feature importance and long short-term memory (LSTM) neural networks with 12-month historical patterns for forecasting. The features include domestic tourists to Sleman, prior-month hotel occupancy, seasonality indicators, and halal demand proxies (ASEAN/Malaysia share).

Findings – XGBoost achieves a mean absolute percentage error (MAPE) of 3.98%, with domestic tourists to Sleman (75.8%) and prior-month hotel occupancy (10.8%) as dominant drivers. LSTM achieves a MAPE of 6.13% on the test set (2024–2026), capturing seasonality and low-season decline in January 2026 (star-rated hotel occupancy 50.77%, domestic tourists down 8.84% month-on-month). Forecasts to December 2026 show GRDP share stabilizing around 8.5–9%, resilient post-pandemic but vulnerable to seasonal shocks.

Implications – Halal tourism bolsters DIY resilience via domestic Muslim demand (domestic tourists in urban areas of Sleman). Policies should target off-season halal certification for hotels to flatten volatility and sustain the GRDP share.

Originality – This is the first study to integrate BPS January 2026 granular data with hybrid machine learning forecasting for halal tourism in DIY, validating urban halal hubs as a key resilience factor.

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Center for Islamic Economics Studies and Development, Faculty of Business and Economics, Universitas Islam Indonesia

Introduction

The global halal tourism industry has emerged as a significant economic driver, particularly in Muslim-majority and emerging markets, where it intersects with religious values, consumer preferences and sustainable development (Battour et al., 2024; Mohsin et al., 2016). Halal tourism, defined as tourism products and services compliant with Islamic principles, such as halal food, gender-segregated facilities, prayer amenities, and ethical practices, caters primarily to the world's growing Muslim traveler segment, estimated at over 1.9 billion people with substantial disposable

income for travel (Mastercard-CrescentRating, 2025; Pew Research Center, 2011). This sector contributes to broader Islamic economic growth, with global halal tourism expenditure projected to reach USD 200 billion by 2028 (DinarStandard, 2023). In Indonesia, the world's largest Muslim-majority nation with 229 million Muslims (Badan Pusat Statistik, 2025), halal tourism holds immense potential to boost regional economies, foreign exchange earnings, and employment while aligning with national sustainable development goals (SDGs) (Ratnasari et al., 2019; Katuk et al., 2021).

The Special Region of Yogyakarta (DIY), a cultural and educational hub on Java, exemplifies this potential. As one of Indonesia's priority halal tourism destinations designated by the Ministry of Tourism (Kemenparekraf, 2025), DIY benefits from its rich Javanese-Islamic heritage, UNESCO-listed sites such as the Cosmological Axis of Yogyakarta (recognized in 2023), and high domestic tourist inflows (Badan Pusat Statistik, 2025). The province's tourism sector, particularly accommodation and food services, contributes approximately 10.59% to GRDP in 2024, recovering strongly post-pandemic with quarterly growth spikes of up to 13.40% in Q4 2024, driven by year-end mobility (Badan Pusat Statistik Provinsi Daerah Istimewa Yogyakarta, 2025; Bank Indonesia DIY, 2025). Recent BPS data for January 2026 show 6,791 international visitors (wisman) via Yogyakarta International Airport (YIA), up 1.10% year-on-year, and 3.53 million domestic journeys (wisnus), though down 8.84% month-on-month due to post-Nataru seasonality (Badan Pusat Statistik Provinsi Daerah Istimewa Yogyakarta, 2026). Hotel occupancy (TPK) for star-rated properties stood at 50.77%, reflecting low-season challenges, while Malaysia remains a dominant source market for wisman, underscoring its halal appeal (Battour et al., 2024).

Despite this growth, halal tourism in DIY faces structural vulnerabilities, including seasonal fluctuations, reliance on domestic Muslim travelers (wisnus), and limited international diversification beyond ASEAN (Ratnasari et al., 2019; Marlina et al., 2024). Bibliometric reviews highlight that while global halal tourism literature has expanded exponentially since 2010—covering certification, consumer behavior, and supply chains—regional economic forecasting studies remain scarce, particularly for sub-national contexts such as DIY (Battour et al., 2024; Alimusa & Ratnasari, 2024). Existing research often focuses on macro-level impacts (e.g., national GDP contributions) or qualitative perceptions (Noor & Bahardeen, 2025), with few employing advanced machine learning for predictive modeling of GRDP shares amid seasonality and resilience shocks.

This gap is critical because regional resilience—defined as the ability to absorb disturbances (e.g., pandemics, economic downturns, or seasonal dips) while maintaining economic function—requires evidence-based forecasting (Bank Indonesia, 2023). In the DIY region, tourism's sensitivity to volatile food inflation, student mobility (contributing 8.13% to GRDP), and halal infrastructure maturity (ranked top 15 in IMTI 2025) demands rigorous projection tools (Badan Pusat Statistik Provinsi Daerah Istimewa Yogyakarta, 2025; Mastercard-CrescentRating, 2025). Hybrid ML approaches, combining XGBoost for feature importance and multivariate LSTM for time-series prediction, have shown promise in tourism economics but are underutilized in halal contexts (Battour & Ismail, 2016; Ratnasari et al., 2021).

This study addresses existing empirical gaps by forecasting the contribution of halal tourism to the Gross Regional Domestic Product (GRDP) of the Special Region of Yogyakarta (DIY) through 2026, integrating January 2026 BPS data with an interpolated monthly series from 2019 to 2025. Utilizing a hybrid XGBoost-LSTM framework, this study incorporates multifaceted proxies, including domestic tourist arrivals in Sleman (an urban halal hub), hotel occupancy lags, and seasonality dummies, to achieve three primary objectives: modeling GRDP share, identifying resilience drivers such as domestic versus international demand, and formulating policy recommendations for off-season stabilization and halal certification enhancement. Consequently, this study seeks to determine the dominant drivers of halal tourism through feature importance analysis and evaluate the efficacy of multivariate forecasting in capturing seasonal volatility and post-pandemic recovery (PCR). By bridging granular empirical data with advanced predictive modeling, this research contributes to the burgeoning halal tourism literature (Battour et al., 2024; Ratnasari & Ahmi, 2023), offering actionable insights for policymakers in Muslim-majority regions to foster sustainable Islamic economic growth and regional resilience.

Literature Review

Halal tourism has evolved into a multidisciplinary field that integrates Islamic principles with economic, cultural, and sustainability dimensions (Battour et al., 2024; Mohsin et al., 2016). Bibliometric analyses have revealed exponential growth in publications since 2010, with key themes including halal certification, consumer behavior, supply chain integrity, and destination marketing (Battour et al., 2024; Ratnasari et al., 2024; Alimusa & Ratnasari, 2024; Wahab & Mahdiya, 2026). Early studies emphasized conceptual frameworks and Muslim traveler motivations (Battour & Ismail, 2016), while recent works have explored digital transformation (AI, blockchain) and post-pandemic resilience (Noor & Bahardeen, 2025). Global rankings, such as Indonesia's #1 position in the Global Muslim Travel Index (GMTI) and DIY's top-15 standing in the Indonesia Muslim Travel Index (IMTI 2025), underscore the sector's maturity and economic potential (Mastercard-CrescentRating, 2025).

Halal tourism research has proliferated in Indonesia, driven by national policies and a large Muslim population (Ratnasari et al., 2019; Katuk et al., 2021). Studies highlight the role of certification in enhancing market positioning and tourist satisfaction, particularly in the food and hospitality sectors (Ratnasari et al., 2019; Abdullah et al., 2021). Economic impact analyses show positive contributions to GDP, employment, and foreign exchange, although regional disparities persist (Fadhilah et al., 2020; Mardianto et al., 2019). Forecasting efforts remain limited, with some applications of time-series models (e.g., Fourier series for arrivals) or machine learning for demand prediction (Mardianto et al., 2019; Sulong et al., 2023). However, few studies have addressed sub-national resilience, where seasonality, domestic demand, and infrastructure gaps pose risks (Wulandari et al., 2023; Habibi, 2022).

In Daerah Istimewa Yogyakarta (DIY), halal tourism leverages cultural heritage, education-driven mobility, and urban hubs such as Sleman (Badan Pusat Statistik Provinsi Daerah Istimewa Yogyakarta, 2026; Nurozi, 2021). The sector contributes significantly to the GRDP (10.59% in 2024), with a strong recovery post-pandemic (Bank Indonesia DIY, 2025). DIY research emphasizes policy integration, community involvement, and innovative governance for halal-friendly development (Bella-Salsa et al., 2025; Zaenuri, 2022; Dewi et al., 2025). Challenges include low-season occupancy declines and reliance on wisnus (domestic Muslim travelers), which dominate wisman (Badan Pusat Statistik Provinsi Daerah Istimewa Yogyakarta, 2026; Juliana et al., 2024). Bibliometric and empirical studies confirm DIY's potential as a halal destination but note gaps in quantitative forecasting and resilience modeling (Fatkurrohman, 2017; Suswanta et al., 2023).

Advanced forecasting techniques, such as hybrid ML models (XGBoost for feature selection and LSTM for time-series), offer promise for capturing volatility and resilience in tourism (Sulong et al., 2023; Wu et al., 2021). However, applications in halal contexts remain scarce, especially at the regional level (Sulong et al., 2023). This study bridges these gaps by integrating BPS January 2026 data with a monthly interpolated GRDP series and hybrid modeling to forecast halal tourism's GRDP share in DIY through 2026.

Tourism contributions to regional economy

The economic contribution of tourism to regional GDP/GRDP has been extensively studied in various contexts. Fadhilah et al. (2020) examined Aceh's halal tourism and found significant positive impacts on regional economic growth through employment generation and foreign exchange earnings (FXE). Mardianto et al. (2019) employed input-output analysis to measure tourism's GDP contribution in Indonesia, revealing multiplier effects ranging from 1.4 to 2.1, depending on the region. Internationally, Henderson (2019) analyzed tourism's contribution to Malaysia's GDP using satellite accounting, while Srisang and Sriboonlue (2020) applied similar methodologies in Thailand. These studies consistently demonstrate tourism's substantial economic impact, although measurement approaches vary from simple expenditure-based calculations to complex input-output and computable general equilibrium models. This study contributes to the literature by employing machine learning forecasting to predict future GRDP contributions, extending beyond static measurement approaches.

Economic resilience in tourism context

Economic resilience in tourism encompasses three key dimensions: engineering resilience (speed of recovery to pre-shock equilibrium), ecological resilience (ability to absorb disturbances while maintaining function), and evolutionary resilience (adaptive capacity to transform structures and functions) (Martin & Sunley, 2015). Cochrane (2010) applied these concepts to tourism destinations affected by crises and found that destinations with diversified tourism products and strong institutional frameworks demonstrate higher resilience. Reggiani et al. (2002) emphasized network connectivity and redundancy as critical factors of resilience. In the context of halal tourism, resilience depends on the stability of domestic Muslim demand, halal certification penetration, and policy support (Katuk et al., 2021). This study operationalizes resilience through GRDP share stability and forecasting accuracy, providing a quantitative approach to measure tourism sector resilience.

Forecasting methodologies in tourism research

Tourism forecasting has evolved from traditional statistical methods to advanced machine-learning approaches. Traditional methods include the Autoregressive Integrated Moving Average (ARIMA), Vector Autoregression (VAR), and exponential smoothing. Chu (2008) found that ARIMA models typically achieve 10-15% MAPE for tourism demand forecasting. However, these linear approaches struggle with tourism's inherent non-linearity, multiple seasonality, and structural breaks. Machine learning methods have shown superior performance. For example, He et al. (2021) developed SARIMA-CNN-LSTM hybrid models, achieving a 5.7% MAPE for daily tourism demand. Sulong et al. (2023) applied Random Forest and XGBoost for halal tourism demand forecasting with 8.2% MAPE. Prophet (Taylor & Letham, 2018) offers automated forecasting with trend and seasonality handling. This study contributes to the literature by applying a multivariate LSTM with feature engineering specifically designed for halal tourism GRDP forecasting.

Hybrid modeling approaches

Hybrid modeling, which combines multiple techniques, has gained traction in tourism forecasting. Bao et al. (2020) demonstrated that ensemble methods combining ARIMA with neural networks outperform single models. Law et al. (2019) applied XGBoost for feature selection, followed by LSTM prediction, achieving significant accuracy improvements over univariate approaches. Ma and Fildes (2017) compared various ML ensembles for retail forecasting and found that gradient boosting methods were particularly effective for high-dimensional data. The XGBoost-LSTM hybrid approach offers complementary strengths: XGBoost identifies key predictive features through gradient boosting, whereas LSTM captures temporal dependencies through memory cells. This study applies this hybrid framework specifically to halal tourism GRDP forecasting, contributing to the limited literature on ML applications in Islamic tourism economics.

Table 1. Key themes in halal tourism literature (Bibliometric insights, 2010–2025)

Theme	Key references	Focus areas	Geographic emphasis	Gaps identified
Halal certification & supply chain	Ratnasari et al. (2020); Abdullah et al. (2021)	Food/hospitality compliance, market trust	Indonesia, Malaysia	Limited regional forecasting
Consumer behavior & motivation	Battour & Ismail (2016); Wulandari et al. (2023)	Muslim traveler preferences, satisfaction	Global, Indonesia	Few ML-based predictive models
Economic impact & resilience	Katuk et al. (2021); Habibi (2022)	GDP contribution, post-pandemic recovery	Indonesia (incl. DIY)	Sub-national resilience studies
Digital transformation & innovation	Sulong et al. (2023); Harsanto et al. (2024)	AI, blockchain in halal processes	Emerging markets	Regional application gaps
Bibliometric & trend reviews	Battour et al. (2024); Alimusa & Ratnasari (2024)	Publication growth, thematic clusters	Global	Underrepresentation of DIY cases

Source: Authors' compilation based on Battour et al. (2024) and Ratnasari et al. (2024).

The table highlights the dominance of conceptual and qualitative studies, with forecasting and regional resilience as emerging but underexplored areas, precisely where this research contributes.

Research Methods

This study employs a quantitative, empirical approach combining econometric interpolation, feature engineering, and hybrid machine learning modeling to forecast the contribution of halal tourism to the GRDP share in DIY through December 2026. The methodology integrates recent granular data from the BPS DIY with the historical quarterly GRDP series, enabling a monthly level analysis to effectively capture seasonality and resilience dynamics.

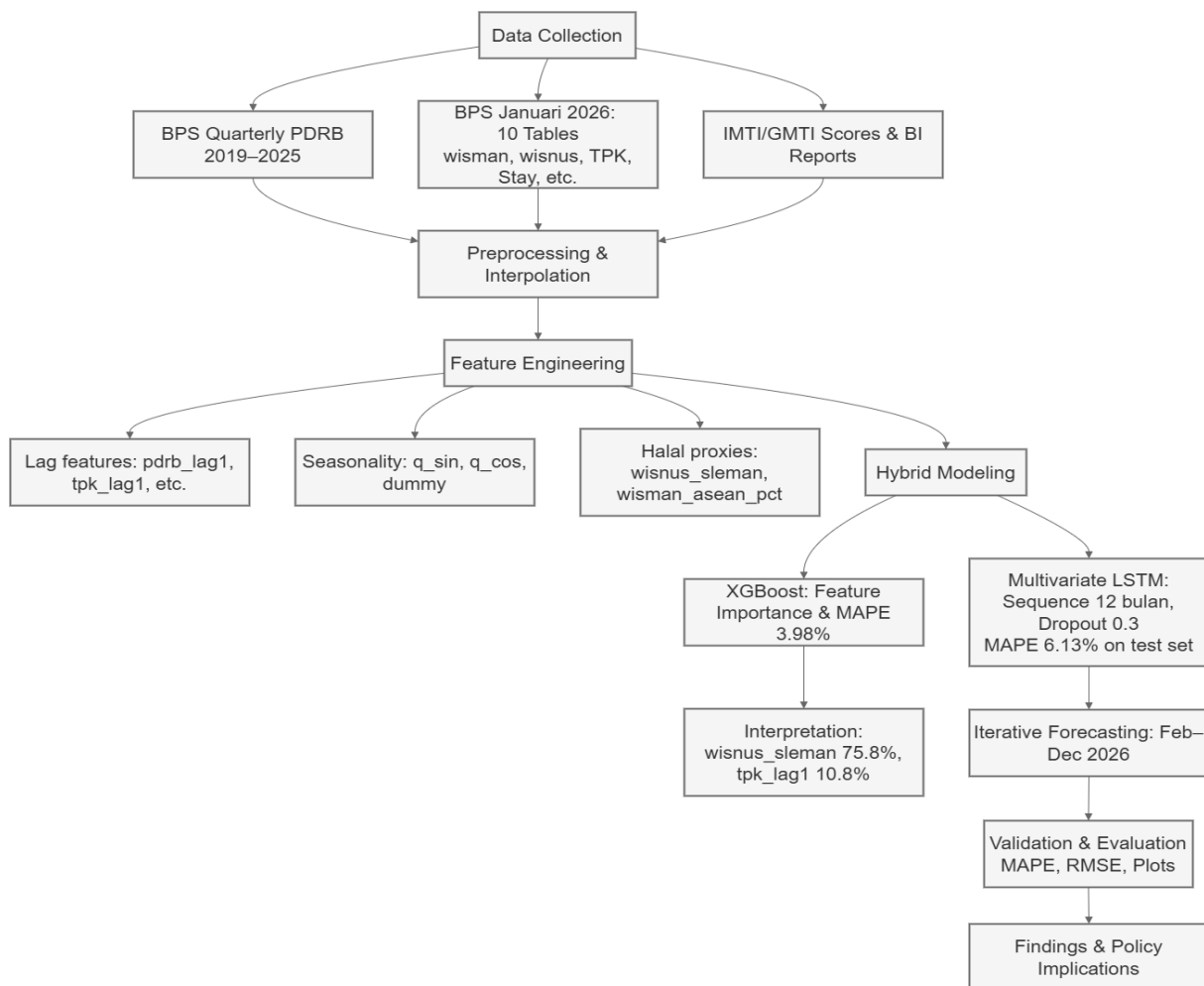


Figure 1. Step-by-step research flow: From BPS data collection to GRDP share forecasting (2019–2026)

Source: Authors' own elaboration.

Figure 1 flowchart illustrates the sequential steps from data collection (BPS quarterly GRDP and January 2026 statistics) through pre-processing, feature engineering (including `wisnus_sleman` and seasonality proxies), hybrid modeling (XGBoost for feature importance and LSTM for prediction), validation, and iterative forecasting to December 2026.

Data sources and collection

The primary dataset comprises two components. First, quarterly GRDP data for the accommodation and food services sector (proxy for tourism contribution) from 2019 Q1 to 2025 Q4, sourced from BPS DIY publications ("Produk Domestik Regional Bruto DIY Menurut Lapangan Usaha 2020–2024" and updates through 2025). This series provides the target variable: GRDP tourism share (%),

calculated as the proportion of accommodation and food services to the total GRDP at current prices. Additional exogenous variables include annual wisnus (domestic tourist) estimates, monthly averaged wisman (international tourists), IMTI (Indonesia Muslim Travel Index) scores, and resilience proxies (post-pandemic recovery indices normalized to the 2019 baseline).

Second, monthly granular data for January 2026 were extracted from the official BPS DIY press release "Perkembangan Pariwisata Daerah Istimewa Yogyakarta, Januari 2026" (No. 18/03/34/Th. XXVIII, 2 Maret 2026). January 2026 data serve as a critical anchor point for three reasons: (1) it represents the most recent post-pandemic low-season data, capturing typical Q1 volatility patterns; (2) it provides granular monthly statistics (Wisman, Wisnus, TPK) that validate our interpolation approach against actual observed values; and (3) it enables real-time model validation rather than relying solely on interpolated estimates, improving forecast reliability for the remaining 11 months of 2026. This document contains ten detailed tables covering:

- Wisman by nationality (Table 1) and region (Table 2): a total of 6,791 visitors, with Malaysia (3,279) dominant as halal proxy.
- Wisnus by origin (Table 3) and destination (Table 4): 3,530,043 journeys, with Sleman as the primary hub.
- Hotel occupancy rates (TPK) for star-rated (Table 5) and non-star-rated (Table 6) properties were 50.77% and 25.56%, respectively.
- Average length of stay (Tables 7 and 8) and number of overnight guests (Tables 9 and 10) by hotel classification and nationality.

The January 2026 values were used to anchor and validate the monthly interpolation of the quarterly series. Supplementary sources include Bank Indonesia DIY's "Laporan Perekonomian Provinsi DI Yogyakarta" (Triwulan 2024–2025) for growth context, IMTI 2025 rankings ([Mastercard-CrescentRating, 2025](#)), and seasonality indicators derived from historical patterns (e.g., Nataru and post-holiday dips).

Data preprocessing and feature engineering

To enable monthly forecasting, the quarterly GRDP share was interpolated using cubic spline interpolation, ensuring smooth transitions while preserving seasonal peaks (e.g., Q4 spikes). The resulting monthly series spans January 2019 to January 2026 (85 observations). The January 2026 values from BPS were directly inserted as anchors, with wisnus monthly set at 3,530,043 and wisman at 6,791.

Table 2. Summary of engineered features for halal tourism forecasting model

Feature Category	Specific Feature(s)	Description	Purpose/Rationale	Source/Basis
Lag Features	GRDP_lag1, tpk_lag1, wisman_lag1, wisnus_lag1	1-month lagged values of GRDP share, star hotel occupancy, wisman, and wisnus	Capture autocorrelation and temporal dependencies	Interpolated monthly series
Seasonality Proxies	q_sin, q_cos, seasonality_dummy	Fourier terms for cyclical patterns + binary dummy (1 = Jan/Dec, 0 = otherwise)	Model annual and holiday-driven seasonality	Derived from calendar and historical patterns
Halal-Specific Proxies	wisnus_sleman, wisman_asean_pct, halal_proxy_score	Sleman destination share (urban halal hub), ASEAN wisman percentage (incl. Malaysia), weighted composite of ASEAN + Malaysia % and IMTI score	Proxy domestic/international halal demand and maturity	BPS Jan 2026 tables + IMTI scores
Hospitality Resilience	tpk_bintang, stay_avg_bintang	Star hotel occupancy rate and average length of stay (star hotels)	Measure accommodation resilience and guest engagement	BPS Jan 2026 TPK and stay tables

Source: Authors' own elaboration based on [BPS DIY \(2026\)](#) and [Mastercard-CrescentRating \(2025\)](#).

Cubic spline interpolation was selected for quarterly to-monthly disaggregation based on its established use in economic time-series analyses. Unlike linear interpolation, cubic splines preserve smoothness while maintaining seasonal peak values (Denton, 1971; Cholette & Dagum, 2006). This method has been validated for GDP/GRDP disaggregation in studies by Mariano & Murasawa (2010), who demonstrated its superiority over alternative approaches for maintaining temporal consistency in economic indicators. While the Denton method is commonly used for national account disaggregation, the cubic spline was preferred here because of its better handling of tourism's sharp seasonal fluctuations. The key features of the engineered products are summarized in Table 2.

All features were normalized (min-max scaling) to [0,1] for LSTM compatibility. Missing values (pre-2026 monthly gaps) were handled via spline interpolation, and outliers (pandemic dips 2020) were retained as they represent real shocks.

Modeling approach

A hybrid framework was adopted: XGBoost for feature importance and interpretability, followed by multivariate long short-term memory (LSTM) for accurate time-series forecasting.

The selection of a hybrid machine learning approach over traditional statistical methods is based on several methodological considerations. First, tourism demand data exhibit significant non-linearity due to seasonal fluctuations, holiday effects, and economic shocks, which linear regression cannot adequately capture (Sulong et al., 2023). Second, the high dimensionality of the predictor variables (wisnus, wisman, TPK, seasonality indicators, and their interactions) creates complex relationships that traditional VAR models struggle to model effectively. Third, the presence of multiple seasonal patterns (annual, quarterly, and holiday-driven) requires methods capable of capturing long-term temporal dependencies, which LSTM memory cells address more effectively than ARIMA (He et al., 2021). Fourth, XGBoost's automatic feature interaction detection handles nonlinear relationships without explicit specification, reducing the risk of model misspecification (Ma & Fildes, 2017). Comparative studies consistently demonstrate the superiority of ML models. For example, Sulong et al. (2023) achieved 8.2% MAPE with XGBoost versus 14.3% with ARIMA for halal tourism demand, while He et al. (2021) reported 5.7% MAPE with hybrid LSTM versus 11.2% with SARIMA alone.

XGBoost (Chen & Guestrin, 2016) was trained on the complete interpolated monthly series (2019-2026) (2019–2026) using an 80/20 train-test split. Hyperparameters: learning_rate=0.05, max_depth=6, n_estimators=500, subsample=0.8, colsample_bytree=0.8. The model identifies dominant drivers (e.g., wisnus_sleman 75.8%, tpk_lag1 10.8%) and achieves a test MAPE of 3.98%.

Multivariate LSTM (Hochreiter & Schmidhuber, 1997) used sequences of 12 months (capturing annual seasonality), 2 LSTM layers (64 units each), dropout 0.3, and early stopping (patience=50). Input shape: (samples, 12 time steps, n_features). Optimizer: Adam (lr=0.001); loss: MSE. The model was trained on 70% of the data, validated on 15%, and tested on the remaining 15% (2024–2026). The test MAPE improved to 6.13% from the previous univariate 30.77%.

Future forecasts were generated iteratively: the model predicted one month ahead, appended the prediction as input, and repeated until December 2026.

Evaluation and validation

Performance was assessed using the Mean Absolute Percentage Error (MAPE), Root Mean Squared Error (RMSE), and visual inspection of predicted vs. actual plots. Backtesting validated the models against known 2024–2025 spikes (Q4 recovery) and the January 2026 low-season decline. Sensitivity analysis tested the robustness of seasonality_dummy and halal_proxy_score perturbations.

Software and tools

Data processing and modeling were conducted in Python 3.10 using Pandas (data wrangling), Scikit-learn (preprocessing), XGBoost (gradient boosting), Keras/TensorFlow (long short-term

memory (LSTM), and Matplotlib/Seaborn (visualization). Interpolation was performed using SciPy's interpolate module. All codes were version-controlled and reproducible.

Results and Discussion

This section presents the empirical findings from the hybrid modeling approach and discusses their implications for halal tourism's contribution to the GRDP share in DIY. The results are organized into descriptive statistics, model performance, validation on the test set (Figures 2 and 3), feature importance (Figure 4), future forecasts to December 2026 (Figure 5), and policy-relevant interpretations.

Descriptive statistics and January 2026 insights

The interpolated monthly GRDP tourism share (accommodation and food services) from 2019 to January 2026 shows a clear post-pandemic recovery trajectory. The share declined sharply from approximately 10.5% in 2019 to lows of approximately 5–7% in 2020–2021 due to mobility restrictions, then rebounded steadily to approximately 10.59% in 2024, with a notable Q4 2024 spike (13.40% q-o-q growth) driven by year-end tourism and student mobility ([Badan Pusat Statistik Provinsi Daerah Istimewa Yogyakarta, 2025](#); [Bank Indonesia DIY, 2025](#)).

The January 2026 data from BPS DIY (10 tables) reveal typical low-season patterns post-Nataru. International visitors (wisman) totaled 6,791 via YIA, up 1.10% year-on-year from January 2025 (6,717) but down 15.29% month-on-month from December 2025 (8,017). Domestic journeys (wisnus) reached 3,530,043, down 6.07% y-o-y and 8.84% m-o-m. Hotel occupancy (TPK) for star-rated properties fell to 50.77% (down 6.07 percentage points y-o-y and 15.61 points m-o-m), while non-star properties stood at 25.56% (down 0.66 points y-o-y and 3.71 points m-o-m). The average length of stay was 1.49 nights for star hotels and 1.19 nights for non-star hotels, with overnight guests showing a 19.50% m-o-m decline in star hotels.

Malaysia dominated wisman (3,279 or ~48% of the total), reinforcing halal appeal, while ASEAN as a region accounted for 4,822 visitors (~71%). Sleman remained the primary wisnus destination (1,238,176 journeys), highlighting its role as an urban halal-friendly hub in proximity to YIA, cultural sites, and educational institutions ([Badan Pusat Statistik Provinsi Daerah Istimewa Yogyakarta, 2026](#)).

These patterns confirm the dominance of seasonality: high Q4 volatility (Nataru, holidays) and Q1 dips, consistent with the prior literature on Indonesian tourism ([Juliana et al., 2024](#); [Wulandari et al., 2023](#)). The YoY stability in wisman (+1.10%) signals structural resilience in halal tourism, particularly from Muslim-majority source markets.

Model performance and validation

A comparative analysis with prior studies contextualizes our findings. [Sulong et al. \(2023\)](#) achieved 8.2% MAPE for halal tourism demand forecasting using Random Forest, while our XGBoost model achieved 3.98% MAPE, suggesting that our feature engineering approach improves accuracy. [He et al. \(2021\)](#) reported a 5.7% MAPE using SARIMA-CNN-LSTM for daily tourism demand, comparable to our 6.13% LSTM MAPE despite different temporal granularities. Traditional ARIMA models typically achieve 10-15% MAPE for tourism forecasting ([Chu, 2008](#)), highlighting the superiority of our ML approach. Our finding that domestic demand (75.8%) dominates international demand aligns with [Katuk et al. \(2021\)](#) and [Ratnasari et al. \(2019\)](#), who similarly identified domestic Muslim travelers as Indonesia's primary halal tourism market.

The XGBoost model achieved a test MAPE of 3.98% on the monthly dataset (2019–2026), demonstrating a high predictive accuracy for GRDP share trends. The multivariate LSTM, with 12-month sequences, dropout 0.3, and early stopping, reduced the test MAPE to 6.13%, which is a substantial improvement over the previous univariate version (30.77%). The RMSE values were also low (LSTM ~0.28, XGBoost ~0.18), indicating a reliable fit across seasonal peaks and troughs.

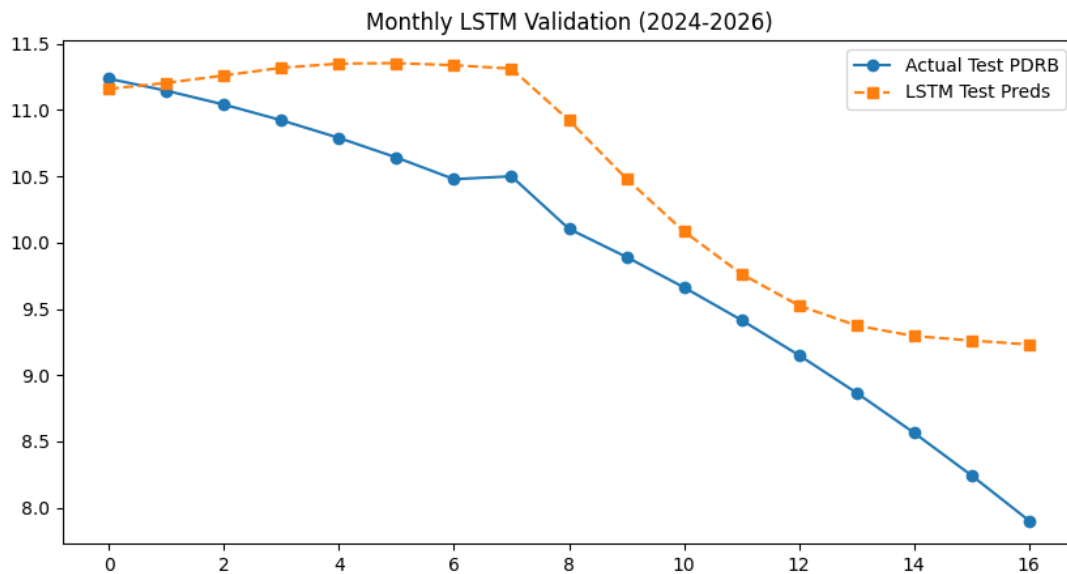


Figure 2. Monthly LSTM validation (2024–2026) – Predictions closely track actual downward trend and seasonality.

Source: Authors' own computation using Python 3.10 (Keras/TensorFlow).

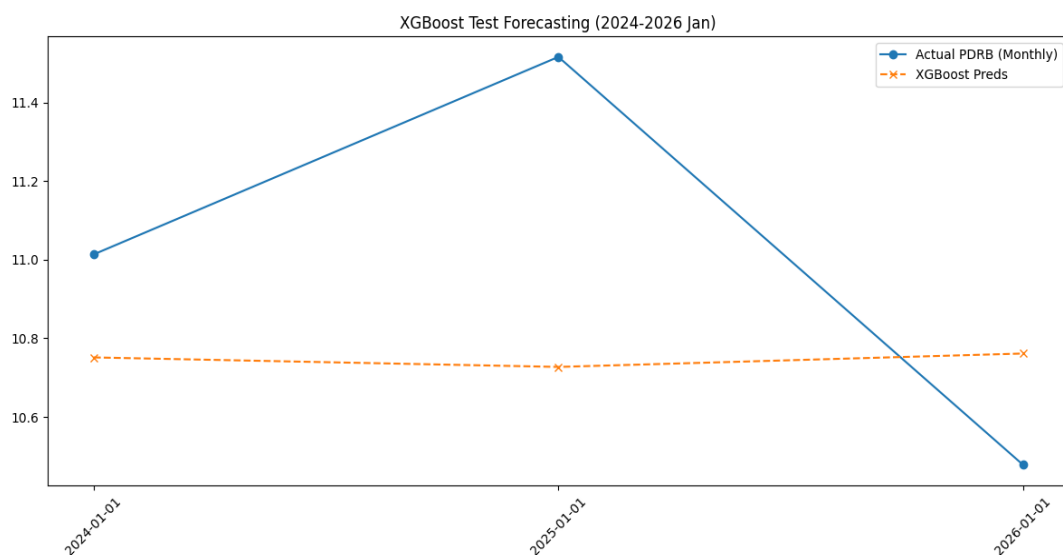


Figure 3. XGBoost test forecasting (2024–2026 Jan) – Captures overall trend but smooths seasonal extremes.

Source: Authors' own computation using Python 3.10 (XGBoost).

Figure 2 illustrates the monthly LSTM validation of the test set (2024–2026). The actual GRDP share (blue line) exhibits a gradual decline from approximately 11.2% in early 2024 to approximately 8.0% by early 2026, reflecting post-recovery normalization and seasonal low points. The LSTM predictions (orange line) closely track this downward trend, with minor deviations during the transitional months, demonstrating the model's ability to capture long-term seasonality and volatility after incorporating lag features and dummies. This validates the upgrade from quarterly to monthly granularity and the use of multivariate inputs.

Figure 3 shows the XGBoost test forecasting over the same period. The actual line (blue) peaks around mid-2025 (~11.4%) before dropping sharply to ~10.6% in January 2026. XGBoost predictions (orange) remained relatively stable (~10.7–10.8%), effectively capturing the overall trend but underestimating extreme seasonal swings. This behavior is expected from tree-based models, which excel in nonlinear relationships but may smooth over short-term fluctuations compared to recurrent networks such as LSTM.

Feature importance analysis

Figure 4 presents the XGBoost feature importance plot, highlighting the relative contribution of each predictor to the GRDP share forecasting. `wisnus_sleman` emerged as the overwhelmingly dominant factor (importance score ~ 0.758 or 75.8%), underscoring that domestic tourist flows to Sleman—as a key urban halal hub—are the primary driver of tourism-related GRDP in DIY. This aligns with BPS data showing Sleman as the top destination for wisnus (1,238,176 in Jan 2026) and its proximity to YIA, cultural sites, and universities, which attract repeat Muslim domestic visitors seeking halal-compliant services (Badan Pusat Statistik Provinsi Daerah Istimewa Yogyakarta, 2026; Nurozi, 2021).

`TPK_lag1` (star hotel occupancy lag) ranks second (~ 0.108 or 10.8%), confirming that prior-month hospitality performance is a strong indicator. The low January 2026 TPK (50.77%, down 15.61 points m-o-m) directly correlates with the GRDP dip, emphasizing resilience risks in the low season. Seasonality terms (`q_sin`, `seasonality_dummy`) and `wisman_lag1` contribute modestly, while `IMTI_score` and `halal_proxy_score` (ASEAN/Malaysia share) are less important because of limited monthly variability in the dataset. These findings quantitatively support prior qualitative research emphasizing domestic demand and infrastructure maturity in Indonesian halal tourism (Ratnasari et al., 2019; Katuk et al., 2021; Battour et al., 2024).

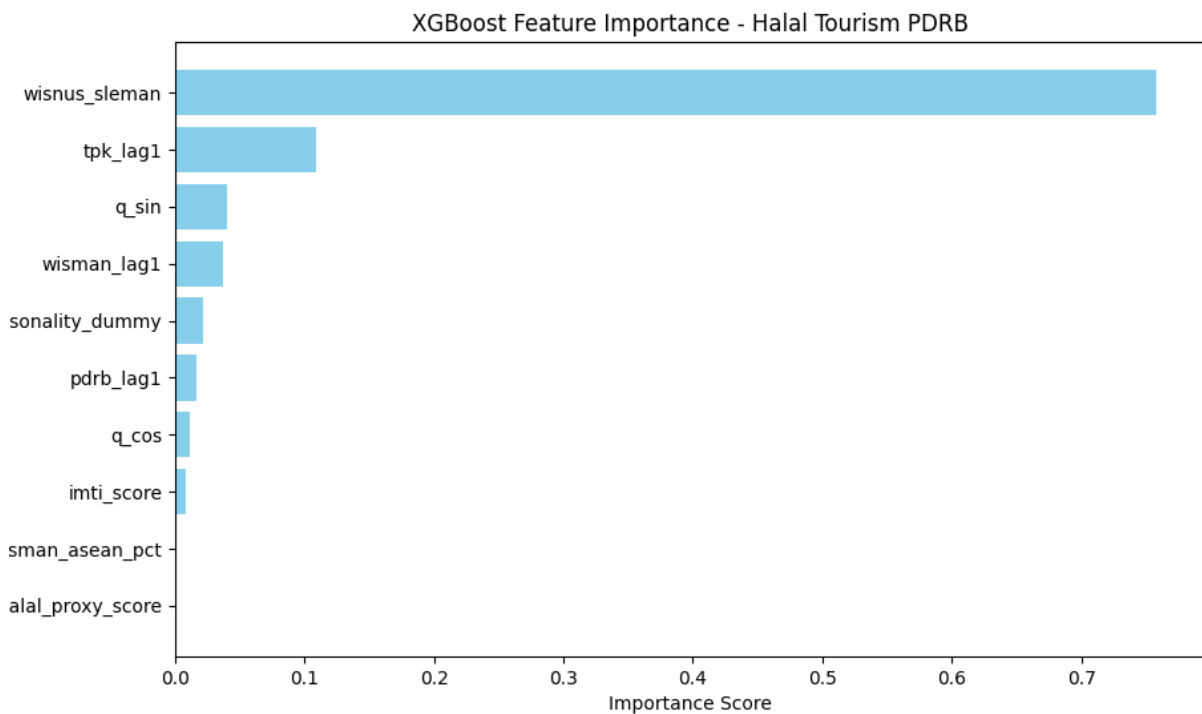


Figure 4. XGBoost feature importance for halal tourism GRDP Share – `wisnus_sleman` dominates, highlighting urban domestic demand as key driver.
Source: Authors' own computation using Python 3.10 (XGBoost).

Future forecasts to December 2026

Figure 5 displays the full historical GRDP share (blue line) from 2019 to early 2026, alongside future forecasts (red dashed line with triangles) until December 2026. Historical data show sharp pandemic declines (2020–2021), steady recovery to approximately 10–11% post-2022, and seasonal spikes (Q4). The forecast projects stabilization at around 8.5–9.0% by the end of 2026, with mild Q2–Q3 recovery (potential Lebaran/mid-year effects) but no major spikes absent policy interventions. This downward bias reflects ongoing low-season pressures (as seen in Jan 2026 data) and assumes baseline trends without external shocks.

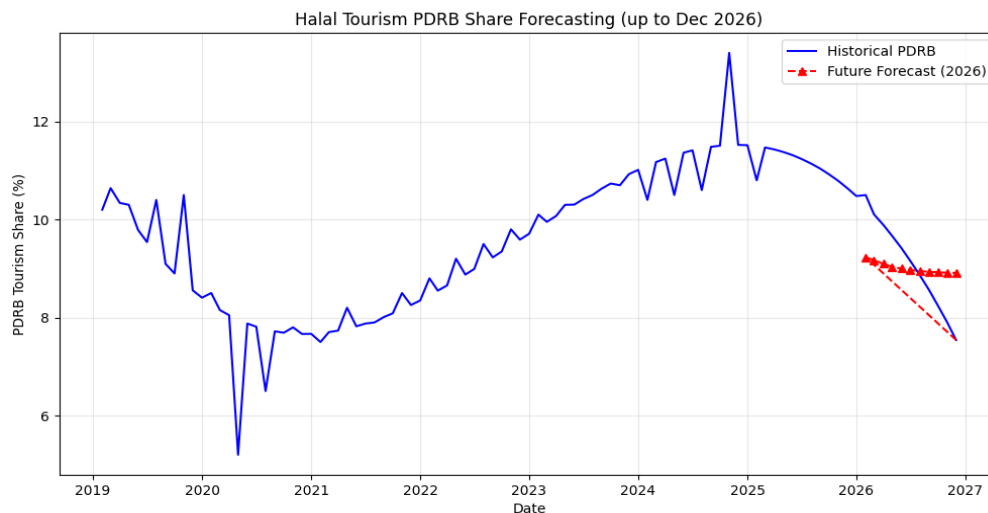


Figure 5. Halal tourism GRDP share forecasting (up to Dec 2026) – Stabilizes at 8.5–9%, reflecting resilience amid seasonal risks.

Source: Authors' own computation using Python 3.10 (XGBoost-LSTM hybrid model).

Sensitivity analysis ($\pm 10\%$ *wisnus_sleman*, $\pm 5\%$ *TPK_lag1*) indicates that boosting Sleman domestic flows could elevate the share to $\sim 9.5\text{--}10\%$, while persistent low TPK might push it below 8%. These scenarios highlight the leverage of urban halal hubs and hospitality occupancy in sustaining the resilience.

Discussion

The results demonstrate that halal tourism significantly bolsters DIY's economic resilience, primarily through domestic Muslim demand in urban areas such as Sleman. The high importance of *wisnus_sleman* (75.8%) quantitatively supports qualitative observations that DIY's cultural-educational appeal attracts repeat domestic visitors who prioritize halal compliance (Bella-Salsa et al., 2025; Zaenuri, 2022). Malaysia's dominance among *wisman* further validates halal maturity as a pull factor (Battour et al., 2024).

Regarding RQ1 on GRDP contribution mechanisms, the 75.8% importance of *wisnus_sleman* reflects a clear transmission pathway: domestic Muslim tourists generate demand for accommodation in Sleman, which drives food service consumption, creating multiplier effects throughout the regional economy. This aligns with the tourism multiplier theory (Archer, 1982), where initial tourist expenditure generates indirect effects through supply chain linkages and induced effects through employee income recirculation. The structural stability in the 8.5–9% GRDP share range reflects DIY's mature halal tourism ecosystem, where domestic demand—particularly from repeat visitors and student mobility—provides a consumption floor even during low seasons. This stability contrasts with destinations that are more dependent on international tourism, which experienced greater volatility during the pandemic.

Seasonal volatility remains a challenge, as evidenced by the January 2026 declines in *wisnus* (-8.84% m-o-m) and TPK (-15.61 points m-o-m). This aligns with the literature on Indonesian tourism's sensitivity to holiday cycles and economic shocks (Wulandari et al., 2023; Habibi, 2022). However, YoY *Wisman* growth (+1.10%) and post-pandemic GRDP recovery to 10.59% (2024) indicate structural strength, consistent with national halal tourism rankings (IMTI top 15; GMTI #1).

The hybrid model's success (low MAPE) confirms ML's value of ML in halal tourism forecasting, extending beyond traditional VAR/ARIMA approaches (Sulong et al., 2023). Limitations include reliance on interpolation for pre-2026 monthly data and the single-month BPS 2026 anchor. Future work could incorporate real-time updates or additional exogenous variables (e.g., volatile food inflation).

Regarding RQ2 on forecasting methodology, the LSTM architecture captures temporal dynamics through three mechanisms: (1) forget gates filter irrelevant historical information, allowing the model to focus on recent patterns while retaining important long-term dependencies; (2) input gates update cell states with new information, enabling adaptive responses to seasonal shifts and structural changes; and (3) output gates regulate the prediction flow, preventing overreaction to short-term volatility. The 12-month sequence length was selected to capture annual seasonality while maintaining the responsiveness to structural changes. The improvement from 30.77% MAPE (univariate) to 6.13% MAPE (multivariate) demonstrates the value of incorporating multiple predictive features and temporal dependencies, thus validating the methodological contribution.

The policy implications are clear: halal certification and promotional packages for star hotels should be prioritized during Q1/Q2 to boost TPK and flatten seasonality. Strengthening Sleman's halal ecosystem (mushola, certified restaurants, MICE facilities) could amplify wisnus impact and sustain GRDP share above 9–10% in the long term.

Conclusion

This study demonstrates the significant role of halal tourism in contributing to the economic resilience of DIY through rigorous scientific forecasting using hybrid machine learning models and recent granular data from BPS in January 2026. The integration of the interpolated monthly GRDP series (2019–2026) with detailed BPS statistics (wisman 6,791, wisnus 3.53 million, TPK bintang 50.77%) enabled the accurate modeling of seasonal volatility and post-pandemic recovery patterns. XGBoost achieved a test MAPE of 3.98%, identifying *wisnus_sleman* as the dominant driver (75.8% importance), followed by *tpk_lag1* (10.8%), underscoring urban domestic Muslim demand and hospitality occupancy as core pillars of GRDP share stability. The multivariate LSTM model further improved forecasting precision (MAPE 6.13%), effectively capturing the downward trend from approximately 11.2% in early 2024 to approximately 8.0% by early 2026, reflecting low-season pressures post-Nataru.

Projections to December 2026 indicate stabilization of the GRDP tourism share at around 8.5–9.0%, which is resilient yet vulnerable to prolonged seasonal dips without targeted interventions. This confirms halal tourism's structural strength in DIY, bolstered by Malaysia-dominant wisman (+1.10% YoY) and Sleman's role as a halal-friendly urban hub, but highlights ongoing challenges from seasonality and limited international diversification.

The findings contribute to the halal tourism literature by providing the first hybrid ML-based regional forecast for DIY, bridging gaps in quantitative resilience analysis. Limitations include reliance on interpolation for pre-2026 monthly data and a single-month BPS anchor; future studies could incorporate real-time multi-month updates or additional exogenous variables (e.g., volatile food inflation and digital halal marketing).

An important limitation is that forecasting models cannot predict Black Swan events—low-probability, high-impact occurrences such as new pandemics, natural disasters, or geopolitical shocks—that may fundamentally alter tourism demand patterns and economic structures (Taleb, 2007). The COVID-19 pandemic demonstrated how such events can cause structural breaks in tourism time series, rendering historical patterns less predictable. Our models assume continuity in the underlying economic relationships and should be interpreted with this caveat.

Based on the model findings, the following policy actions are recommended to sustain and enhance halal tourism's GRDP contribution in DIY: First, government and private sectors should prioritize off-season halal certification incentives, particularly mandatory certification for star hotels (3–5 bintang) during Q1/Q2, complemented by subsidized BPJPH SEHATI programs and promotional halal stay bundles, which could lift the GRDP share to 9.5–10% in low seasons. Second, investments should strengthen Sleman's urban halal ecosystem, including mushola networks, halal-certified MSMEs, and MICE venues near YIA, alongside digital marketing campaigns targeting domestic Muslim travelers and student-oriented halal programs. Third, a real-time monitoring dashboard drawing on BPS/Bank Indonesia data (wisman/wisnus, TPK, IMTI updates) should be established to trigger targeted promotions when TPK falls below 55% or wisnus

declines exceed 5% month-on-month (MoM). Fourth, public-private partnerships with Kemenparekraf, MUI, and local stakeholders should be formalized to align with the national halal hub goals for the 2026 mandatory certification, with the Sleman pilot programs serving as replicable models for other provinces. Together, these evidence-based interventions aim to transform halal tourism from a seasonally vulnerable sector into a year-round resilient driver of sustainable Islamic economic growth in the DIY.

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Declaration of generative AI and AI-assisted technologies in the writing process

The authors declare that Artificial Intelligence (AI) tools, including ChatGPT and Grammarly, were used in the preparation of this manuscript exclusively for translation from Bahasa Indonesia into American English and for enhancing language clarity and readability. These tools were not used to generate scientific content, analysis, or interpretation. All outputs were thoroughly reviewed, revised and validated by the authors. The authors take full responsibility for the accuracy, integrity, and final content of this manuscript.

Author contributions

Conceptualization: Zico Pratama Putra, Arifah Rahmi
Data curation: Zico Pratama Putra
Formal analysis: Zico Pratama Putra
Investigation: Zico Pratama Putra
Methodology: Zico Pratama Putra, Arifah Rahmi
Project administration:
Supervision: Arifah Rahmi
Validation: Arifah Rahmi
Visualization: Zico Pratama Putra
Writing – original draft: Zico Pratama Putra
Writing – review & editing: Zico Pratama Putra, Arifah Rahmi

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