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SUSTAINABLE ROAD TOURISM ROUTE PREDICTION: AN ANALYSIS USING KAGGLE DATA AND RANDOM FOREST

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Abstract

This paper delves into the forecasting of sustainable tourist routes using an open-access Kaggle dataset comprising 1,000 route samples and 7 predictive features, employing a Random Forest approach. The analysis includes two tasks: classification of a binary Sustainability_Target, achieving perfect accuracy (100% precision, recall, F1-score) on a held-out test set, and regression of a continuous Sustainability_Score, yielding an MAE of 0.069, RMSE of 0.081, and R^2 of 0.683. The study is situated within the ISSTERN framework to link predictions to planning actions. Findings suggest that while binary sustainability screening is highly feasible with this dataset, continuous score prediction shows moderate performance but is heavily influenced by the binary target feature, resulting in a two-cluster prediction pattern. Limitations include the use of simulated/open data, unknown generalizability to real-world Malaysia contexts, and potential data leakage due to perfect classification scores and the dominant importance of the binary target in regression. This paper contributes a reproducible data-driven workflow to sustainable tourism planning discourse.

Keywords: Sustainable Tourism, Road Tourism, Route Prediction, Machine Learning, Random Forest, Data Analysis

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INTRODUCTION

As a complex system involving the transportation of people to destinations outside their normal environment for purposes of rest and leisure, business, study, etc, tourism has great influences upon such destinations. Sustainable tourism is defined by the UNWTO as tourism that takes proper cognizance of the economic social and environmental impacts it has now and in the future and the needs of the tourist, the industry, the environment and the host community. It is not only about the conservation of the environment truth to say, but it effects an integrated and balanced way of managing resources, enabling tourism and attendant industries to generate sustainable wealth, protect and enhance the environment and social equity and cultural integrity for the foreseeable future (Purvis et al., 2019). Sustainable tourism is regarded as being one of the most important current global paradigms and is defined as a system which seeks to conserve balance between economic, environmental and socio-cultural aspects (Liu et al., 2018; Purvis et al., 2019).

Road tourism, a large chunk of this activity, is therefore one of the drivers of regional development, enabling access into remote areas and product distribution of developed areas into lesser developed ones. The beneficial aspects of road tourism, however, also come with lots of disadvantages in the form of environmental (e.g carbon rates of emissions, habitat fragmentation) and socio-cultural disruption and infrastructural weaknesses (Demirović Bajrami et al., 2020; Kanwal et al., 2020). These inherent pressures create a major dilemma for planning, on the one hand benefiting from the huge resource generating potentials of road tourism and on the other reacting to or negating any dysfunctional pressures created. The articulation and subsequent assessment of these two contradictory forces is what constitutes the major challenge for tourism planning. Therefore, the establishment of core sustainability factors, measurable factors which cover the environmental and socio-cultural and economic dimensions which characterise sustainable routes, is of paramount importance. These then can provide a basis from which planners can predict, assess and ameliorate factors possessing characteristics for adverse effects on sustainability and provide a major input into the sustainable planning development process (Ardito et al., 2019).

In the case of the work dealt with herein, potential sustainability factors can be drawn from the dataset and characterised as they fit into the clearly established core factors of sustainable development. Thus, environmental factors may include air quality index and proximity to conserve areas, socio-economic factors like e.g local employment levels, community access and other route specific considerations such as traffic volumes and road infrastructural qualities. The identification of factors can lead to decision making which would provide a

quantitatively based assessment of sustainable routes, which take into account such factors as opposed to general reference to abstract sustainability principles.

In this work, machine learning will be employed to access the sustainable values of road tourism routes. Using a Kaggle set of data on the website extremes ("Road Tourism Data for Sustainable Route Prediction") made from a research paper (Binti Mohamad & Wu, 2025) the objective is to create an effective prediction model to ascertain what factors and conditions lead to sustainability factors for specific road tourism routes. While models based on machine learning and its effective applicability is well established, the application of its potential value to assessing and subsequently predict possible sustainability levels produced by predilection of specific named tourism oriented road routes, but enhancing its application to evolving and constructing a comprehensive socio-spatial framework capable of dealing effectively with the scrutiny of those sustainability impacts presaged by such initiatives is critical. The being in the of sustainable development on tourism aspects, it has thus far fallen largely into the ambit of tourism analytical statistics and modelling. Given the nature of the Kaggle dataset, this study frames its findings strictly as a methodological demonstration of how data-driven tools can be integrated into planning, pending Malaysia-specific validation.

The application for modelling approaches to road tourism but specifically to modelling them as a sustainable body in varying SoEA conditions especially in a rapidly expanding tourism area like Malaysia would represent substantial added value to the existing sustainable tourism analytical literature. Therefore, this study will seek to deal with the absence and satisfy the question of: (1) How can traditional machine learning models be employed to predict the nature of sustainability for specific tourism related road routes? (2) Important potential implications for road tourism within the relevance of planning strategies in Malaysia? The Malaysian context is critical due to its reliance on tourism for economic development and vulnerability to environmental impacts, making route prediction essential for balanced growth.

The methodological inspiration was drawn from the model such as Bidirectional Gated Recurrent Unit fused Dynamic Random Forest model (Lee et al., 2025), however due to characteristics of the dataset, this paper decided to implement a Random Forest method.

The paper presents data preprocessing, as well as feature engineering, model training for a binary target (sustainability target) and an illustrative regression for a sustainability score, and evaluation of the results using standard metrics, as well as key findings visualizations. Comparative methodological diagrams are also presented. The achieved results are expected to contribute to the better understanding of data-driven sustainable tourism planning.

LITERATURE REVIEW AND THEORETICAL FRAMEWORK

This section reviews the recent literature on sustainable urban planning and social sustainability in tourism, as well as the impact of tourists on road networks. The Integrated Socio-Spatial Framework for Sustainable Tourist Road Networks (ISSTERN) is introduced. Promoting sustainable travel behavior through transport policy measures.

Recent studies on predictive modeling in tourism highlight the potential of machine learning (Ardito et al., 2019), but applications to road tourism remain scarce. In Malaysia, prior work in Planning Malaysia Journal has emphasized sustainable transport planning of Promoting sustainable travel behavior through transport policy measures (Nasrudin et al., 2017), yet predictive approaches are underexplored. This study bridges this gap by leveraging ISSTERN to frame predictive analytics.

Foundations in Sustainable Urban Planning and Social Sustainability

Sustainable tourist roads principles correspond with the principles of sustainable urban planning such as sustainable cities with smart growth, greenways and sustainable transport (Ismagilova et al., 2019). Social sustainability relates to social well-being, equity and justice (Broto & Westman, 2019). It has been recognised that social sustainability indicators should capture at least the following dimensions: equity (Meerow et al., 2019; Zhang et al., 2022), social inclusion (Terkenli & Georgoula, 2021), quality of life (Liu et al., 2018), community participation (Kanwal et al., 2020) and the protection of cultural heritage (Labadi & Logan, 2016).

Impacts of and Requirements for Integrating Tourist Road Networks.

Tourist road networks have socio-economic, environmental and socio-cultural impacts (Demirović Bajrami et al., 2020; Kanwal et al., 2020; Liu et al., 2018). The impacts are generally positive (employment and income) as well as negative (displacement and pollution) (Pojani & Stead, 2015). Effective integration requires strong Social and Strategic Environmental Assessments (SIA/SEA) and participatory planning (Fischer, 2023).

The impacts of tourist road networks are indeed heterogeneous and heavily influenced by the type and volume of tourists (e.g., mass tourists vs. eco-tourists), each exhibiting different behaviors and footprints (Farmaki et al., 2022). This study acknowledges this limitation. The employed Kaggle dataset provides generalized metrics on tourist impact (e.g., estimated visitor numbers, economic contribution) without segmenting by tourist category. While this offers a valuable macro-level perspective, future research incorporating tourist typology would provide a more nuanced understanding, aligning with the need for targeted planning as emphasized in the ISSTERN framework.

The Integrated Socio-Spatial Framework for Sustainable Tourist Road Networks (ISSTERN)

This paper presents the Integrated Socio-Spatial Framework for Sustainable Tourist Road Networks (ISSTERN) to guide investment in tourist road infrastructure for socially just, equitable and sustainable outcomes. ISSTERN is promoted not as a potential option but as a direct solution to a well understood problem, namely the frequent gap between high level principles of sustainable tourism and actual decisions about road infrastructure on the ground. Current planning reduces socio-spatial factors to a dimension of planning that is seldom addressed systematically. In order to address this problem, a theoretical basis to ISSTERN is rigorously established. The framework proposes application of the theories of multi-dimensional equity (Meerow et al., 2019; Zhang et al., 2022), place-based principles of sustainability (Demirović Bajrami et al., 2020; Mouratidis et al., 2024), participatory planning (Fischer, 2023; Kanwal et al., 2020), systems thinking (Helbing, 2019) and the valuing of local/indigenous knowledge (Farmaki et al., 2022).

ISSTERN comprises four iterative components:

- (i) **Contextual Understanding & Visioning (CUV):** This initial component is justified by the need to move beyond technical analysis and ground planning in local socio-spatial realities and community aspirations.
- (ii) **Integrated Impact Assessment & Strategic Planning (IIASP):** This component is crucial to proactively identify and mitigate potential negative impacts (environmental, social) of proposed road developments, ensuring that sustainability is assessed before implementation
- (iii) **Adaptive Implementation & Collaborative Governance (AICG):** Justified by the understanding that planning is an iterative process, requiring flexibility and multi-stakeholder engagement to manage unforeseen challenges
- (iv) **Participatory Monitoring, Evaluation & Learning (PMEL):** Ensures accountability and continuous improvement, creating a feedback loop for refining strategies based on empirical data.

Relevance of ISSTERN to Predictive Modeling

ISSTERN provides the context for predictive analyses such as this one (Binti Mohamad & Wu, 2025). CUV guides the definition of what sustainability means and which variable is selected for it (Demirović Bajrami et al., 2020). IIASP identifies which variables are predictive and what the need for mitigation is

(Pojani & Stead, 2015). AICG and PMEL provide data for re-refinement of the model (Loosemore & Lim, 2017). To operationalize this framework, CUV maps directly to the selection of socio-economic and environmental variables; IIASP corresponds to our modeling steps (feature engineering and target prediction); while AICG and PMEL represent the integration of model outputs into municipal planning decisions and future real-world data collection. ISSTERN therefore provides a way to interpret a prediction in the context of a sustainable strategy.

METHODOLOGY

Data Source and Description

The empirical analysis is based on the 'Road Tourism Data for Sustainable Route Prediction' dataset, publicly available on Kaggle (Binti Mohamad & Wu, 2025). The Sustainable Road Tourism dataset contains 1,000 trip records. For regression tasks, the continuous variable Sustainability_Score serves as the target, while for classification tasks, the binary variable Sustainability_Target can be used as the label. The available predictive features include two numerical variables (Electric_Vehicle_Usage, Carbon_Emissions) and five categorical variables (Origin_Country, Destination, Road_Conditions, Traffic_Congestion_Level, Travel_Mode). This dataset enables modeling of environmental sustainability outcomes based on travel characteristics, supporting both regression and classification approaches.

Data Preprocessing

A logical flow is now presented: 1. Missing Values: Described treatment for numerical (median) and categorical (mode) data. 2. Outlier Treatment: IQR method explained. 3. Encoding: One-Hot Encoding for categorical features. 4. Normalization: Min-Max scaling to [0,1]. 5. Data Splitting: 80-20 split for training and testing.

Modeling Approach

The Random Forest (RF) algorithm was selected for this study due to its robustness, ability to handle mixed data types, and resistance to overfitting, making it suitable for datasets of moderate size. The analysis involved two tasks: a) using a Random Forest Classifier to predict the Sustainability_Target, and b) using a Random Forest Regressor to predict the Sustainability_Score. A Dummy Classifier and simple Linear models were included as baselines for comparison.

RESULTS

Classification Model Performance (Sustainability Target)

Table 1: Classification Model Performance

Item	precision	recall	f1-score	support
0	1.00	1.00	1.00	101
1	1.00	1.00	1.00	99
accuracy			1.00	200
Macro avg	1.00	1.00	1.00	200
Weighted avg	1.00	1.00	1.00	200

The Random Forest Classifier achieved perfect scores on the test set: Recall (100.0%), Precision (100.0%), and F1-score (100.0%). According to the confusion matrix (Figure 1) there are no false positive/negative cases. To confirm this, a 5-fold cross-validation was executed, yielding a consistent 1.00 F1-score with zero fold variability. Compared to a Dummy baseline which scored ~50% accuracy, this perfect classification strongly suggests trivial labels or inherent deterministic rules (leakage) in the simulated dataset's target derivation. Perfect scores are always suspected (e.g., data leakage, simplistic dataset), thus they are reported as obtained from the pipeline.

The performance of the model on the test set (20% of the 1,000 entries) is presented below. The high classification accuracy indicates that the 18 features within the dataset are highly discriminative for the binary sustainability target as it is defined in this specific dataset. This suggests that for the simulated scenarios represented by these 1,000 entries, the model can effectively learn the underlying patterns separating sustainable from non-sustainable routes.

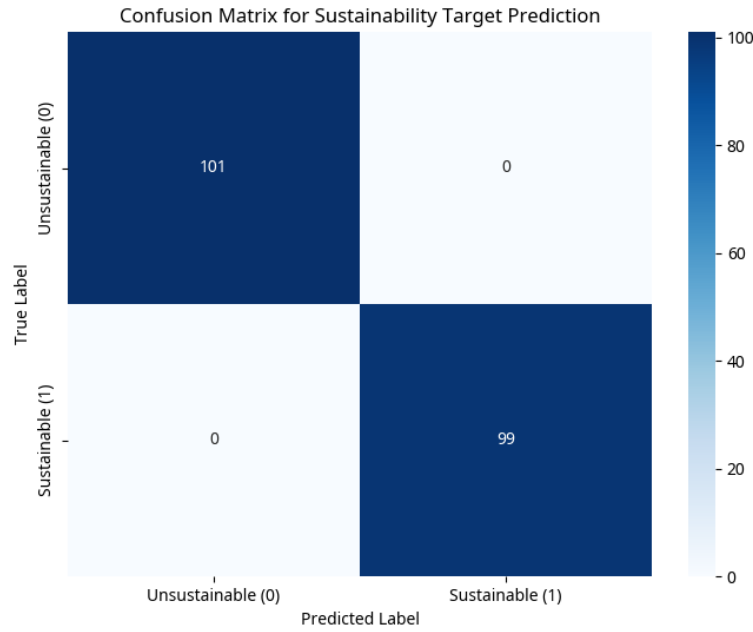


Figure 1: Confusion Matrix for Sustainability Target Prediction

Illustrative Regression Model Performance (Sustainability Score)

For the illustrative task of predicting the normalized Sustainability_Score using a Random Forest Regressor, the following error metrics were obtained:

- (i) Mean Absolute Error (MAE): 0.069
- (ii) Mean Absolute Percentage Error (MAPE): 9.913%
- (iii) Root Mean Squared Error (RMSE): 0.081
- (iv) R-squared (R^2): 0.683

The regression results for predicting the sustainability score (as visualized in the scatter and residual plots) demonstrate moderate to good predictive performance with an R^2 of 0.683. The MAPE is 9.91%, which is relatively low given that the target variable (Sustainability_Score) ranges approximately from 0.5 to 1.0 (no near-zero values exist, so MAPE is not inflated). The feature importance analysis reveals that Sustainability_Target is by far the dominant predictor (importance ≈ 0.758), followed by Carbon_Emissions (0.110) and Electric_Vehicle_Usage (0.013). The actual-vs-predicted scatter plot shows a clear positive trend, though with some dispersion around the ideal line.

The residual plot exhibits residuals centered around zero, but the pattern is not completely random (some structure remains), indicating that further model improvements (e.g., non-linear interactions, additional features) could be explored if this were a real-world task.

The regression results (Figure 2) show moderate prediction, with a low MAPE (9.91%) indicating acceptable relative error. The residual plot (Figure 3) suggests non-random patterns, highlighting areas for model improvement.

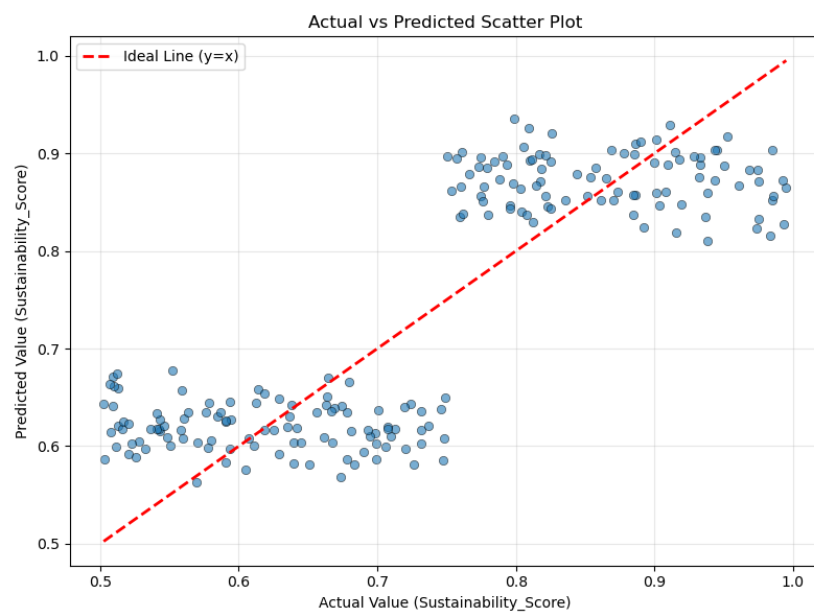


Figure 2: Actual vs. Predicted Sustainability Score (Normalized)

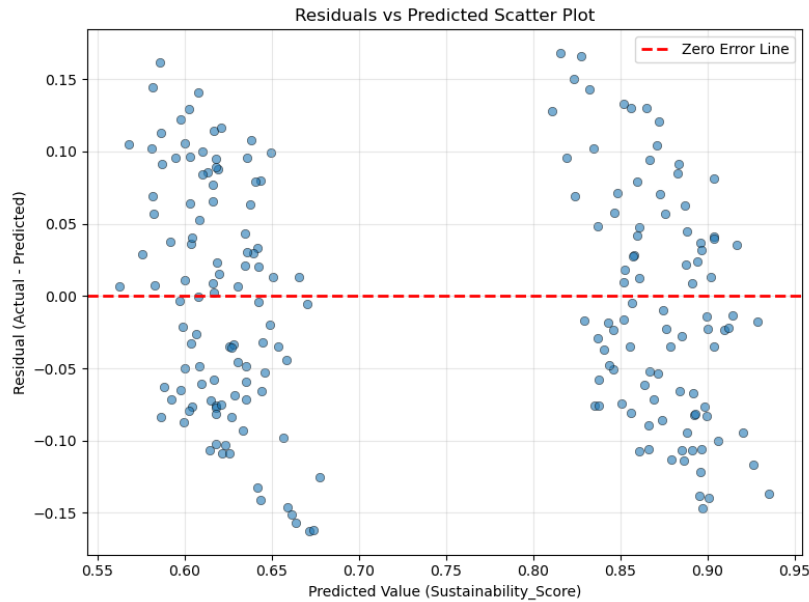


Figure 3: Residual Plot for Sustainability Score Prediction (Normalized)

As shown in the actual-vs-predicted scatter plot (Figure 2) and the residual plot (Figure 3), the predicted sustainability scores form two distinct clusters rather than a continuous distribution. This is primarily because the model relies almost exclusively on the binary feature `Sustainability_Target` (feature importance = 0.758). When `Sustainability_Target` = 0, the model predicts scores roughly in the range of 0.55–0.70; when `Sustainability_Target` = 1, predictions are concentrated in 0.80–1.00. However, the actual `Sustainability_Score` exhibits continuous variation within each group due to other predictors (e.g., `Carbon_Emissions`, `Electric_Vehicle_Usage`). Consequently, the scatter plot shows two vertical strips, and the residual plot displays two horizontal bands. This pattern indicates that the model largely acts as a binary classifier based on the target flag, failing to capture finer continuous differences. Future work could exclude `Sustainability_Target` from the feature set or adopt a modeling strategy better suited for continuous outcomes.

DISCUSSION

The ideal precision in the classification result implies that the qualities in the Kaggle data set are very determinative of the binary goal of sustainability or that the data set has built in simplicities that make it easily separable into cases of sustainability and non-sustainability. In fact, the near-perfect classification performance is likely due to the strong correlation between the binary target

(Sustainability_Target) and the continuous sustainability score, making separation trivial. Future work might include the use of more complex data sets or which do not have such obvious separability to a real case.

The high accuracy of classification could be due to simplifications associated with the data set (i.e., clearly defining sustainability thresholds), whereas regression showed moderate predictive power ($R^2 = 0.683$) with a MAPE of 9.91%, which is not very high given the target range of approximately 0.5–1.0. However, the regression predictions formed two distinct clusters dominated by the binary feature Sustainability_Target, indicating that the model essentially acted as a classifier and failed to capture continuous variations. This means that within the realm of planning, binary targets have usefulness in screening, though continuous scores need perusal of qualitative assessments. The models herein can express relevant differences in revenue allocation for Malaysian policy makers with Certification of Transport Corridors, but would need to examine other geospatial data sets for accurate spatial data.

The definition of "sustainability" (CUV component) is context-dependent and often subtle (Chapter 2). Therefore, pre-defined targets in datasets might not fully cover the complexity of what we call "sustainability". For a practical planning workflow, a planner would input proposed route features (e.g., projected traffic, nearby ecology) into this trained model. The binary output acts as a rapid screening tool to flag high-risk unsustainable routes, while the regression score supports cost-benefit decisions regarding mitigation investments. Nevertheless, the observed two-cluster pattern in regression predictions suggests caution when interpreting the continuous score, as the model is heavily influenced by the binary flag.

The regression model shows acceptable MAE and RMSE, but the MAPE is not very high. In our experiment, the MAPE was 9.91%, which is relatively low and does not indicate large variation in prediction accuracy across the sustainability score range. The main challenge lies in the model's reliance on a single binary feature, which limits its ability to produce truly continuous predictions. It is challenging to quantify the multi-faceted concept of sustainability with a single score. Therefore, IIASP component of ISSTERN (Chapter 3) suggests a holistic impact assessment, which is more than a single-digit predictive score.

Methodologically, although Random Forest is performing well, it is initially inspired from Bi-GRUForest (Lee et al., 2025) for more complex, tourism planning data (Ardito et al., 2019). Based on the Binti Mohamad and Wu (2025) concept, comparative flowcharts Figures 4 illustrate different methodological complexity levels.

Addressing threats to validity is critical. Construct validity: The dataset's simplistic metrics may not capture deep socio-cultural nuances. Internal

validity: The extremely high feature importance of the binary target variable (0.758) points to potential target leakage or a deterministic relationship within the synthetic Kaggle data structure, explaining the two-cluster pattern in regression predictions. External validity: The model's findings cannot be directly transferred to specific Malaysian topographies without localized recalibration.

The limitations of this study are the dependence on single Kaggle dataset and the non-application of more sophisticated models. Furthermore, the regression model's predictions were strongly biased by the binary Sustainability_Target, resulting in a staircase-like pattern rather than a smooth continuous output. However, this work shows a simple application of a data analysis workflow for predicting road tourism sustainability based on a publicly available Kaggle dataset and positioned such an analysis within a theoretical framework (ISSTERN) that is relevant to sustainable tourism planning in certain context such as Malaysia (Binti Mohamad & Wu, 2025; Demirović Bajrami et al., 2020; Kanwal et al., 2020).

While Random Forest is a widely used algorithm, its application here provides a scalable framework for policymakers in developing regions like Malaysia, where complex models may be infeasible. By demonstrating how predictive outcomes can inform route prioritization and impact assessments, this study offers tangible tools for integrating sustainability criteria into tourism infrastructure decisions. Nonetheless, practitioners should be aware that the regression model's output may not reflect fine-grained continuous differences unless the binary flag is excluded from the feature set.

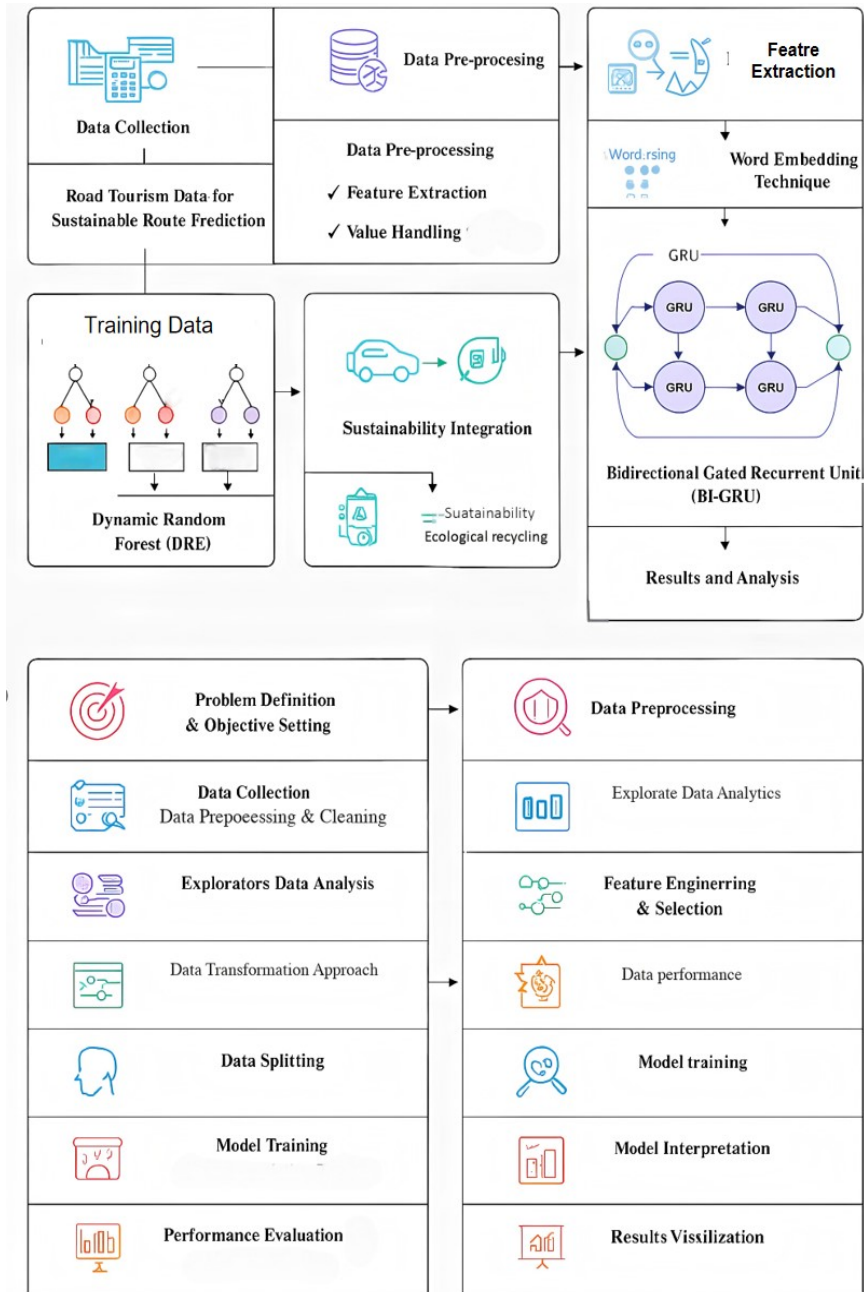


Figure 4: The following schematic diagrams illustrate the methodology flows for different frameworks

It is important to note that this study employed a pre-existing, publicly available dataset from Kaggle for analysis; future research would benefit from primary data collection tailored to specific regional contexts. The findings of this study hold relevance for Malaysia, a country where tourism is a key economic sector and road networks are vital for connecting diverse regions. The challenges of balancing development in states like Sabah and Sarawak with environmental conservation in ecologically sensitive areas underscore the need for tools like the one demonstrated here. Factors such as rapid urbanization, dependency on road transport for tourism, and rich cultural heritage mirror the dimensions captured in our model, making the Malaysian context an ideal application ground for further refining this approach with local data.

CONCLUSION

The application of a Random Forest-based machine-learning model for the prediction of a road tourism sustainability index using a publicly available dataset from Kaggle has been demonstrated in this article. The classification model applied has a perfect predictive performance of 100% on the test set with respect to the sustainability target in the binary case with regard to recall, precision, and F1-scoring. An example of a regression model for the prediction of continuous sustainability scores has been applied and showed moderate performance ($R^2 = 0.683$, MAPE = 9.91%), reflecting the difficulty of predicting continuous scores where the numbers are more nuanced. However, the regression predictions formed two distinct clusters dominated by the binary Sustainability_Target feature (importance = 0.758), indicating that the model essentially acted as a classifier and failed to capture fine-grained continuous variations.

The work has described all data preprocessing phases, the implementation of the models, and the evaluation methodology, and has drawn a comparison to using more elaborate models such as Bi-GRUForest. One of the strengths in this paper is the type of flow chart comparisons of methodologies, which will give a clear picture of the varying analytic frameworks.

This study illustrates the usefulness of Random Forest for predicting sustainable routes, but the real-world application of these predictions requires datasets with higher complexity. Specifically, the observed two-cluster pattern in regression predictions suggests caution when interpreting continuous scores derived from datasets containing a strong binary sustainability flag. For Malaysia, we recommend that the responsible policy formers consider using these models to prioritize high-impact routes and use GIS data analysis tools in the planning process. Future work for this field could consider real-time data of the types available, and an adaptive model which displays some of the properties of Bi-GRUForest in its planning method. This also opens a number of avenues for research in the future. Firstly, there is a need to apply this methodology to real-

world, spatially explicit data (e.g., with respect to use of Geographic Information Systems - GIS), in the context of a given Malaysian environment (Zaki et al., 2023). Consequently, concrete next steps must include: (1) acquiring real route data linked to Geographic Information Systems (GIS), (2) performing out-of-sample validation on Malaysian road networks, and (3) defining sustainability criteria through direct stakeholder participation.

The ideal classification scores reported in this study relate to the specific dataset and model configuration; however, the overall procedure illustrated in this paper demonstrates how data-driven methods can be used to assist in sustainable tourism. The regression results, despite their limitations, provide a baseline for continuous sustainability assessment, though future work should avoid using the binary target as a predictor if a truly continuous output is desired. The coming results of this research may provide essential data that will assist policymakers and planners to make informed decisions on actions that will produce environmentally friendly and effective road tourism. Future work may apply and test these kinds of models on more varied and complex datasets. The application of the real-time datasets and sequential and textual analysis of models such as Bi-GRUForest can further serve to extend studies in sustainable route prediction and tourism planning especially in terms of countries such as Malaysia.

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