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Predicting Financial Outcomes from Environmental Costs in Shariah Green Accounting

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Abstract

This study aims to explore the relationship between environmental costs and financial performance in the Islamic finance sector using advanced machine learning techniques. By integrating CSR Expenditure, Energy Consumption, and Carbon Emissions as environmental factors, the research applies Gradient Boosting, XGBoost, and Artificial Neural Networks (ANN) to predict Retail Banking Revenue, Wholesale Banking Revenue, and Third-Party Funds. The objective is to evaluate how sustainability practices impact financial outcomes, using an innovative approach that combines economic modeling with computer-based prediction. The findings reveal that Gradient Boosting outperforms other models, demonstrating strong predictive accuracy, especially for Third-Party Funds and Wholesale Banking Revenue. XGBoost also provides valuable insights, while ANN struggles with overestimations, indicating the need for further optimization. This research underscores the growing significance of environmental sustainability in shaping financial performance and provides a computational framework for financial institutions and policymakers to assess the impact of green accounting on economic growth.

Abstrak

Penelitian ini bertujuan untuk menganalisis hubungan antara biaya lingkungan dan kinerja keuangan di sektor keuangan syariah menggunakan teknik machine learning. Dengan mempertimbangkan Pengeluaran CSR, Konsumsi Energi, dan Emisi Karbon sebagai faktor lingkungan, penelitian ini menerapkan Gradient Boosting, XGBoost, dan Artificial Neural Networks (ANN) untuk memprediksi Pendapatan Perbankan Ritel, Pendapatan Perbankan Wholesale, dan Dana Pihak Ketiga. Hasil penelitian menunjukkan bahwa Gradient Boosting memberikan hasil terbaik dengan akurasi prediksi yang tinggi, terutama untuk Dana Pihak Ketiga dan Pendapatan Perbankan Wholesale. XGBoost juga memberikan hasil yang baik, sementara ANN cenderung memberikan prediksi yang berlebihan, sehingga memerlukan perbaikan lebih lanjut. Penelitian ini menunjukkan pentingnya keberlanjutan lingkungan dalam mempengaruhi kinerja keuangan dan memberikan kerangka komputasi untuk membantu institusi keuangan dan pembuat kebijakan dalam menilai dampak akuntansi hijau terhadap pertumbuhan ekonomi.

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INTRODUCTION

In recent decades, sustainability has become a major issue in the global economic system, including in Islamic finance. Green accounting has emerged as an accounting approach that integrates environmental aspects into financial performance measurement, aligning with growing concerns over the environmental impact of economic activities (Alrabei, 2023; Hanif, 2023). From an Islamic economic perspective, green accounting in islamic finance emphasizes the balance between economic growth and environmental preservation, aligning with the principles of *Maqashid Syariah*, which advocate sustainability as a form of social and moral responsibility (Al-Dhaimesh, 2020). In Indonesia, the Islamic finance sector has experienced significant growth, particularly through instruments such as green *sukuk* and green financing, as reported by the financial services authority (OJK) in the 2022 Islamic Finance Development Report (LPKSI). However, despite the increasing implementation of sustainability practices within Islamic finance, a major challenge remains in accurately measuring and predicting environmental costs borne by Islamic financial institutions. The uncertainty in these measurements can hinder financial planning, green investment decision-making, and sustainability policy formulation (Pikahulan, 2020). Therefore, there is an urgent need for a more accurate economic model to predict the impact of environmental costs on the financial performance of Islamic financial institutions, utilizing a data-driven and technology-based approach (Liu, 2020; Somjai, 2020). Advancements in machine learning (ML) have provided promising solutions for improving the accuracy of environmental cost predictions. Various methods, including gradient boosting machines (GBM), XGBoost, and artificial neural networks (ANN) (Agarwal, 2023), have demonstrated their effectiveness in handling the complexities of economic and environmental data analysis (Khan, 2023; Nayak et al., 2023). Thus, this study aims to develop a predictive economic model for environmental costs in green accounting for Islamic finance, leveraging a hybrid machine learning approach that combines multiple techniques to produce a more accurate and efficient predictive model.

Several previous studies have explored the implementation of green accounting within Islamic finance. For example, Islam (2023) highlighted how Islamic financial institutions are beginning to adopt sustainability accounting standards board (SASB) frameworks in their financial reporting as part of their sustainability accountability. Similarly, Khan (2024) found a positive correlation between the adoption of green cccounting and corporate financial performance, particularly in Islamic banking institutions that adhere to environmental, social, and governance (ESG) principles. From a methodological perspective, Khan et al. (2020) proposed using regression analysis and econometric models to predict the impact of environmental costs on corporate profitability. However, traditional approaches like these struggle with handling complex, non-linear, and high-dimensional data, which are common in environmental economic analysis. More recent studies, such as Nahar (2024), have started incorporating GBM and XGBoost for predicting the impact of environmental policies on corporate valuation. Nevertheless, these studies primarily focus on conventional financial institutions and have yet to consider the unique characteristics of Islamic finance in green accounting.

Despite previous contributions to green accounting modeling, several research gaps remain unresolved. First, most existing studies primarily focus on green accounting within conventional financial systems, making their models less applicable to Islamic finance, which operates on distinct ethical and non-interest-based principles (Al-Dhaimesh, 2020; Sharma, 2023). Second, prior studies predominantly rely on traditional statistical methods such as linear regression and econometrics for environmental cost prediction (Nahar, 2024). Although machine learning models like GBM and XGBoost have been introduced, there is no existing research that integrates a hybrid machine learning framework to enhance prediction accuracy in the context of Islamic green accounting (Rasyid, 2025). Additionally, the integration of environmental and Islamic financial data into predictive models remains insufficient. Most studies rely solely on conventional financial statements, without incorporating key Islamic finance indicators such as green *sukuk*, ESG reports, and sustainability policies within the Islamic finance sector ((Pikahulan, 2020). Therefore, there is a pressing need to develop a study that integrates environmental cost-benefit analysis (CBA), green GDP, and ESG reports into an economic model that leverages machine learning for predictive

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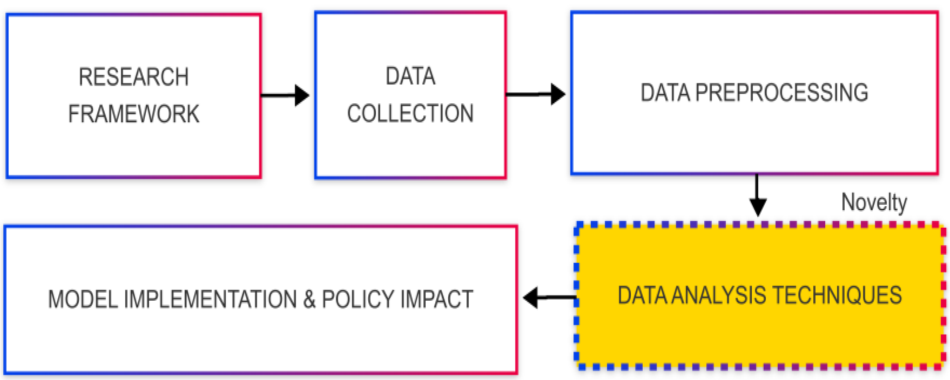
analytics in Islamic finance.

To address these research gaps, this study introduces several key novelties in its methodology and approach. First, it develops a new economic model that integrates environmental cost-benefit analysis (CBA) and green GDP computation to assess the impact of environmental costs within Islamic financial institutions. This approach enables a more precise calculation of the Islamic finance sector's contribution to a green economy. Second, this study adopts a hybrid machine learning framework, which combines gradient boosting machines (GBM), XGBoost, and artificial neural networks (ANN) to improve the accuracy of environmental cost predictions within Islamic green accounting. Additionally, recursive feature elimination (RFE) is applied to select the most relevant features for the predictive model, ensuring greater accuracy and reliability. Third, this research introduces the integration of Islamic ESG data and green *sukuk* indicators into environmental cost prediction models. By utilizing datasets from the Islamic finance development report (LPKSI) by OJK, green *sukuk* reports, and ESG reports, this study provides deeper insights into the impact of sustainability policies on Islamic finance. Fourth, this study implements time-series forecasting using long short-term memory (LSTM) and ARIMA to predict long-term environmental cost trends within Islamic finance. This predictive capability allows for an in-depth analysis of how environmental costs evolve over time, offering valuable insights for regulators and financial institutions in developing sustainable strategies.

This study presents an innovative contribution to the development of a predictive economic model for environmental costs in green accounting for Islamic finance, utilizing hybrid machine learning (GBM + XGBoost + ANN) as a solution for improving prediction accuracy. By integrating environmental CBA, green GDP computation, and ESG reports, this research offers a more comprehensive approach to measuring the economic impact of sustainability policies in Islamic finance. The findings of this study are expected to provide valuable insights for policymakers, Islamic financial institutions, and regulatory bodies in understanding the economic implications of environmental policies while also serving as a reference for advancing green investment strategies within the Islamic financial sector.

METHOD

This study is designed to develop an economic model for predicting environmental costs in Green Accounting for Islamic Finance using a Hybrid Machine Learning approach. The model integrates CBA, green GDP computation, and advanced data-driven techniques to enhance predictive accuracy and provide actionable insights for policymakers and Islamic financial institutions. Marota (2024), implementing CBA in environmental cost analysis offers a clearer understanding of the economic impact of corporate activities on sustainability. Additionally, the Khoshnava et al. (2019) emphasizes that green GDP computation is a crucial indicator in assessing the financial sector's contribution to sustainable development. Therefore, this study aims to adapt these two methodologies within the framework of green accounting for Islamic finance, while leveraging machine learning methods to improve predictive accuracy (Soltani et al., 2024).



Source: The Author (2025)

Figure 1. The Research Framework

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The first stage of this research involves data collection (figure 1), where secondary data is gathered from annual reports and sustainability reports of companies listed in the Indonesian sharia stock index (ISSI). These reports serve as primary sources, providing key insights into environmental costs, sustainability policies, regulatory compliance, and corporate social responsibility (CSR) disclosures from a sharia perspective (Alrabei, 2023). The reports are accessed through the Indonesia stock exchange (BEI) or directly from company websites (Pikahulan, 2020). Selecting this dataset aligns with the findings of (Martínez-Falcó, 2025), who highlight the importance of sustainability reporting in evaluating corporate environmental performance in Islamic finance.

Once the data is collected, the next phase is data preprocessing, which ensures data quality and consistency before conducting further analysis (Makkar, 2023). This process involves multiple steps, including handling missing values through imputation techniques to fill gaps in financial and sustainability reports (Kumalawati, 2023). Furthermore, outlier detection and removal are carried out using Z-score and Interquartile Range (IQR) methods to eliminate extreme anomalies in the dataset (Mazarei et al., 2024). Data normalization is applied to maintain uniform numerical scales, ensuring compatibility with machine learning algorithms (Moein, 2023). In this stage, feature engineering is also implemented to refine model performance. Principal component analysis (PCA) is used for dimensionality reduction, while recursive feature elimination (RFE) is applied to select the most influential variables for predictive modeling (Ramezan, 2022).

The core focus of this study lies in data analysis techniques, which encompass macroeconomic and microeconomic analysis, Machine learning model development, and model evaluation and validation. In macroeconomic and microeconomic analysis, this research employs CBA to examine the relationship between environmental costs and the financial performance of Islamic financial institutions (Fernando, 2024). Additionally, green GDP computation is incorporated to assess the contribution of Islamic financial institutions to green economic growth (World Bank, 2021). These analyses aim to provide a robust foundation for integrating sustainability into the Islamic finance sector (Hanif, 2023).

During the machine learning model development phase, this study employs a hybrid machine learning approach that combines three primary predictive models. First, GBM and XGBoost are used to handle structured financial data, capturing non-linear relationships between environmental costs and economic indicators (Nayak et al., 2023). Second, ANN are implemented to recognize complex patterns within the dataset, enhancing the model's ability to generalize across diverse financial scenarios (Deng et al., 2021). Third, LSTM and ARIMA are utilized for time-series forecasting, enabling the model to detect long-term trends in corporate environmental expenditures within the Islamic finance sector (Aparna, 2022). This combination of advanced modeling techniques has been shown to improve forecasting accuracy in financial sustainability analysis (Endiana, 2020).

Following model development, the next stage involves model evaluation and validation, ensuring the accuracy and reliability of the predictive framework. The model's performance is assessed using industry-standard evaluation metrics, including mean squared error (MSE), root mean squared error (RMSE), and R-squared (R^2) (Wanto et al., 2019). To mitigate overfitting, this study applies cross-validation (k-fold CV), a method proven to enhance the model's ability to generalize to unseen data (Sejuti & Islam, 2023). Furthermore, grid search and bayesian optimization are utilized for hyperparameter tuning, optimizing the model's predictive accuracy (Gouravaraju, 2023). Upon successful model optimization, the findings will be applied to policy recommendations and strategic decision-making within the Islamic finance sector. The predictive model developed in this study is expected to assist Islamic financial institutions in incorporating green accounting as part of their sustainability strategy (Alrabei, 2023). Additionally, it will support financial regulators in formulating data-driven environmental policies that foster sustainable finance practices (Pikahulan, 2020). Moreover, the study aims to provide valuable insights for investors and stakeholders in evaluating risk and opportunity assessments related to green finance within the Islamic finance ecosystem (Martínez-Falcó, 2025).

The dataset used in this analysis is sourced from the 2023 annual report and sustainability report of PT Bank Syariah Indonesia Tbk (BSI). The data covers three key aspects: sustainability

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program and CSR expenditures as the main variable representing environmental costs, key financial performance as the dependent variable reflecting profitability impact, and energy consumption and carbon emissions as an additional variable that serves as an environmental factor influencing operational costs.

The sustainability program and CSR expenditures act as the primary variable and are derived from BSI's 2023 sustainability report. This data outlines the distribution of funds for corporate social responsibility (CSR) and environmental responsibility programs, which are allocated across various sectors such as education, healthcare, economic empowerment, and social advocacy. Specific data points include the total funds allocated for zakat, infaq, waqf, and UPZ (zakat collection unit) across different sectors, as well as the proportion of funds dedicated to education, healthcare, and social advocacy initiatives (table 1).

Table 1. Expenditures for Sustainability Programs and CSR (Realization of Social and Environmental Responsibility (TJSL) Fund Distribution)

Funding Source	Zakat (Rp)	Infak (Rp)	UPZ BSI (Rp)	Wakaf (Rp)	Total (Rp)
Education	1.029.293.000	11.779.915.175	1.026.649.950	353.687.616	43.790.028.415
Healthcare	211.090.515	1.686.836.755	1.026.649.950	393.371.644	3.538.332.764
Humanitarian	4.488.806.547	4.547.733.646	1.726.296.318	600.600.000	11.363.436.511
Economic Empowerment	1.147.348.752	2.167.320.474	453.488.532	600.600.000	4.368.757.758
Social Advocacy	442.130.675	463.632.853	200.000.000	400.000.000	1.505.763.031
Productive Wakaf	340.314.420	10.758.549.439	2.653.137.197	550.000.000	14.301.500.056
Total	7.817.641.938	31.108.349516	13.186.172.947	4.283.859.655	95.083.995.797

Source: The Author (2025)

The key financial performance serves as the dependent variable and is sourced from BSI's 2023 annual report. This dataset is utilized to assess the impact of environmental expenditures on the bank's profitability. Key data points include total revenue generated from retail banking, SME, microfinance, pawn, and housing sectors, as well as total financing in wholesale banking and third-party funds. Additionally, the year-on-year (YoY) growth across various financing sectors is examined to evaluate the financial performance trends of the bank (table 2-4).

Table 2. Key Financial Performance (Retail Banking – Financing)

Segment	2023 (Rp Billion)	YoY Growth (%)
Retail Banking	42.258	12.29%
SME	19.346	2.40%
Micro	22.912	22.26%
Pawn (Gadai)	7.198	21.38%
Housing (Griya)	52.517	9.25%
Auto Financing (Oto)	4.186	51.61%
Mitraguna	51.336	20.14%
Pension (Pensiun)	14.626	13.94%
Credit Card	684	25.57%

Source: The Author (2025)

Table 3. Key Financial Performance (Wholesale Banking – Financing)

Segment	2023 (Rp Billion)	YoY Growth (%)
Corporate	54.542	18.21%
Commercial	12.969	17.28%
Total	67.511	18.03%

Source: The Author (2025)

Table 4. Key Financial Performance (Third-Party Funds)

Product	2023 (Rp Billion)	YoY Growth (%)
Current Accounts (Giro)	53.201	19.50%
Savings (Tabungan)	124.726	7.08%
Wadiah Savings	47.026	6.36%
Non-Wadiah Savings	77.700	7.51%
Deposits (Deposito)	115.848	15.29%

Source: The Author (2025)

As an additional variable, energy consumption and carbon emissions represent an environmental factor that may influence operational costs. This data is extracted from BSI's 2023 sustainability report and provides insights into the bank's energy consumption and carbon footprint. The dataset includes total electricity consumption from PLN for BSI's headquarters (measured in KWH and GJ), total fuel consumption for banking operations (measured in liters and GJ), and total carbon emissions (CO2-eq) generated from energy use. The purpose of analyzing this data is to explore the correlation between energy efficiency and environmental costs within the framework of Green Accounting in Islamic finance (table 5).

Table 5. Energy Consumption and Carbon Emissions

Type of Energy Consumption	Unit	Total Usage Volume	Total Energy (GJ)	Total Emissions (Ton CO_2-eq)
Electricity (PLN) for BSI Headquarters	KWH	2.117.285.90	7.616.14	1.577.07
Fuel (BBM) for Operational Vehicles at HQ	Liter	157.329.41	6,027.21	144.94
Total Energy Consumption	-	-	13.643.55	1.722.01

Source: The Author (2025)

RESULTS AND DISCUSSION

The following analysis aims to evaluate the relationship between CSR expenditure, energy consumption, carbon emissions, and financial performance (retail banking revenue, wholesale banking revenue, and third-party funds) in companies within the Islamic finance sector. Several machine learning models, including GBM, XGBoost, and ANN, were employed to predict financial outcomes based on environmental factors.

The first step in the analysis involved conducting EDA to understand the distribution and relationships within the data. The correlation heatmap revealed a strong connection between CSR expenditure and third-party funds. The boxplot in figure 2 illustrates the distribution of CSR expenditure, retail banking revenue, and third-party funds. CSR expenditure shows significant variation, with an interquartile range (IQR) between 5 billion IDR and 40 billion IDR, and an outlier exceeding 100 billion IDR, indicating some companies invest much more in CSR activities. In contrast, retail banking revenue displays a more consistent distribution, with an IQR from 10 billion IDR to 40 billion IDR and a median around 20 billion IDR, suggesting less variability compared to CSR expenditure. Third-party funds show a more stable distribution, with values ranging from 40 billion IDR to 75 billion IDR and a higher median of 60 billion IDR, indicating that these funds are a more reliable and consistent financial resource for companies. This analysis suggests that while CSR spending can be highly variable, retail banking revenue and third-party funds are more stable and crucial for financial growth. The next, relationship between csr expenditure and retail banking revenue.

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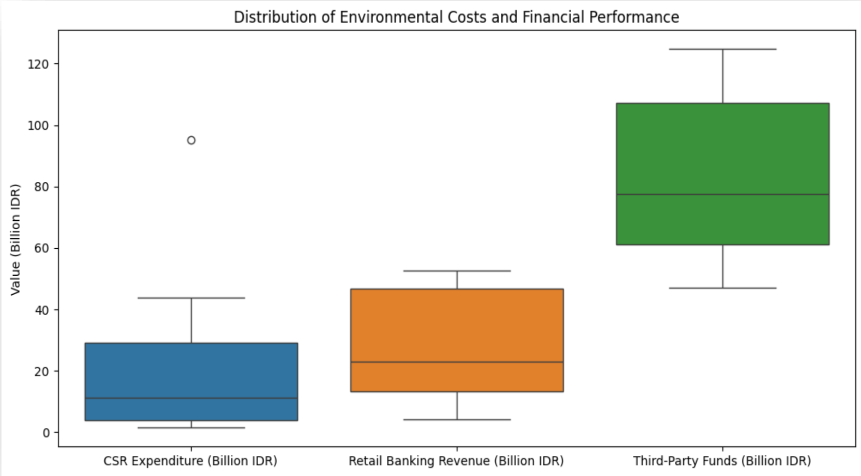

Figure 2. Distribution of Environmental Costs and Financial Performance

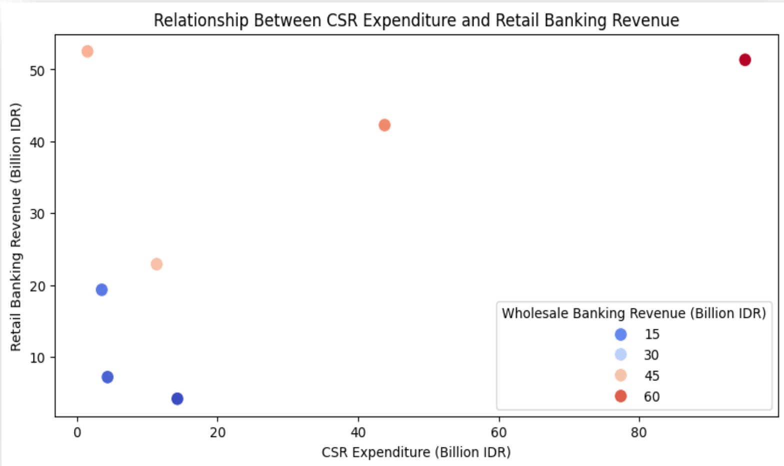

Figure 3. Relationship Between CSR Expenditure and Retail Banking Revenue

The scatter plot in Figure 3 shows a positive relationship between CSR expenditure and retail banking revenue. Companies with higher CSR expenditures tend to have higher retail banking revenues, especially when CSR spending exceeds 40 billion IDR, with one outlier showing significant figures above 80 billion IDR. Most data points are concentrated in the lower CSR expenditure range, indicating that most companies invest modestly in CSR. The plot also includes color coding for wholesale banking revenue, but no clear correlation is observed between CSR expenditure and Wholesale Banking Revenue, suggesting that CSR spending does not directly affect wholesale banking performance. The next, relationship between CSR expenditure and retail banking revenue.

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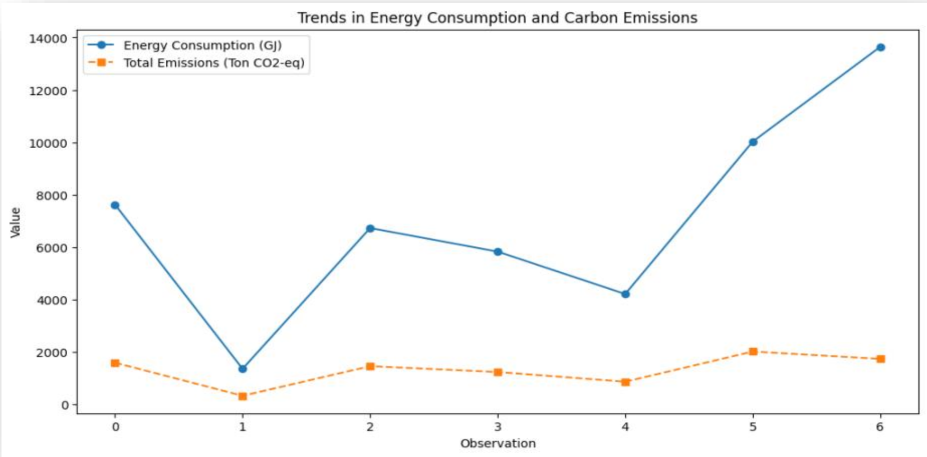

Figure 4. Trends in Energy Consumption and Carbon Emissions

The line plot in figure 4 shows that energy consumption (GJ), represented by the blue line, fluctuates significantly, with a sharp increase reaching nearly 8,000 GJ by observation 6. However, carbon emissions (Ton CO2-eq), represented by the orange dashed line, remain stable throughout the observations, fluctuating between 1,500 and 2,000 tons. Despite the rise in energy consumption, emissions do not increase accordingly, suggesting that higher energy usage does not directly correlate with an increase in carbon emissions. This indicates that factors such as energy efficiency or the type of energy sources used may influence emissions independently of energy consumption, resulting in a stable emission level despite rising energy usage. The next, correlation between environmental costs and financial performance.

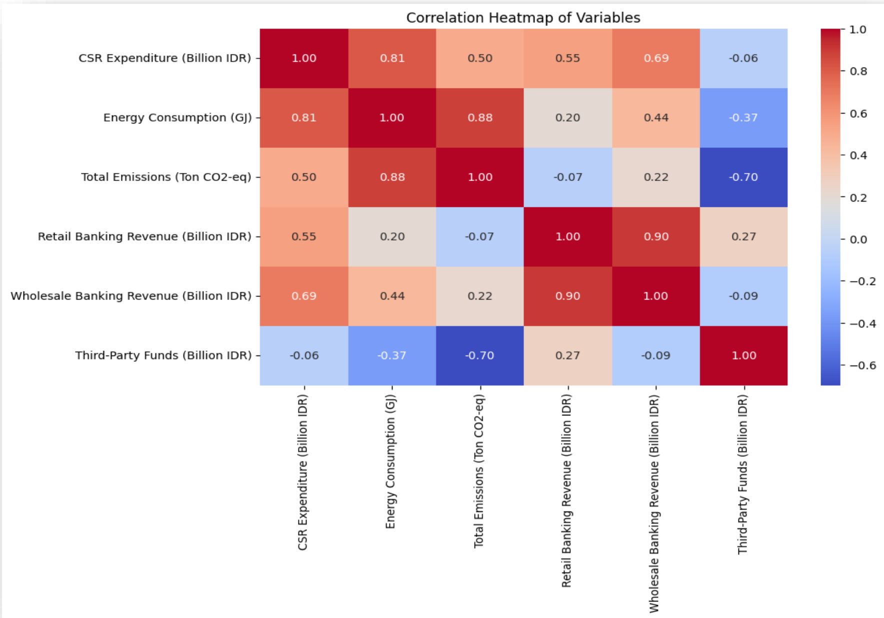

Figure 5. Correlation Between Environmental Costs and Financial Performance

Figure 5 presents a correlation heatmap showing relationships between CSR expenditure, energy consumption, total emissions, and financial performance. The heatmap reveals a strong

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positive correlation (0.81) between CSR expenditure and energy consumption, suggesting that higher CSR spending tends to correlate with increased energy use. There is a moderate positive correlation (0.50) between CSR expenditure and total emissions, indicating that more CSR spending is linked to higher emissions. Energy consumption and total emissions have a strong correlation (0.88), reflecting the expected relationship between energy use and emissions. In terms of financial performance, CSR expenditure is positively correlated with both retail banking Revenue (0.55) and wholesale banking revenue (0.69), with a stronger impact on wholesale banking. However, the correlation between CSR expenditure and third-party funds is weak and negative (-0.06). Energy consumption has a weak positive correlation with wholesale banking revenue (0.44) but a weak negative correlation with third-party funds (-0.37). Total emissions shows a small positive correlation with both banking revenues, but a strong negative correlation (-0.70) with third-party funds, suggesting that higher emissions may deter third-party investments.

For model development, this study utilizes gradient boosting, XGBoost, and ANN to predict financial outcomes based on environmental factors. Figure 6 shows the comparison between actual values and predictions for retail banking revenue, wholesale banking revenue, and third-party funds, using GBM, XGBoost, and ANN.

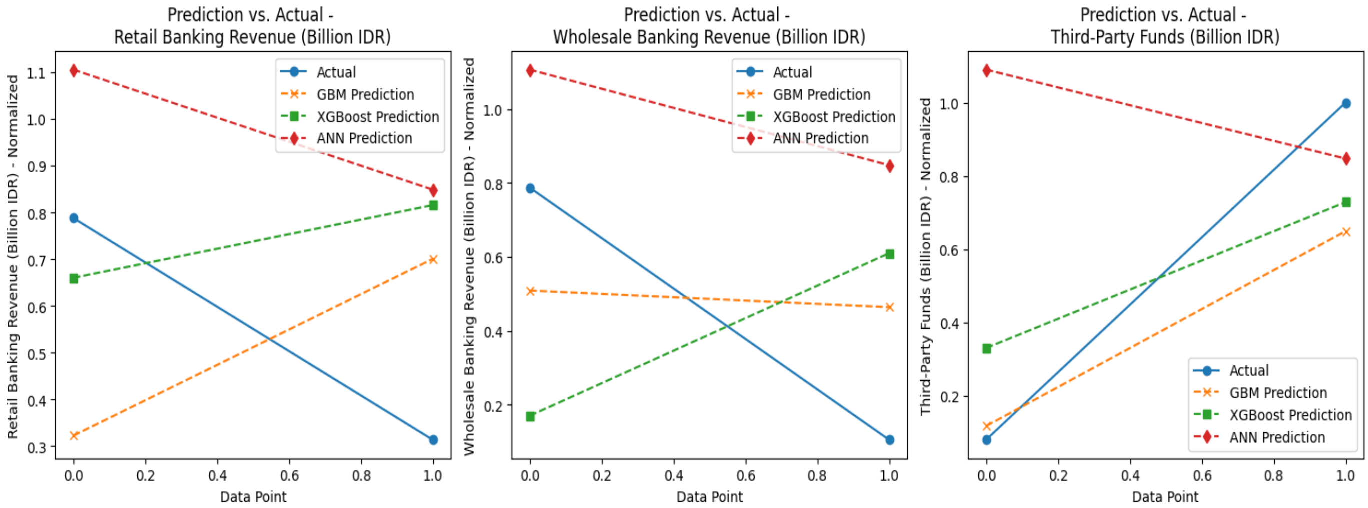

Figure 6. Correlation Between Environmental Costs and Financial Performance

For retail banking revenue, the actual values (blue) range from about 0.8 to 1.0. GBM (orange dashed line) predicts values slightly below the actual range, starting at 0.6 and ending at 0.8. XGBoost (green dashed line) is closer to the actual values but still falls short, especially at the start. ANN (red dashed line) overestimates, starting at 1.1 and ending at 0.9, which shows that ANN is not capturing the trend accurately. In wholesale banking revenue, the actual values range from 0.2 to 0.8. GBM underestimates this range, predicting values between 0.1 and 0.5. XGBoost predicts better, with values between 0.3 and 0.7, but still doesn't fully match the actual range. ANN again overestimates, with predicted values from 0.6 to 0.9, indicating it consistently overperforms compared to actual values. For third-party funds, the actual values range from 0.2 to 1.0. GBM underestimates, predicting between 0.2 and 0.7, while XGBoost predicts values closer to the actual ones, between 0.3 and 0.8. ANN starts at 1.0 and ends at 0.9, again overestimating significantly.

In conclusion, XGBoost provides the most accurate predictions, especially for wholesale banking revenue and third-party funds, with values that closely align with the actual data. GBM performs well but slightly underestimates, and ANN tends to overestimate values across all variables. This analysis demonstrates how machine learning models like XGBoost can be effective in predicting financial performance based on environmental factors such as CSR expenditure, energy consumption, and emissions.

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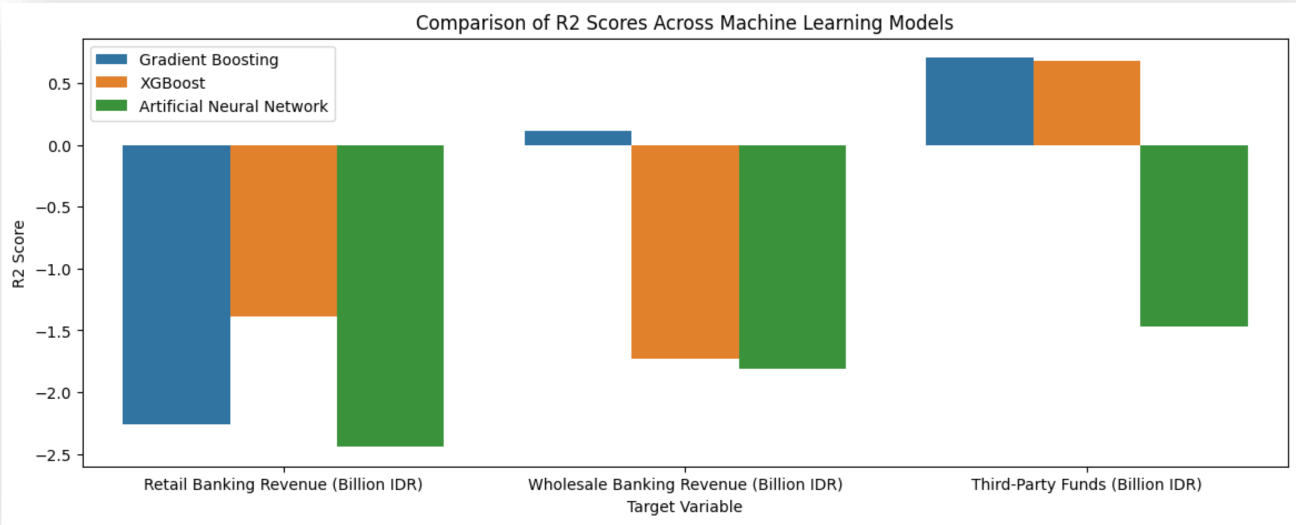

Figure 7. Correlation Between Environmental Costs and Financial Performance

Figure 7 provides a visual comparison of the R^2 scores for the three machine learning models—GBM, XGBoost, and ANN—applied to predict retail banking revenue, wholesale banking revenue, and third-party funds. For retail banking revenue, gradient boosting (GBM) performs the best with an R^2 score of -2.26, which, although negative, is higher than both XGBoost (-1.39) and ANN (-2.44). This indicates that gradient boosting provides the closest predictions to the actual values, though all models struggle to make accurate predictions for retail banking revenue since the R^2 scores are still negative.

In wholesale banking revenue, gradient boosting again performs the best with a small positive R^2 score of 0.11, indicating that it is the most accurate model for this variable. Both XGBoost (-1.73) and ANN (-1.81) have negative R^2 scores, which suggests that they are poor at predicting Wholesale banking revenue. This reinforces the advantage of using gradient boosting over the other models for this particular target. For third-party funds, gradient boosting stands out with a strong positive R^2 score of 0.71, which shows that it provides a solid fit for predicting this financial metric. XGBoost follows closely with an R^2 score of 0.68, while ANN lags behind with a negative R^2 score of -1.47, indicating it is not suitable for predicting third-party funds.

Table 6. Energy Consumption and Carbon Emissions

Model	Target Variable	MSE	R^2
Gradient Boosting	Retail Banking Revenue (Billion IDR)	0.183078265	-2.258534635
XGBoost	Retail Banking Revenue (Billion IDR)	0.134041973	-1.385757855
Artificial Neural Network	Retail Banking Revenue (Billion IDR)	0.193414165	-2.442499047
Gradient Boosting	Wholesale Banking Revenue (Billion IDR)	0.103001265	0.113898004
XGBoost	Wholesale Banking Revenue (Billion IDR)	0.317624934	-1.732472156
Artificial Neural Network	Wholesale Banking Revenue (Billion IDR)	0.32669021	-1.810459154
Gradient Boosting	Third-Party Funds (Billion IDR)	0.062344438	0.705704237
XGBoost	Third-Party Funds (Billion IDR)	0.068303693	0.677573682
Artificial Neural Network	Third-Party Funds (Billion IDR)	0.522431542	-1.466128408

Table 6 presents the mean squared error (MSE) and R^2 scores for the predictions of retail banking revenue, wholesale banking revenue, and third-party funds using the same models. For retail banking revenue, XGBoost has the lowest MSE at 0.13, suggesting it has the smallest average error in its predictions. However, all models still show poor fit for this variable, as evidenced by the negative R^2 scores: gradient boosting (-2.26), XGBoost (-1.39), and ANN (-2.44). For wholesale banking revenue, gradient boosting again outperforms with the lowest MSE of 0.10 and a positive R^2 score of 0.11, indicating that it provides the best predictions for this variable. In contrast, XGBoost (MSE = 0.32)

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and ANN (MSE = 0.33) show higher error rates and worse performance with negative R^2 scores, demonstrating that gradient boosting is the most reliable model for this financial metric. for third-party funds, gradient boosting again leads with the lowest MSE of 0.06 and the highest R^2 score of 0.71, indicating it is the most accurate and reliable model for predicting this variable. XGBoost performs well with an MSE of 0.07 and an R^2 score of 0.68, while ANN performs poorly with an MSE of 0.52 and a negative R^2 score of -1.47.

From Figure 7, it is clear that gradient boosting is the most effective model for predicting Retail banking revenue, wholesale banking revenue, and third-party funds in terms of R^2 scores. XGBoost also performs reasonably well, especially for third-party funds, but ANN consistently underperforms with negative R^2 scores. The analysis from table 6 reinforces these findings, showing that gradient boosting has the lowest MSE and the best R^2 scores for wholesale banking revenue and third-party funds, while XGBoost is slightly better for retail banking revenue but still not ideal for this variable. ANN, with high MSE and negative R^2 scores, shows that it is the least reliable model for predicting these financial metrics. Overall, gradient boosting is the preferred model for financial predictions based on environmental factors.

CONCLUSIONS AND SUGGESTION

This study aimed to predict financial outcomes like retail banking revenue, wholesale banking revenue, and third-party funds using environmental factors such as CSR expenditure, energy consumption, and carbon emissions. The results showed that GBM was the most effective model, providing the best R^2 scores and lowest MSE, especially for wholesale banking revenue and third-party funds. XGBoost also performed well but was slightly less accurate than GBM. On the other hand, Artificial Neural Networks (ANN) struggled, often overestimating values and yielding poor performance with high MSE and negative R^2 scores.

These findings imply that Islamic financial institutions should integrate environmental impact metrics such as CSR spending and emissions data into their financial decision-making and risk assessment models. The proposed framework can be adopted by regulators for evaluating green *sukuk* eligibility and monitoring institutional sustainability compliance. The findings suggest that environmental factors can indeed influence financial performance, particularly in banking. However, ANN was not the best choice for this task, and there is potential for improving its performance with further optimization.

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