In [1]:
```
import pandas as pd
import seaborn as sns
import numpy as np
import matplotlib.pyplot as plt
from sklearn.preprocessing import MinMaxScaler
from imblearn.over_sampling import SMOTE
```

In [2]:
```
dataset = pd.read_csv('Loan prediction mini dataset.csv', header=0)
```

In [3]:
```
print(dataset.head())
```

```
      Id  Age  Income      Home  Emp_length             Intent  Amount  
Rate  \
0  13116   23   88000  MORTGAGE         2.0            MEDICAL    6625   
11.22   
1   1742   23   30000      RENT         0.0           PERSONAL    1925   
12.18   
2  27672   32  160000  MORTGAGE         9.0  DEBTCONSOLIDATION   12000   
7.88   
3  24694   29   75000       OWN         3.0    HOMEIMPROVEMENT   12000   
7.51   
4   1994   22   28800      RENT         2.0            VENTURE   14000   
7.90   

   Status  Percent_income Default  Cred_length  
0       0            0.08       Y            3  
1       0            0.06       N            2  
2       0            0.07       N            8  
3       0            0.16       N            5  
4       1            0.49       N            2  
```

In [4]:
```
print(dataset.info)
```

```
<bound method DataFrame.info of          Id  Age  Income      Home  Emp
_length            Intent  Amount  \
0     13116   23   88000  MORTGAGE        2.0            MEDICAL    66
25
1      1742   23   30000      RENT        0.0           PERSONAL    19
25
2     27672   32  160000  MORTGAGE        9.0  DEBTCONSOLIDATION   120
00
3     24694   29   75000       OWN        3.0    HOMEIMPROVEMENT   120
00
4      1994   22   28800      RENT        2.0            VENTURE   140
00
...     ...  ...     ...       ...        ...                ...
...
8140  28269   34   98000       OWN       19.0            MEDICAL   160
00
8141  17403   22   24000       OWN        3.0            VENTURE    25
00
8142   7305   22   33000      RENT        4.0            MEDICAL    65
00
8143  27625   28   18000       OWN       12.0            VENTURE    35
00
8144  28486   30  148000      RENT        8.0            VENTURE   100
00

       Rate  Status  Percent_income Default  Cred_length
0     11.22       0            0.08       Y            3
1     12.18       0            0.06       N            2
2      7.88       0            0.07       N            8
3      7.51       0            0.16       N            5
4      7.90       1            0.49       N            2
...     ...     ...             ...     ...          ...
8140  10.99       0            0.16       N           10
8141  10.59       0            0.10       N            2
8142   6.17       0            0.20       N            4
8143  14.22       1            0.19       N            5
8144  13.55       0            0.07       N            9

[8145 rows x 12 columns]>
```

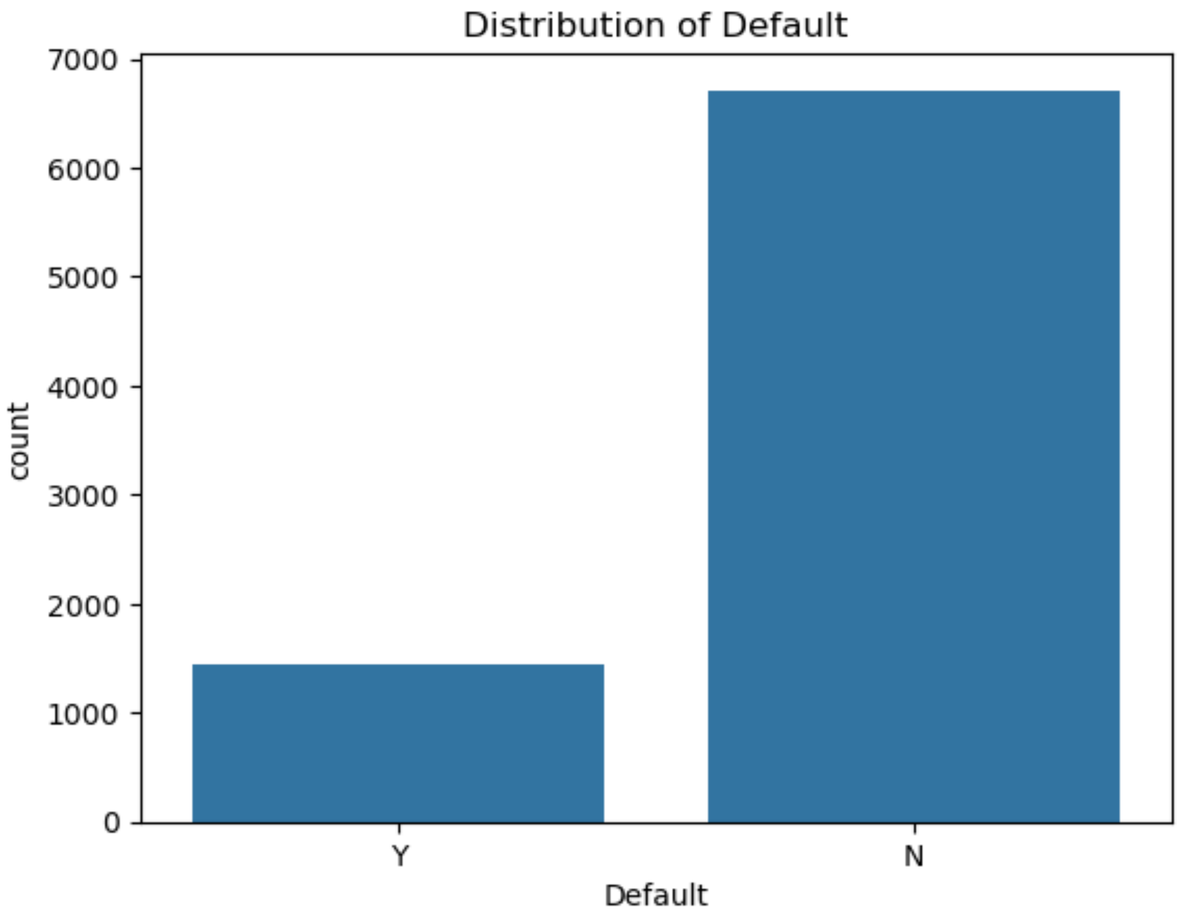
In [5]:
```
print(dataset.describe())
```

```
                 Id          Age        Income   Emp_length        Amou
nt  \
count   8145.000000  8145.000000  8.145000e+03  7909.000000   8145.0000
00
mean   16269.966974    27.689748  6.528496e+04     4.728790   9695.6568
45
std     9394.610528     6.229731  5.278421e+04     3.991919   6389.9753
88
min        4.000000    20.000000  4.000000e+03     0.000000    500.0000
00
25%     8134.000000    23.000000  3.860400e+04     2.000000   5000.0000
00
50%    16280.000000    26.000000  5.500000e+04     4.000000   8000.0000
00
75%    24325.000000    30.000000  7.800000e+04     7.000000  12500.0000
00
max    32579.000000   144.000000  1.900000e+06    41.000000  35000.0000
00

              Rate       Status  Percent_income  Cred_length
count  7383.000000  8145.000000     8145.000000  8145.000000
mean     11.040731     0.218171        0.171769     5.767342
std       3.226149     0.413029        0.106168     3.981448
min       5.420000     0.000000        0.000000     2.000000
25%       7.900000     0.000000        0.090000     3.000000
50%      10.990000     0.000000        0.150000     4.000000
75%      13.470000     0.000000        0.230000     8.000000
max      21.740000     1.000000        0.770000    30.000000
```

In [6]:
```
print(dataset.isnull().sum())
```

```
Id                  0
Age                 0
Income              0
Home                0
Emp_length        236
Intent              0
Amount              0
Rate              762
Status              0
Percent_income      0
Default             0
Cred_length         0
dtype: int64
```

In [7]:
```
# Visualizing the distribution of Default
sns.countplot(x='Default', data=dataset)
plt.title('Distribution of Default')
plt.show()
```



In [8]:
```
# Impute missing values with the mode and median for the Emp_length an
dataset['Emp_length'].fillna(dataset['Emp_length'].mode()[0], inplace=
dataset['Rate'].fillna(dataset['Rate'].median(), inplace=True)
```

```
/var/folders/bx/tys9l3gs3t5b_hqdsqy6wc940000gn/T/ipykernel_78299/242005
8516.py:2: FutureWarning: A value is trying to be set on a copy of a Da
taFrame or Series through chained assignment using an inplace method.
The behavior will change in pandas 3.0. This inplace method will never
work because the intermediate object on which we are setting values alw
ays behaves as a copy.

For example, when doing 'df[col].method(value, inplace=True)', try usin
g 'df.method({col: value}, inplace=True)' or df[col] = df[col].method(v
alue) instead, to perform the operation inplace on the original object.


  dataset['Emp_length'].fillna(dataset['Emp_length'].mode()[0], inplace
=True)
/var/folders/bx/tys9l3gs3t5b_hqdsqy6wc940000gn/T/ipykernel_78299/242005
8516.py:3: FutureWarning: A value is trying to be set on a copy of a Da
taFrame or Series through chained assignment using an inplace method.
The behavior will change in pandas 3.0. This inplace method will never
work because the intermediate object on which we are setting values alw
ays behaves as a copy.

For example, when doing 'df[col].method(value, inplace=True)', try usin
g 'df.method({col: value}, inplace=True)' or df[col] = df[col].method(v
alue) instead, to perform the operation inplace on the original object.


  dataset['Rate'].fillna(dataset['Rate'].median(), inplace=True)
```

In [9]:
```
print(dataset.isnull().sum())
```

```
Id                0
Age               0
Income            0
Home              0
Emp_length        0
Intent            0
Amount            0
Rate              0
Status            0
Percent_income    0
Default           0
Cred_length       0
dtype: int64
```

In [10]:
```
dataset.dtypes
```

Out[10]:
```
Id                  int64
Age                 int64
Income              int64
Home               object
Emp_length        float64
Intent             object
Amount              int64
Rate              float64
Status              int64
Percent_income    float64
Default            object
Cred_length         int64
dtype: object
```

In [11]:
```
dataset['Intent'].value_counts()
```

Out[11]:
```
Intent
EDUCATION            1636
MEDICAL              1495
VENTURE              1400
PERSONAL             1396
DEBTCONSOLIDATION    1310
HOMEIMPROVEMENT       908
Name: count, dtype: int64
```

In [12]:
```
dataset['Home'].value_counts()
```

Out[12]:
```
Home
RENT        4081
MORTGAGE    3377
OWN          664
OTHER         23
Name: count, dtype: int64
```

In [13]:
```
dataset['Default'].value_counts()
```

Out[13]:
```
Default
N    6710
Y    1435
Name: count, dtype: int64
```

In [14]:
```
# Converting the predictor column to 1 and 0 for better useability
dataset['Default'] = dataset['Default'].apply(lambda x: 1 if x == 'Y'

# Verify the conversion
print(dataset['Default'].value_counts())
```

```
Default
0    6710
1    1435
Name: count, dtype: int64
```

In [15]:
```
# Assigning age to Loan applicants who are above the age of 100
```

```
dataset['Age'] = dataset['Age'].apply(lambda x: x if x <= 100 else 100
```

In [16]:

```
# Doing one-hot encoding to the categorical object values for columns
dataset_one_hot = pd.get_dummies(dataset, columns=['Home', 'Intent'],

# Display the updated dataset
print("Columns after one-hot encoding:")
print(dataset_one_hot.dtypes)
```

```
Columns after one-hot encoding:
Id                             int64
Age                            int64
Income                         int64
Emp_length                   float64
Amount                         int64
Rate                         float64
Status                         int64
Percent_income               float64
Default                        int64
Cred_length                    int64
Home_MORTGAGE                   bool
Home_OTHER                      bool
Home_OWN                        bool
Home_RENT                       bool
Intent_DEBTCONSOLIDATION        bool
Intent_EDUCATION                bool
Intent_HOMEIMPROVEMENT          bool
Intent_MEDICAL                  bool
Intent_PERSONAL                 bool
Intent_VENTURE                  bool
dtype: object
```

In [17]:

```
columns_to_drop = ['Home_MORTGAGE', 'Intent_DEBTCONSOLIDATION']
dataset_linear = dataset_one_hot.drop(columns=columns_to_drop)
```

In [18]:

```
# Columns to scale
num_cols = ['Age', 'Income', 'Amount', 'Rate', 'Percent_income', 'Cred

# Apply Min-Max Scaling
scaler = MinMaxScaler()
dataset_one_hot[num_cols] = scaler.fit_transform(dataset_one_hot[num_c

# Verify scaling
print(dataset_one_hot[num_cols].describe())
```

```
                Age       Income       Amount         Rate  Percent_inco
me  \
count  8145.000000  8145.000000  8145.000000  8145.000000     8145.0000
00
mean      0.096054     0.032323     0.266541     0.344117        0.2230
77
std       0.076842     0.027840     0.185217     0.188208        0.1378
80
min       0.000000     0.000000     0.000000     0.000000        0.0000
00
25%       0.037500     0.018251     0.130435     0.188113        0.1168
83
50%       0.075000     0.026899     0.217391     0.341299        0.1948
05
75%       0.125000     0.039030     0.347826     0.474265        0.2987
01
max       1.000000     1.000000     1.000000     1.000000        1.0000
00

       Cred_length
count  8145.000000
mean      0.134548
std       0.142195
min       0.000000
25%       0.035714
50%       0.071429
75%       0.214286
max       1.000000
```

In [19]:

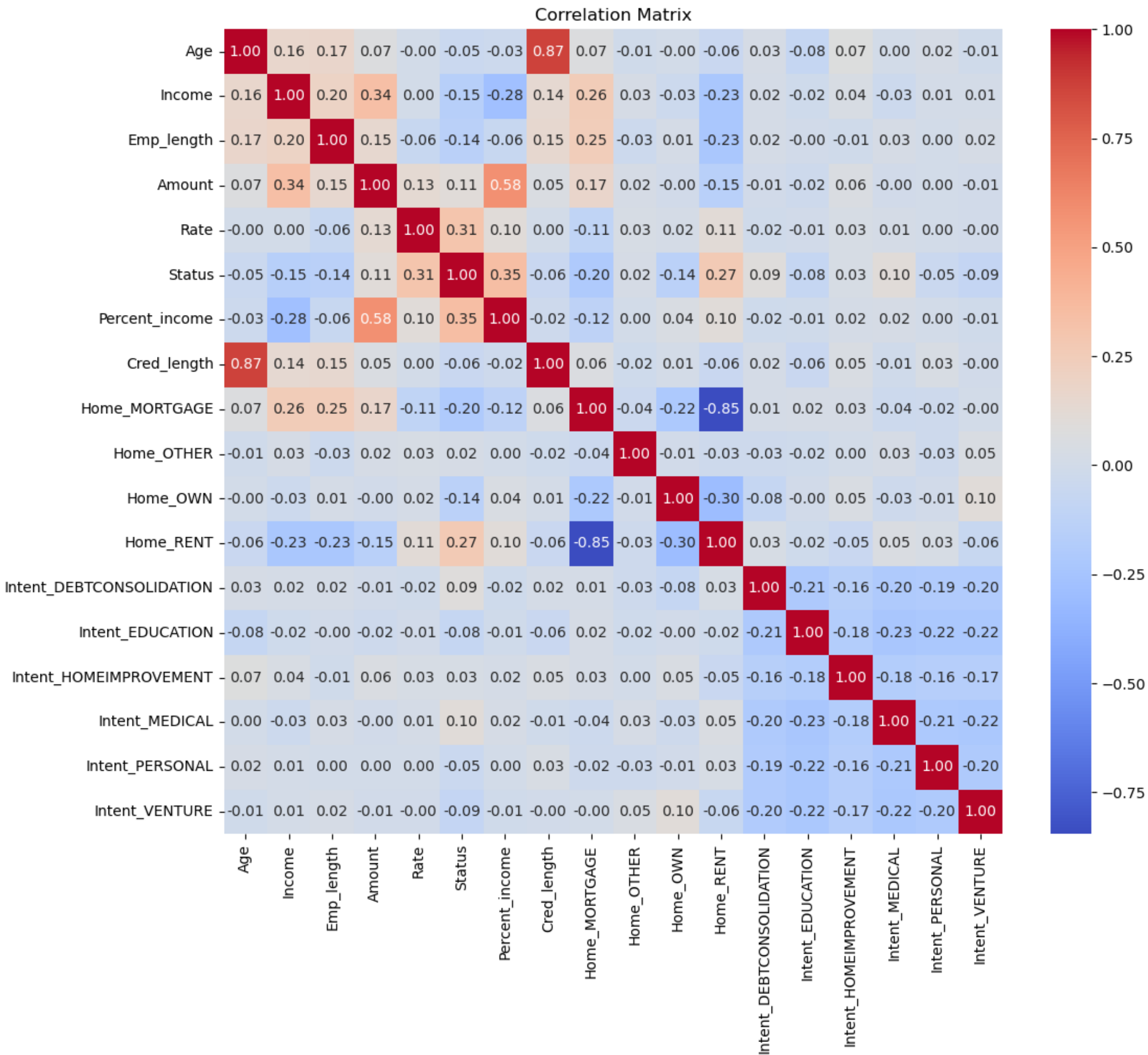
```
# Separate features and target
X = dataset_one_hot.drop(['Id', 'Default'], axis=1)
y = dataset_one_hot['Default']

# Apply SMOTE
smote = SMOTE(random_state=42)
X_resampled, y_resampled = smote.fit_resample(X, y)

# Verify class distribution
from collections import Counter
print("Class distribution after SMOTE:", Counter(y_resampled))
```

```
Class distribution after SMOTE: Counter({1: 6710, 0: 6710})
```

In [20]:

```
import seaborn as sns
import matplotlib.pyplot as plt

# Compute correlation matrix
corr_matrix = X_resampled.corr()

# Plot the heatmap
plt.figure(figsize=(12, 10))
sns.heatmap(corr_matrix, annot=True, fmt='.2f', cmap='coolwarm')
plt.title('Correlation Matrix')
```

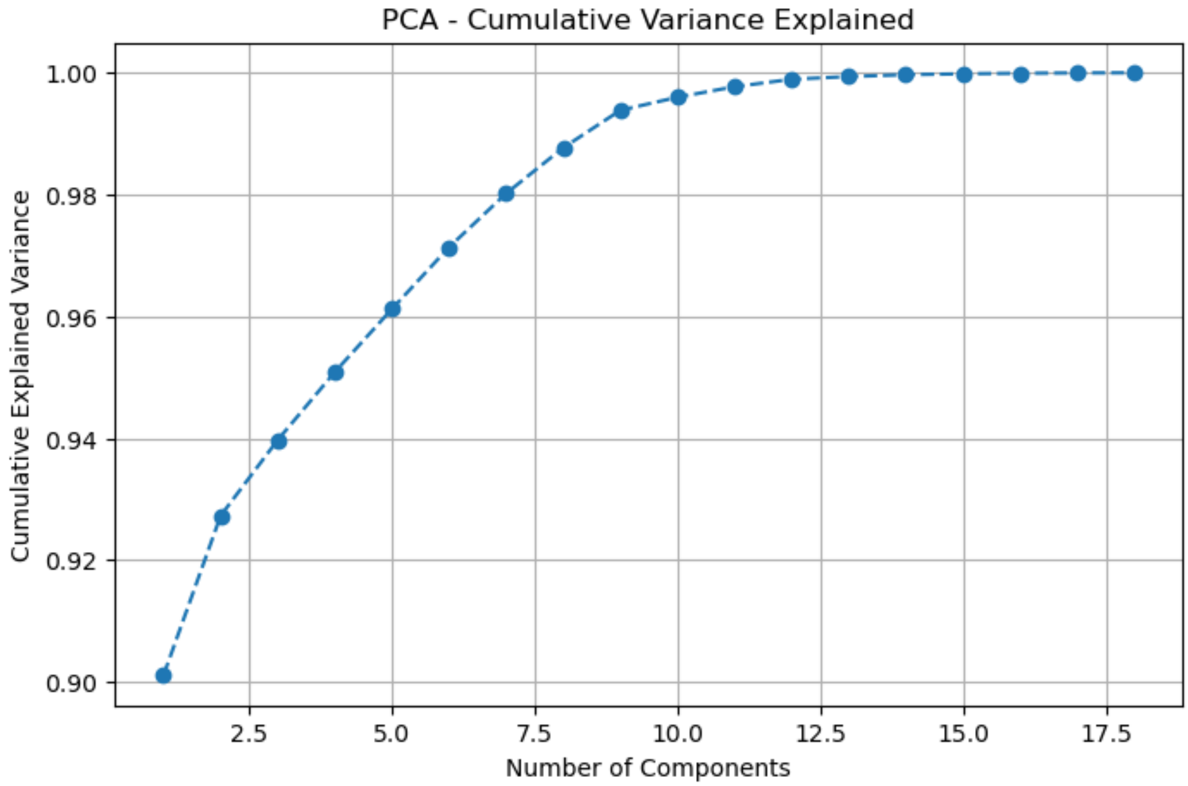
```
plt.show()
```



In [21]:

```
from sklearn.decomposition import PCA
import numpy as np

# Apply PCA
pca = PCA()
pca.fit(X_resampled)

# Variance explained by each component
explained_variance_ratio = pca.explained_variance_ratio_
cumulative_variance = np.cumsum(explained_variance_ratio)

# Plot cumulative variance
plt.figure(figsize=(8, 5))
plt.plot(range(1, len(cumulative_variance) + 1), cumulative_variance,
plt.xlabel('Number of Components')
plt.ylabel('Cumulative Explained Variance')
plt.title('PCA - Cumulative Variance Explained')
plt.grid()
plt.show()
```

```
# Print the number of components to retain 95% variance
n_components_95 = np.argmax(cumulative_variance >= 0.95) + 1
print(f"Number of components to retain 95% variance: {n_components_95}
```




```
Number of components to retain 95% variance: 4
```

In [22]:
```
from sklearn.decomposition import PCA
from sklearn.model_selection import train_test_split

# Step 1: Apply PCA with 4 components
pca = PCA(n_components=4)
X_pca = pca.fit_transform(X_resampled)

# Step 2: Check the shape of the transformed dataset
print(f"Shape of data after PCA: {X_pca.shape}")

# Step 3: Split the PCA-transformed dataset into training and testing
X_train_pca, X_test_pca, y_train, y_test = train_test_split(X_pca, y_r

# Verify the shape of training and test sets
print(f"Training data shape: {X_train_pca.shape}")
print(f"Test data shape: {X_test_pca.shape}")
```

```
Shape of data after PCA: (13420, 4)
Training data shape: (10736, 4)
Test data shape: (2684, 4)
```

In [23]:
```
from sklearn.linear_model import LogisticRegression
from sklearn.metrics import classification_report, roc_auc_score
```

```python
# Train Logistic Regression
log_model = LogisticRegression()
log_model.fit(X_train_pca, y_train)

# Evaluate Logistic Regression
y_pred_log = log_model.predict(X_test_pca)
print("Logistic Regression Performance:")
print(classification_report(y_test, y_pred_log))
print("ROC-AUC:", roc_auc_score(y_test, log_model.predict_proba(X_test
```

```
Logistic Regression Performance:
              precision    recall  f1-score   support

           0       0.55      0.62      0.58      1361
           1       0.55      0.47      0.51      1323

    accuracy                           0.55      2684
   macro avg       0.55      0.55      0.54      2684
weighted avg       0.55      0.55      0.54      2684

ROC-AUC: 0.5772310720353127
```

In [24]:

```python
from sklearn.ensemble import RandomForestClassifier

# Train Random Forest
rf_model = RandomForestClassifier(random_state=42)
rf_model.fit(X_train_pca, y_train)

# Evaluate Random Forest
y_pred_rf = rf_model.predict(X_test_pca)
print("Random Forest Performance:")
print(classification_report(y_test, y_pred_rf))
print("ROC-AUC:", roc_auc_score(y_test, rf_model.predict_proba(X_test_
```

```
Random Forest Performance:
              precision    recall  f1-score   support

           0       0.87      0.80      0.83      1361
           1       0.81      0.88      0.84      1323

    accuracy                           0.84      2684
   macro avg       0.84      0.84      0.84      2684
weighted avg       0.84      0.84      0.84      2684

ROC-AUC: 0.9173024259095426
```

In [25]:

```python
from xgboost import XGBClassifier

# Train XGBoost
xgb_model = XGBClassifier(eval_metric='logloss', random_state=42)
xgb_model.fit(X_train_pca, y_train)

# Evaluate XGBoost
```

```
y_pred_xgb = xgb_model.predict(X_test_pca)
print("XGBoost Performance:")
print(classification_report(y_test, y_pred_xgb))
print("ROC-AUC:", roc_auc_score(y_test, xgb_model.predict_proba(X_test
```

```
XGBoost Performance:
              precision    recall  f1-score   support

           0       0.86      0.76      0.80      1361
           1       0.78      0.87      0.82      1323

    accuracy                           0.81      2684
   macro avg       0.82      0.81      0.81      2684
weighted avg       0.82      0.81      0.81      2684

ROC-AUC: 0.8783479756503794
```

In [26]:

```
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense, Dropout
from tensorflow.keras.optimizers import Adam
from sklearn.metrics import classification_report

# Define the Neural Network model
nn_model = Sequential([
    Dense(64, activation='relu', input_dim=X_train_pca.shape[1]),
    Dropout(0.3),  # Regularization to prevent overfitting
    Dense(32, activation='relu'),
    Dense(1, activation='sigmoid')  # Output layer for binary classifi
])

# Compile the model
nn_model.compile(optimizer=Adam(learning_rate=0.001), loss='binary_cro

# Train the model
nn_model.fit(X_train_pca, y_train, epochs=20, batch_size=32, validatio

# Evaluate the model
nn_loss, nn_accuracy = nn_model.evaluate(X_test_pca, y_test)
print(f"Neural Network Accuracy: {nn_accuracy:.4f}")

# Predict and evaluate
y_pred_nn = (nn_model.predict(X_test_pca) > 0.5).astype("int32")
print("Neural Network Performance:")
print(classification_report(y_test, y_pred_nn))
```

```
Epoch 1/20
/opt/anaconda3/lib/python3.11/site-packages/keras/src/layers/core/dens
e.py:87: UserWarning: Do not pass an `input_shape`/`input_dim` argument
to a layer. When using Sequential models, prefer using an `Input(shape)
` object as the first layer in the model instead.
  super().__init__(activity_regularizer=activity_regularizer, **kwargs)
336/336 ━━━━━━━━━━━━━━━━━━━━ 1s 485us/step - accuracy: 0.5125 - loss:
0.6996 - val_accuracy: 0.5600 - val_loss: 0.6820
```

```
Epoch 2/20
336/336 ━━━━━━━━━━━━━━━━━━━━ 0s 338us/step - accuracy: 0.5477 - loss: 0.6861 - val_accuracy: 0.5671 - val_loss: 0.6798
Epoch 3/20
336/336 ━━━━━━━━━━━━━━━━━━━━ 0s 338us/step - accuracy: 0.5624 - loss: 0.6823 - val_accuracy: 0.5548 - val_loss: 0.6812
Epoch 4/20
336/336 ━━━━━━━━━━━━━━━━━━━━ 0s 330us/step - accuracy: 0.5599 - loss: 0.6800 - val_accuracy: 0.5760 - val_loss: 0.6792
Epoch 5/20
336/336 ━━━━━━━━━━━━━━━━━━━━ 0s 321us/step - accuracy: 0.5661 - loss: 0.6777 - val_accuracy: 0.5671 - val_loss: 0.6758
Epoch 6/20
336/336 ━━━━━━━━━━━━━━━━━━━━ 0s 315us/step - accuracy: 0.5703 - loss: 0.6757 - val_accuracy: 0.5782 - val_loss: 0.6770
Epoch 7/20
336/336 ━━━━━━━━━━━━━━━━━━━━ 0s 317us/step - accuracy: 0.5720 - loss: 0.6767 - val_accuracy: 0.5849 - val_loss: 0.6757
Epoch 8/20
336/336 ━━━━━━━━━━━━━━━━━━━━ 0s 314us/step - accuracy: 0.5731 - loss: 0.6754 - val_accuracy: 0.5864 - val_loss: 0.6729
Epoch 9/20
336/336 ━━━━━━━━━━━━━━━━━━━━ 0s 315us/step - accuracy: 0.5706 - loss: 0.6749 - val_accuracy: 0.5775 - val_loss: 0.6728
Epoch 10/20
336/336 ━━━━━━━━━━━━━━━━━━━━ 0s 321us/step - accuracy: 0.5695 - loss: 0.6759 - val_accuracy: 0.5715 - val_loss: 0.6766
Epoch 11/20
336/336 ━━━━━━━━━━━━━━━━━━━━ 0s 324us/step - accuracy: 0.5797 - loss: 0.6754 - val_accuracy: 0.5782 - val_loss: 0.6719
Epoch 12/20
336/336 ━━━━━━━━━━━━━━━━━━━━ 0s 334us/step - accuracy: 0.5777 - loss: 0.6703 - val_accuracy: 0.5816 - val_loss: 0.6727
Epoch 13/20
336/336 ━━━━━━━━━━━━━━━━━━━━ 0s 337us/step - accuracy: 0.5800 - loss: 0.6732 - val_accuracy: 0.5641 - val_loss: 0.6752
Epoch 14/20
336/336 ━━━━━━━━━━━━━━━━━━━━ 0s 334us/step - accuracy: 0.5844 - loss: 0.6742 - val_accuracy: 0.5812 - val_loss: 0.6740
Epoch 15/20
336/336 ━━━━━━━━━━━━━━━━━━━━ 0s 333us/step - accuracy: 0.5798 - loss: 0.6744 - val_accuracy: 0.5879 - val_loss: 0.6713
Epoch 16/20
336/336 ━━━━━━━━━━━━━━━━━━━━ 0s 336us/step - accuracy: 0.5875 - loss: 0.6686 - val_accuracy: 0.5700 - val_loss: 0.6729
Epoch 17/20
336/336 ━━━━━━━━━━━━━━━━━━━━ 0s 332us/step - accuracy: 0.5846 - loss: 0.6737 - val_accuracy: 0.5849 - val_loss: 0.6721
Epoch 18/20
336/336 ━━━━━━━━━━━━━━━━━━━━ 0s 331us/step - accuracy: 0.5911 - loss: 0.6701 - val_accuracy: 0.5894 - val_loss: 0.6703
Epoch 19/20
```

```
336/336 ━━━━━━━━━━━━━━━━━━━━ 0s 338us/step - accuracy: 0.5781 - loss:
0.6732 - val_accuracy: 0.5905 - val_loss: 0.6699
Epoch 20/20
336/336 ━━━━━━━━━━━━━━━━━━━━ 0s 338us/step - accuracy: 0.5774 - loss:
0.6727 - val_accuracy: 0.5958 - val_loss: 0.6690
84/84 ━━━━━━━━━━━━━━━━━━━━ 0s 233us/step - accuracy: 0.6074 - loss: 0.6
716
Neural Network Accuracy: 0.5958
84/84 ━━━━━━━━━━━━━━━━━━━━ 0s 354us/step
Neural Network Performance:
              precision    recall  f1-score   support

           0       0.59      0.68      0.63      1361
           1       0.61      0.50      0.55      1323

    accuracy                           0.60      2684
   macro avg       0.60      0.59      0.59      2684
weighted avg       0.60      0.60      0.59      2684
```

In [27]:

```python
from sklearn.linear_model import LogisticRegression
from sklearn.metrics import classification_report, roc_auc_score

# Train Lasso Regression (Logistic Regression with L1 regularization)
lasso_model = LogisticRegression(penalty='l1', solver='liblinear', C=0
lasso_model.fit(X_train_pca, y_train)

# Evaluate Lasso Regression
y_pred_lasso = lasso_model.predict(X_test_pca)
print("Lasso Regression Performance:")
print(classification_report(y_test, y_pred_lasso))
print("ROC-AUC:", roc_auc_score(y_test, lasso_model.predict_proba(X_te
```

```
Lasso Regression Performance:
              precision    recall  f1-score   support

           0       0.56      0.61      0.58      1361
           1       0.56      0.50      0.52      1323

    accuracy                           0.56      2684
   macro avg       0.56      0.55      0.55      2684
weighted avg       0.56      0.56      0.55      2684

ROC-AUC: 0.5816146035522545
```

In [28]:

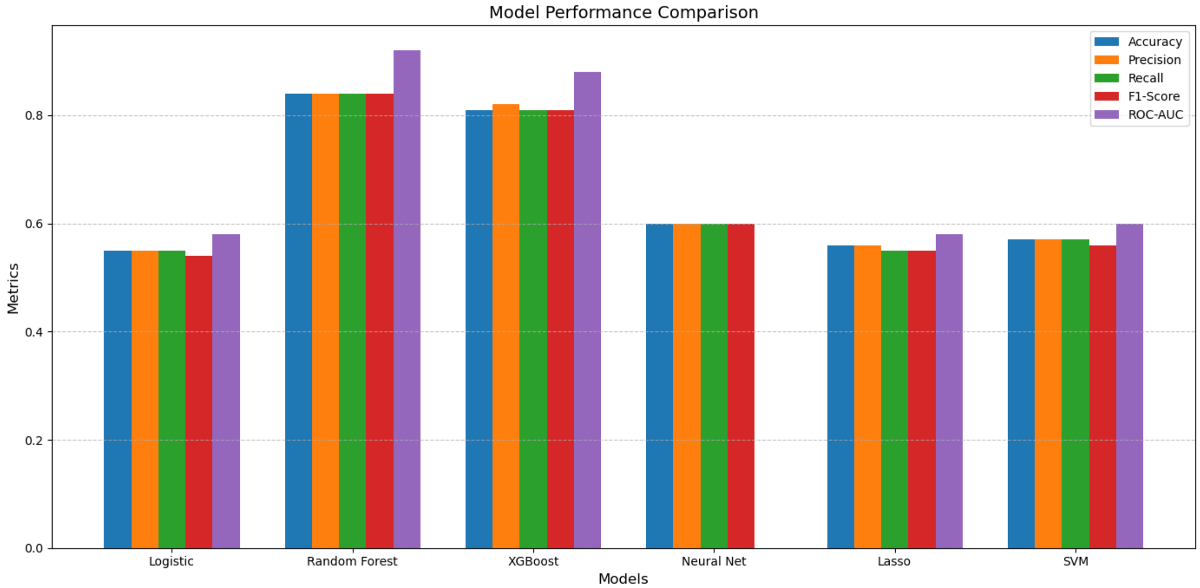
```python
from sklearn.svm import SVC

# Train SVM with RBF kernel
svm_model = SVC(kernel='rbf', probability=True, random_state=42)
svm_model.fit(X_train_pca, y_train)

# Evaluate SVM
y_pred_svm = svm_model.predict(X_test_pca)
```

```
print("SVM Performance:")
print(classification_report(y_test, y_pred_svm))
print("ROC-AUC:", roc_auc_score(y_test, svm_model.predict_proba(X_test
```

```
SVM Performance:
              precision    recall  f1-score   support

           0       0.56      0.73      0.63      1361
           1       0.59      0.40      0.48      1323

    accuracy                           0.57      2684
   macro avg       0.58      0.57      0.56      2684
weighted avg       0.57      0.57      0.56      2684

ROC-AUC: 0.5963113468099298
```

In [29]:

```
import matplotlib.pyplot as plt
import numpy as np

# Model names and metrics
models = ['Logistic', 'Random Forest', 'XGBoost', 'Neural Net', 'Lasso
accuracy = [0.55, 0.84, 0.81, 0.60, 0.56, 0.57]
precision = [0.55, 0.84, 0.82, 0.60, 0.56, 0.57]
recall = [0.55, 0.84, 0.81, 0.60, 0.55, 0.57]
f1_score = [0.54, 0.84, 0.81, 0.60, 0.55, 0.56]
roc_auc = [0.58, 0.92, 0.88, None, 0.58, 0.60]

# Number of models
x = np.arange(len(models))

# Bar width
width = 0.15

# Plot metrics
plt.figure(figsize=(14, 7))
plt.bar(x - 2*width, accuracy, width, label='Accuracy')
plt.bar(x - width, precision, width, label='Precision')
plt.bar(x, recall, width, label='Recall')
plt.bar(x + width, f1_score, width, label='F1-Score')
plt.bar(x + 2*width, [v if v is not None else 0 for v in roc_auc], wid

# Add labels and title
plt.xlabel('Models', fontsize=12)
plt.ylabel('Metrics', fontsize=12)
plt.title('Model Performance Comparison', fontsize=14)
plt.xticks(x, models, fontsize=10)
plt.legend(fontsize=10)
plt.grid(axis='y', linestyle='--', alpha=0.7)

# Show plot
plt.tight_layout()
plt.show()
```



In [30]:

```
# Step 1: Prepare dataset_linear
# Separate features and target
X_linear = dataset_linear.drop(['Id', 'Default'], axis=1)  # Drop 'Id'
y_linear = dataset_linear['Default']

# Step 2: Handle class imbalance using SMOTE
from imblearn.over_sampling import SMOTE

smote = SMOTE(random_state=42)
X_linear_resampled, y_linear_resampled = smote.fit_resample(X_linear,

# Step 3: Scale the numerical features
from sklearn.preprocessing import MinMaxScaler

scaler = MinMaxScaler()
X_linear_resampled_scaled = scaler.fit_transform(X_linear_resampled)

# Step 4: Split the data
from sklearn.model_selection import train_test_split

X_train_linear, X_test_linear, y_train_linear, y_test_linear = train_t
    X_linear_resampled_scaled, y_linear_resampled, test_size=0.2, rand
)

# Step 5: Train Logistic Regression
from sklearn.linear_model import LogisticRegression
from sklearn.metrics import classification_report, roc_auc_score

log_model_linear = LogisticRegression()
log_model_linear.fit(X_train_linear, y_train_linear)

# Evaluate Logistic Regression
y_pred_log_linear = log_model_linear.predict(X_test_linear)
print("Logistic Regression with dataset_linear Performance:")
print(classification_report(y_test_linear, y_pred_log_linear))
```

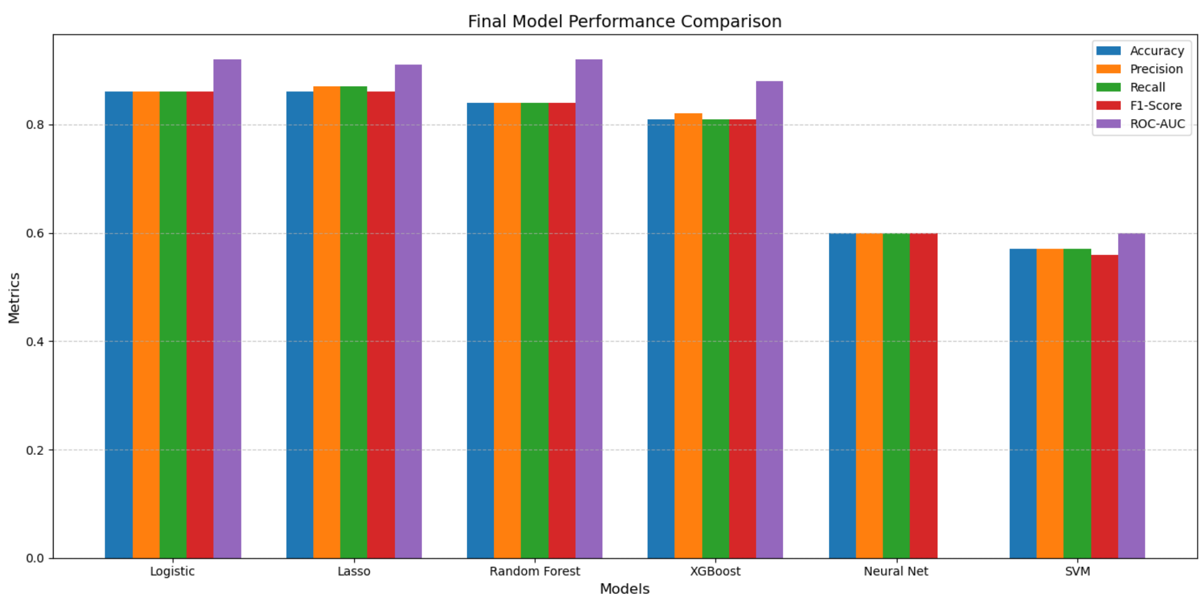
```
print("ROC-AUC:", roc_auc_score(y_test_linear, log_model_linear.predic

# Step 6: Train Lasso Regression (Logistic Regression with L1 regulari
lasso_model_linear = LogisticRegression(penalty='l1', solver='liblinea
lasso_model_linear.fit(X_train_linear, y_train_linear)

# Evaluate Lasso Regression
y_pred_lasso_linear = lasso_model_linear.predict(X_test_linear)
print("Lasso Regression with dataset_linear Performance:")
print(classification_report(y_test_linear, y_pred_lasso_linear))
print("ROC-AUC:", roc_auc_score(y_test_linear, lasso_model_linear.pred
```

```
Logistic Regression with dataset_linear Performance:
              precision    recall  f1-score   support

           0       0.87      0.84      0.85      1361
           1       0.84      0.88      0.86      1323

    accuracy                           0.86      2684
   macro avg       0.86      0.86      0.86      2684
weighted avg       0.86      0.86      0.86      2684

ROC-AUC: 0.9244514198854497
Lasso Regression with dataset_linear Performance:
              precision    recall  f1-score   support

           0       0.91      0.81      0.86      1361
           1       0.82      0.92      0.87      1323

    accuracy                           0.86      2684
   macro avg       0.87      0.87      0.86      2684
weighted avg       0.87      0.86      0.86      2684

ROC-AUC: 0.9149065618573334
```

In [31]:

```
import matplotlib.pyplot as plt
import numpy as np

# Model names and metrics
models = ['Logistic', 'Lasso', 'Random Forest', 'XGBoost', 'Neural Net
accuracy = [0.86, 0.86, 0.84, 0.81, 0.60, 0.57]  # Update these based
precision = [0.86, 0.87, 0.84, 0.82, 0.60, 0.57]  # Update these based
recall = [0.86, 0.87, 0.84, 0.81, 0.60, 0.57]     # Update these based
f1_score = [0.86, 0.86, 0.84, 0.81, 0.60, 0.56]   # Update these based
roc_auc = [0.92, 0.91, 0.92, 0.88, None, 0.60]    # Update these based

# Number of models
x = np.arange(len(models))

# Bar width
width = 0.15

# Plot metrics
```

```
plt.figure(figsize=(14, 7))
plt.bar(x - 2*width, accuracy, width, label='Accuracy')
plt.bar(x - width, precision, width, label='Precision')
plt.bar(x, recall, width, label='Recall')
plt.bar(x + width, f1_score, width, label='F1-Score')
plt.bar(x + 2*width, [v if v is not None else 0 for v in roc_auc], wid

# Add labels and title
plt.xlabel('Models', fontsize=12)
plt.ylabel('Metrics', fontsize=12)
plt.title('Final Model Performance Comparison', fontsize=14)
plt.xticks(x, models, fontsize=10)
plt.legend(fontsize=10)
plt.grid(axis='y', linestyle='--', alpha=0.7)

# Show plot
plt.tight_layout()
plt.show()
```



In [32]:
```
from sklearn.model_selection import GridSearchCV
from sklearn.ensemble import RandomForestClassifier

# Define hyperparameters to tune
param_grid_rf = {
    'n_estimators': [100, 200, 500],
    'max_depth': [None, 10, 20, 30],
    'min_samples_split': [2, 5, 10],
    'min_samples_leaf': [1, 2, 4],
    'bootstrap': [True, False]
}

# Grid search
rf_grid_search = GridSearchCV(
    estimator=RandomForestClassifier(random_state=42),
    param_grid=param_grid_rf,
```

```
    cv=3,
    scoring='roc_auc',
    verbose=2,
    n_jobs=-1
)

rf_grid_search.fit(X_train_pca, y_train)
print(f"Best parameters for Random Forest: {rf_grid_search.best_params
print(f"Best ROC-AUC: {rf_grid_search.best_score_}")
```

```
Fitting 3 folds for each of 216 candidates, totalling 648 fits
Best parameters for Random Forest: {'bootstrap': False, 'max_depth': 3
0, 'min_samples_leaf': 1, 'min_samples_split': 2, 'n_estimators': 500}
Best ROC-AUC: 0.8972211329389284
```

In [33]:

```
from xgboost import XGBClassifier
from sklearn.model_selection import RandomizedSearchCV

# Define hyperparameters to tune
param_grid_xgb = {
    'n_estimators': [100, 200, 500],
    'learning_rate': [0.01, 0.05, 0.1, 0.2],
    'max_depth': [3, 5, 7, 10],
    'subsample': [0.6, 0.8, 1.0],
    'colsample_bytree': [0.6, 0.8, 1.0]
}

# Randomized search
xgb_random_search = RandomizedSearchCV(
    estimator=XGBClassifier(use_label_encoder=False, eval_metric='logl
    param_distributions=param_grid_xgb,
    n_iter=50,
    scoring='roc_auc',
    cv=3,
    verbose=2,
    random_state=42,
    n_jobs=-1
)

xgb_random_search.fit(X_train_pca, y_train)
print(f"Best parameters for XGBoost: {xgb_random_search.best_params_}"
print(f"Best ROC-AUC: {xgb_random_search.best_score_}")
```

```
Fitting 3 folds for each of 50 candidates, totalling 150 fits
```

```
/opt/anaconda3/lib/python3.11/site-packages/xgboost/core.py:158: UserWa
rning: [16:18:32] WARNING: /Users/runner/work/xgboost/xgboost/src/learn
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  warnings.warn(smsg, UserWarning)
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Best parameters for XGBoost: {'subsample': 0.8, 'n_estimators': 500, 'm
ax_depth': 10, 'learning_rate': 0.1, 'colsample_bytree': 0.8}
Best ROC-AUC: 0.8773016051869522
```

In [34]:

```
from tensorflow.keras.layers import BatchNormalization

# Updated model
nn_model = Sequential([
    Dense(128, activation='relu', input_dim=X_train_pca.shape[1]),
    BatchNormalization(),
    Dropout(0.3),
    Dense(64, activation='relu'),
    BatchNormalization(),
    Dropout(0.3),
    Dense(32, activation='relu'),
    Dense(1, activation='sigmoid')
])

# Compile and train
nn_model.compile(optimizer=Adam(learning_rate=0.001), loss='binary_cro
nn_model.fit(X_train_pca, y_train, epochs=50, batch_size=64, validatio
```

```
Epoch 1/50
/opt/anaconda3/lib/python3.11/site-packages/keras/src/layers/core/dens
e.py:87: UserWarning: Do not pass an `input_shape`/`input_dim` argument
to a layer. When using Sequential models, prefer using an `Input(shape)
` object as the first layer in the model instead.
  super().__init__(activity_regularizer=activity_regularizer, **kwargs)
168/168 ━━━━━━━━━━━━━━━━━━━━ 1s 904us/step - accuracy: 0.5246 - loss:
0.7448 - val_accuracy: 0.5708 - val_loss: 0.6829
Epoch 2/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 537us/step - accuracy: 0.5445 - loss:
0.6985 - val_accuracy: 0.5589 - val_loss: 0.6780
Epoch 3/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 530us/step - accuracy: 0.5542 - loss:
0.6877 - val_accuracy: 0.5719 - val_loss: 0.6715
Epoch 4/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 515us/step - accuracy: 0.5714 - loss:
0.6833 - val_accuracy: 0.5775 - val_loss: 0.6704
Epoch 5/50
```

```
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 526us/step - accuracy: 0.5662 - loss:
0.6806 - val_accuracy: 0.5827 - val_loss: 0.6747
Epoch 6/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 523us/step - accuracy: 0.5667 - loss:
0.6806 - val_accuracy: 0.5857 - val_loss: 0.6704
Epoch 7/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 563us/step - accuracy: 0.5653 - loss:
0.6791 - val_accuracy: 0.5950 - val_loss: 0.6689
Epoch 8/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 567us/step - accuracy: 0.5733 - loss:
0.6753 - val_accuracy: 0.5917 - val_loss: 0.6708
Epoch 9/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 569us/step - accuracy: 0.5762 - loss:
0.6748 - val_accuracy: 0.5842 - val_loss: 0.6693
Epoch 10/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 572us/step - accuracy: 0.5692 - loss:
0.6769 - val_accuracy: 0.5931 - val_loss: 0.6669
Epoch 11/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 574us/step - accuracy: 0.5838 - loss:
0.6736 - val_accuracy: 0.5954 - val_loss: 0.6684
Epoch 12/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 583us/step - accuracy: 0.5830 - loss:
0.6721 - val_accuracy: 0.5842 - val_loss: 0.6682
Epoch 13/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 569us/step - accuracy: 0.5797 - loss:
0.6727 - val_accuracy: 0.5969 - val_loss: 0.6678
Epoch 14/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 577us/step - accuracy: 0.5762 - loss:
0.6712 - val_accuracy: 0.5887 - val_loss: 0.6671
Epoch 15/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 551us/step - accuracy: 0.5653 - loss:
0.6739 - val_accuracy: 0.6017 - val_loss: 0.6646
Epoch 16/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 539us/step - accuracy: 0.5896 - loss:
0.6699 - val_accuracy: 0.5939 - val_loss: 0.6676
Epoch 17/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 529us/step - accuracy: 0.5818 - loss:
0.6756 - val_accuracy: 0.5976 - val_loss: 0.6659
Epoch 18/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 536us/step - accuracy: 0.5879 - loss:
0.6666 - val_accuracy: 0.5935 - val_loss: 0.6646
Epoch 19/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 532us/step - accuracy: 0.5896 - loss:
0.6689 - val_accuracy: 0.5984 - val_loss: 0.6646
Epoch 20/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 533us/step - accuracy: 0.5829 - loss:
0.6683 - val_accuracy: 0.5924 - val_loss: 0.6678
Epoch 21/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 532us/step - accuracy: 0.5991 - loss:
0.6628 - val_accuracy: 0.6028 - val_loss: 0.6656
Epoch 22/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 532us/step - accuracy: 0.5890 - loss:
```

```
0.6694 - val_accuracy: 0.6025 - val_loss: 0.6639
Epoch 23/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 538us/step - accuracy: 0.5983 - loss: 0.6667 - val_accuracy: 0.5883 - val_loss: 0.6682
Epoch 24/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 527us/step - accuracy: 0.5960 - loss: 0.6671 - val_accuracy: 0.6002 - val_loss: 0.6630
Epoch 25/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 573us/step - accuracy: 0.5934 - loss: 0.6669 - val_accuracy: 0.5823 - val_loss: 0.6663
Epoch 26/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 606us/step - accuracy: 0.6017 - loss: 0.6605 - val_accuracy: 0.6036 - val_loss: 0.6615
Epoch 27/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 610us/step - accuracy: 0.5955 - loss: 0.6692 - val_accuracy: 0.6054 - val_loss: 0.6628
Epoch 28/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 646us/step - accuracy: 0.5933 - loss: 0.6670 - val_accuracy: 0.5928 - val_loss: 0.6637
Epoch 29/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 614us/step - accuracy: 0.6065 - loss: 0.6593 - val_accuracy: 0.5965 - val_loss: 0.6603
Epoch 30/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 589us/step - accuracy: 0.6013 - loss: 0.6633 - val_accuracy: 0.5946 - val_loss: 0.6613
Epoch 31/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 615us/step - accuracy: 0.5965 - loss: 0.6658 - val_accuracy: 0.6039 - val_loss: 0.6592
Epoch 32/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 590us/step - accuracy: 0.6066 - loss: 0.6618 - val_accuracy: 0.6025 - val_loss: 0.6633
Epoch 33/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 580us/step - accuracy: 0.6023 - loss: 0.6609 - val_accuracy: 0.5939 - val_loss: 0.6603
Epoch 34/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 579us/step - accuracy: 0.6085 - loss: 0.6598 - val_accuracy: 0.6021 - val_loss: 0.6600
Epoch 35/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 544us/step - accuracy: 0.6047 - loss: 0.6626 - val_accuracy: 0.5950 - val_loss: 0.6609
Epoch 36/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 559us/step - accuracy: 0.6156 - loss: 0.6554 - val_accuracy: 0.6021 - val_loss: 0.6604
Epoch 37/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 542us/step - accuracy: 0.6086 - loss: 0.6614 - val_accuracy: 0.5987 - val_loss: 0.6559
Epoch 38/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 539us/step - accuracy: 0.6044 - loss: 0.6591 - val_accuracy: 0.6051 - val_loss: 0.6594
Epoch 39/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 526us/step - accuracy: 0.6167 - loss: 0.6563 - val_accuracy: 0.6017 - val_loss: 0.6594
```

```
Epoch 40/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 531us/step - accuracy: 0.6096 - loss: 0.6588 - val_accuracy: 0.5965 - val_loss: 0.6568
Epoch 41/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 528us/step - accuracy: 0.6063 - loss: 0.6604 - val_accuracy: 0.6062 - val_loss: 0.6593
Epoch 42/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 540us/step - accuracy: 0.6008 - loss: 0.6604 - val_accuracy: 0.6036 - val_loss: 0.6562
Epoch 43/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 531us/step - accuracy: 0.6050 - loss: 0.6569 - val_accuracy: 0.6066 - val_loss: 0.6570
Epoch 44/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 536us/step - accuracy: 0.6097 - loss: 0.6573 - val_accuracy: 0.6006 - val_loss: 0.6565
Epoch 45/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 534us/step - accuracy: 0.6149 - loss: 0.6549 - val_accuracy: 0.6125 - val_loss: 0.6514
Epoch 46/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 523us/step - accuracy: 0.6115 - loss: 0.6565 - val_accuracy: 0.6039 - val_loss: 0.6539
Epoch 47/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 530us/step - accuracy: 0.6150 - loss: 0.6585 - val_accuracy: 0.6084 - val_loss: 0.6562
Epoch 48/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 525us/step - accuracy: 0.6048 - loss: 0.6602 - val_accuracy: 0.5972 - val_loss: 0.6574
Epoch 49/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 525us/step - accuracy: 0.6120 - loss: 0.6573 - val_accuracy: 0.6196 - val_loss: 0.6526
Epoch 50/50
168/168 ━━━━━━━━━━━━━━━━━━━━ 0s 521us/step - accuracy: 0.6315 - loss: 0.6488 - val_accuracy: 0.6159 - val_loss: 0.6481
```

Out[34]:
```
<keras.src.callbacks.history.History at 0x339ed0dd0>
```

In [35]:
```python
from sklearn.metrics import classification_report, roc_auc_score

# Step 1: Evaluate the model on the test set
loss, accuracy = nn_model.evaluate(X_test_pca, y_test)
print(f"Neural Network Test Accuracy: {accuracy:.4f}")

# Step 2: Generate predictions
y_pred_prob = nn_model.predict(X_test_pca)  # Predicted probabilities
y_pred = (y_pred_prob > 0.5).astype("int32")  # Convert probabilities

# Step 3: Calculate metrics
print("Neural Network Performance:")
print(classification_report(y_test, y_pred))

# Step 4: Compute ROC-AUC
roc_auc = roc_auc_score(y_test, y_pred_prob)
print(f"Neural Network ROC-AUC: {roc_auc:.4f}")
```

```
84/84 ━━━━━━━━━━━━━━━━━━━━ 0s 296us/step - accuracy: 0.6157 - loss: 0.6
522
Neural Network Test Accuracy: 0.6159
84/84 ━━━━━━━━━━━━━━━━━━━━ 0s 502us/step
Neural Network Performance:
              precision    recall  f1-score   support

           0       0.61      0.68      0.64      1361
           1       0.63      0.55      0.58      1323

    accuracy                           0.62      2684
   macro avg       0.62      0.61      0.61      2684
weighted avg       0.62      0.62      0.61      2684

Neural Network ROC-AUC: 0.6719
```

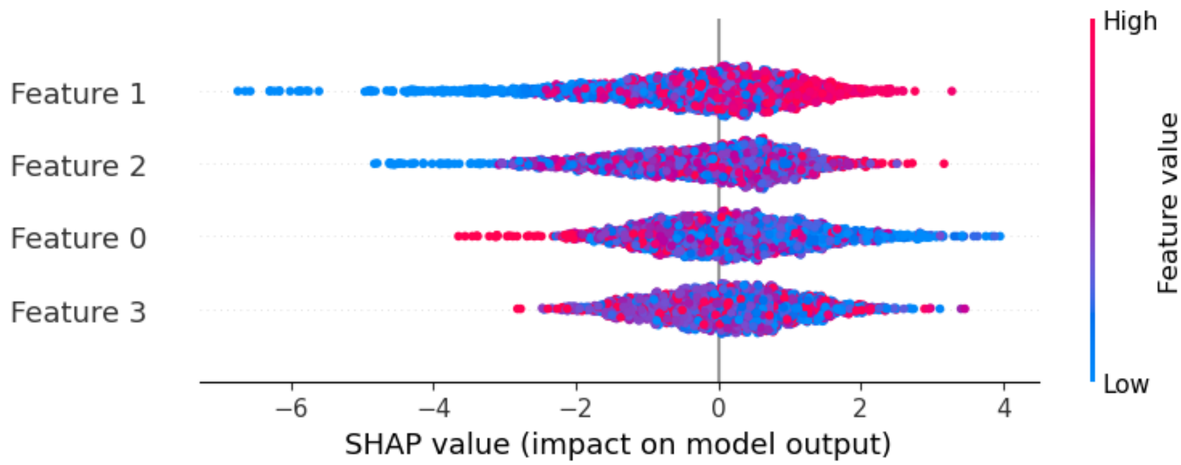
In [36]:

```python
from sklearn.ensemble import StackingClassifier

# Define base models
estimators = [
    ('rf', RandomForestClassifier(random_state=42)),
    ('xgb', XGBClassifier(use_label_encoder=False, eval_metric='loglos
]

# Stacking classifier
stacked_model = StackingClassifier(
    estimators=estimators,
    final_estimator=LogisticRegression(),
    cv=3
)

stacked_model.fit(X_train_pca, y_train)
y_pred_stacked = stacked_model.predict(X_test_pca)

# Evaluate
print("Stacking Model Performance:")
print(classification_report(y_test, y_pred_stacked))
print("ROC-AUC:", roc_auc_score(y_test, stacked_model.predict_proba(X_
```

```
/opt/anaconda3/lib/python3.11/site-packages/xgboost/core.py:158: UserWa
rning: [16:20:27] WARNING: /Users/runner/work/xgboost/xgboost/src/learn
er.cc:740:
Parameters: { "use_label_encoder" } are not used.

  warnings.warn(smsg, UserWarning)
/opt/anaconda3/lib/python3.11/site-packages/xgboost/core.py:158: UserWa
rning: [16:20:30] WARNING: /Users/runner/work/xgboost/xgboost/src/learn
er.cc:740:
Parameters: { "use_label_encoder" } are not used.

  warnings.warn(smsg, UserWarning)
```

```
Stacking Model Performance:
              precision    recall  f1-score   support

           0       0.87      0.81      0.84      1361
           1       0.82      0.87      0.85      1323

    accuracy                           0.84      2684
   macro avg       0.84      0.84      0.84      2684
weighted avg       0.84      0.84      0.84      2684

ROC-AUC: 0.9169622620866454
```

In [38]:
```python
import shap

# Explain the model predictions
explainer = shap.TreeExplainer(xgb_random_search.best_estimator_)
shap_values = explainer.shap_values(X_test_pca)

# Visualize feature importance
shap.summary_plot(shap_values, X_test_pca)
```



In [ ]: