In [3]:

```
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import seaborn as sns
from sklearn.model_selection import train_test_split, GridSearchCV
from sklearn.preprocessing import MinMaxScaler
from sklearn.ensemble import RandomForestRegressor
from sklearn.preprocessing import StandardScaler
from sklearn.metrics import mean_squared_error, r2_score, accuracy_score
```

In [5]:

```
data = pd.read_csv("data/sustainability_dataset2.csv")
```

In [7]:

```
print("\n--- Dataset Overview ---")
print("Shape:", data.shape)
print("Columns:", data.columns)
print("\nData Types:\n", data.dtypes)
print("\nMissing Values:\n", data.isnull().sum())
print("\nDescriptive Statistics:\n", data.describe())
```

```
--- Dataset Overview ---
Shape: (1500, 7)
Columns: Index(['Product Name', 'Material Type', 'Carbon Footprint (kg CO
₂)',
       'Energy Consumption (kWh)', 'Brand Policy (Eco-Certified)',
       'Number of Certifications', 'Sustainability Score'],
      dtype='object')

Data Types:
 Product Name                     object
Material Type                     int64
Carbon Footprint (kg CO₂)       float64
Energy Consumption (kWh)        float64
Brand Policy (Eco-Certified)      int64
Number of Certifications          int64
Sustainability Score            float64
dtype: object

Missing Values:
 Product Name                   0
Material Type                   0
Carbon Footprint (kg CO₂)       0
Energy Consumption (kWh)        0
Brand Policy (Eco-Certified)    0
Number of Certifications        0
Sustainability Score            0
dtype: int64

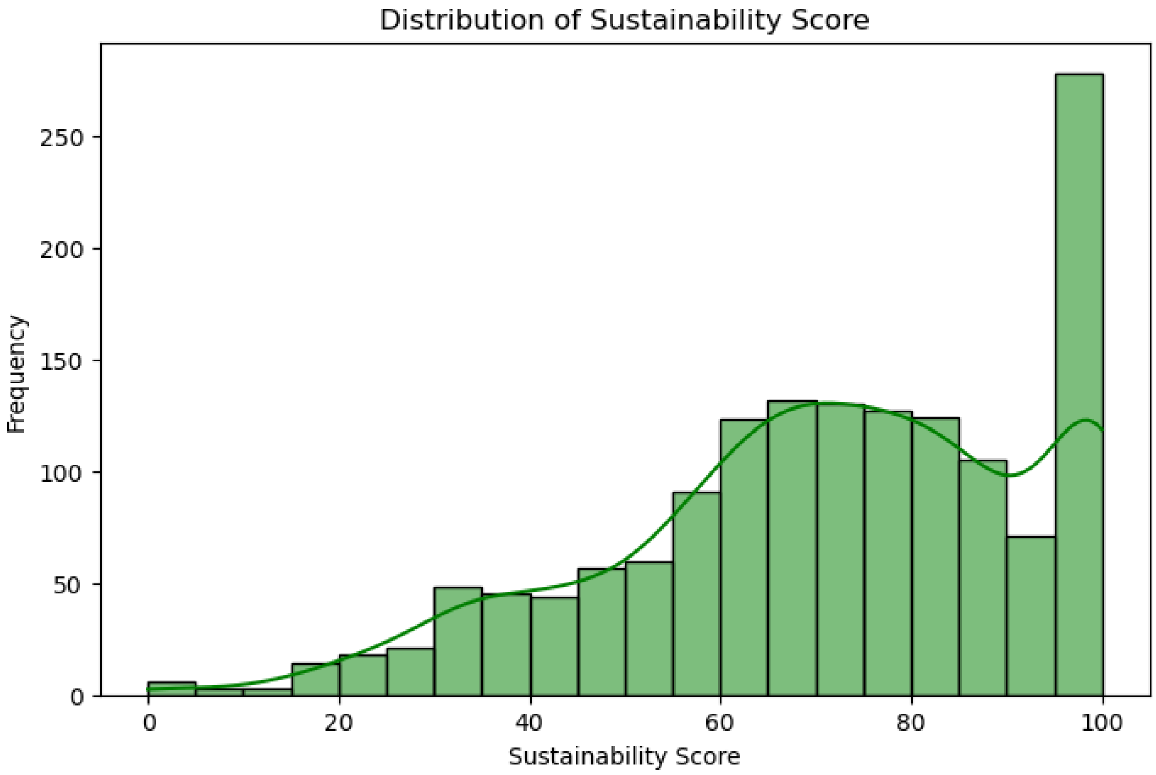
Descriptive Statistics:
        Material Type  Carbon Footprint (kg CO₂)  Energy Consumption (kWh)  
\
count    1500.000000                1500.000000               1500.000000   
mean        2.142000                  44.987216                151.237163   
std         0.945039                  28.731402                 74.660456   
min         1.000000                  10.092640                 48.730088   
25%         1.000000                  23.941632                 91.005148   
50%         2.000000                  40.294500                136.960072   
75%         3.000000                  61.429049                203.103788   
max         4.000000                 373.142395                697.941023   

       Brand Policy (Eco-Certified)  Number of Certifications  \
count                   1500.000000               1500.000000   
mean                       0.509333                  2.304667   
std                        0.500080                  1.618721   
min                        0.000000                  0.000000   
25%                        0.000000                  1.000000   
50%                        1.000000                  2.000000   
75%                        1.000000                  4.000000   
max                        1.000000                  5.000000   

       Sustainability Score  
count           1500.000000  
mean              71.372955  
std               21.868172  
min                0.000000  
25%               58.155674  
50%               73.190102  
75%               88.414978  
max              100.000000  
```

In [9]:

```
plt.figure(figsize=(8, 5))
sns.histplot(data["Sustainability Score"], bins=20, kde=True, color="gree
plt.title("Distribution of Sustainability Score")
plt.xlabel("Sustainability Score")
plt.ylabel("Frequency")
plt.show()
```



In [11]:

```
X = data.drop(columns=["Product Name", "Sustainability Score"])
y = data["Sustainability Score"]
```

In [13]:

```
scaler = StandardScaler()
X_scaled = scaler.fit_transform(X)
```

In [15]:

```
X_train, X_test, y_train, y_test = train_test_split(X_scaled, y, test_siz
```

In [17]:

```
# hyper parameter
param_grid = {
    "n_estimators": [50, 100, 200],
    "max_depth": [None, 10, 20, 30],
    "min_samples_split": [2, 5, 10],
    "min_samples_leaf": [1, 2, 4],
    "max_features": ["auto", "sqrt", "log2"]
}
```

In [19]:

```
rf = RandomForestRegressor(random_state=42)
grid_search = GridSearchCV(rf, param_grid, scoring='r2', cv=5, n_jobs=-1,
grid_search.fit(X_train, y_train)
import warnings
warnings.filterwarnings('ignore')
```

```
Fitting 5 folds for each of 324 candidates, totalling 1620 fits
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```

```
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```

```
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```

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```

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```

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```

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```

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```

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```

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```

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```

```
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```

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[CV] END max_depth=None, max_features=sqrt, min_samples_leaf=4, min_sample
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```

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```

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split=2, n_estimators=100; total time=   0.1s
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split=5, n_estimators=200; total time=   0.0s
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split=10, n_estimators=50; total time=   0.0s
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[CV] END max_depth=30, max_features=auto, min_samples_leaf=1, min_samples_
split=10, n_estimators=100; total time=   0.0s
```

```
[CV] END max_depth=30, max_features=auto, min_samples_leaf=1, min_samples_
split=10, n_estimators=100; total time=   0.0s
```

```
/opt/anaconda3/lib/python3.11/site-packages/sklearn/model_selection/_valid
ation.py:528: FitFailedWarning:
540 fits failed out of a total of 1620.
The score on these train-test partitions for these parameters will be set
to nan.
If these failures are not expected, you can try to debug them by setting e
rror_score='raise'.

Below are more details about the failures:
--------------------------------------------------------------------------
------
265 fits failed with the following error:
Traceback (most recent call last):
  File "/opt/anaconda3/lib/python3.11/site-packages/sklearn/model_selectio
n/_validation.py", line 866, in _fit_and_score
    estimator.fit(X_train, y_train, **fit_params)
  File "/opt/anaconda3/lib/python3.11/site-packages/sklearn/base.py", line
1382, in wrapper
    estimator._validate_params()
  File "/opt/anaconda3/lib/python3.11/site-packages/sklearn/base.py", line
436, in _validate_params
    validate_parameter_constraints(
  File "/opt/anaconda3/lib/python3.11/site-packages/sklearn/utils/_param_v
alidation.py", line 98, in validate_parameter_constraints
    raise InvalidParameterError(
sklearn.utils._param_validation.InvalidParameterError: The 'max_features'
parameter of RandomForestRegressor must be an int in the range [1, inf), a
float in the range (0.0, 1.0], a str among {'log2', 'sqrt'} or None. Got
'auto' instead.

--------------------------------------------------------------------------
------
275 fits failed with the following error:
Traceback (most recent call last):
  File "/opt/anaconda3/lib/python3.11/site-packages/sklearn/model_selectio
n/_validation.py", line 866, in _fit_and_score
    estimator.fit(X_train, y_train, **fit_params)
  File "/opt/anaconda3/lib/python3.11/site-packages/sklearn/base.py", line
1382, in wrapper
    estimator._validate_params()
  File "/opt/anaconda3/lib/python3.11/site-packages/sklearn/base.py", line
436, in _validate_params
    validate_parameter_constraints(
  File "/opt/anaconda3/lib/python3.11/site-packages/sklearn/utils/_param_v
alidation.py", line 98, in validate_parameter_constraints
    raise InvalidParameterError(
sklearn.utils._param_validation.InvalidParameterError: The 'max_features'
parameter of RandomForestRegressor must be an int in the range [1, inf), a
float in the range (0.0, 1.0], a str among {'sqrt', 'log2'} or None. Got
'auto' instead.

  warnings.warn(some_fits_failed_message, FitFailedWarning)
/opt/anaconda3/lib/python3.11/site-packages/sklearn/model_selection/_searc
h.py:1108: UserWarning: One or more of the test scores are non-finite: [
nan        nan        nan        nan        nan        nan
        nan        nan        nan        nan        nan        nan
        nan        nan        nan        nan        nan        nan
        nan        nan        nan        nan        nan        nan
        nan        nan        nan 0.90458065 0.90422603 0.9042407
 0.90154555 0.90109919 0.90123471 0.89411844 0.89432123 0.89605091
 0.89746687 0.89857306 0.89914058 0.89677983 0.89776524 0.89922844
 0.88998722 0.8917746  0.89274801 0.88318668 0.8841201  0.88481313
 0.88318668 0.8841201  0.88481313 0.88334807 0.88316757 0.8825256
 0.90458065 0.90422603 0.9042407  0.90154555 0.90109919 0.90123471
 0.89411844 0.89432123 0.89605091 0.89746687 0.89857306 0.89914058
 0.89677983 0.89776524 0.89922844 0.88998722 0.8917746  0.89274801
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        nan        nan        nan        nan        nan        nan
        nan        nan        nan        nan        nan        nan
        nan        nan        nan        nan        nan        nan
 0.90140684 0.90211433 0.90256605 0.89834074 0.89939992 0.90093736
 0.89415359 0.89646797 0.89573559 0.89470218 0.89839301 0.8992903
 0.89714071 0.89756731 0.89862595 0.89236609 0.89337565 0.89340479
 0.88096668 0.88264196 0.88372937 0.88096668 0.88264196 0.88372937
 0.88416862 0.88349838 0.88211967 0.90140684 0.90211433 0.90256605
 0.89834074 0.89939992 0.90093736 0.89415359 0.89646797 0.89573559
 0.89470218 0.89839301 0.8992903  0.89714071 0.89756731 0.89862595
 0.89236609 0.89337565 0.89340479 0.88096668 0.88264196 0.88372937
 0.88096668 0.88264196 0.88372937 0.88416862 0.88349838 0.88211967
        nan        nan        nan        nan        nan        nan
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        nan        nan        nan 0.90458065 0.90424931 0.90424649
 0.90154555 0.90109919 0.901236   0.89411844 0.89432123 0.89605091
 0.89746687 0.89857306 0.89914058 0.89677983 0.89776524 0.89922844
 0.88998722 0.8917746  0.89274801 0.88318668 0.8841201  0.88481313
 0.88318668 0.8841201  0.88481313 0.88334807 0.88316757 0.8825256
 0.90458065 0.90424931 0.90424649 0.90154555 0.90109919 0.901236
 0.89411844 0.89432123 0.89605091 0.89746687 0.89857306 0.89914058
 0.89677983 0.89776524 0.89922844 0.88998722 0.8917746  0.89274801
 0.88318668 0.8841201  0.88481313 0.88318668 0.8841201  0.88481313
 0.88334807 0.88316757 0.8825256         nan        nan        nan
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        nan        nan        nan        nan        nan        nan
        nan        nan        nan        nan        nan        nan
        nan        nan        nan        nan        nan        nan
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 0.89411844 0.89432123 0.89605091 0.89746687 0.89857306 0.89914058
 0.89677983 0.89776524 0.89922844 0.88998722 0.8917746  0.89274801
 0.88318668 0.8841201  0.88481313 0.88318668 0.8841201  0.88481313
 0.88334807 0.88316757 0.8825256  0.90458065 0.90422603 0.9042407
 0.90154555 0.90109919 0.90123471 0.89411844 0.89432123 0.89605091
 0.89746687 0.89857306 0.89914058 0.89677983 0.89776524 0.89922844
 0.88998722 0.8917746  0.89274801 0.88318668 0.8841201  0.88481313
 0.88318668 0.8841201  0.88481313 0.88334807 0.88316757 0.8825256 ]
  warnings.warn(
```

```
In [20]: print("Best Hyperparameters:", grid_search.best_params_)
         best_rf = grid_search.best_estimator_
```

```
Best Hyperparameters: {'max_depth': None, 'max_features': 'sqrt', 'min_sam
ples_leaf': 1, 'min_samples_split': 2, 'n_estimators': 50}
```

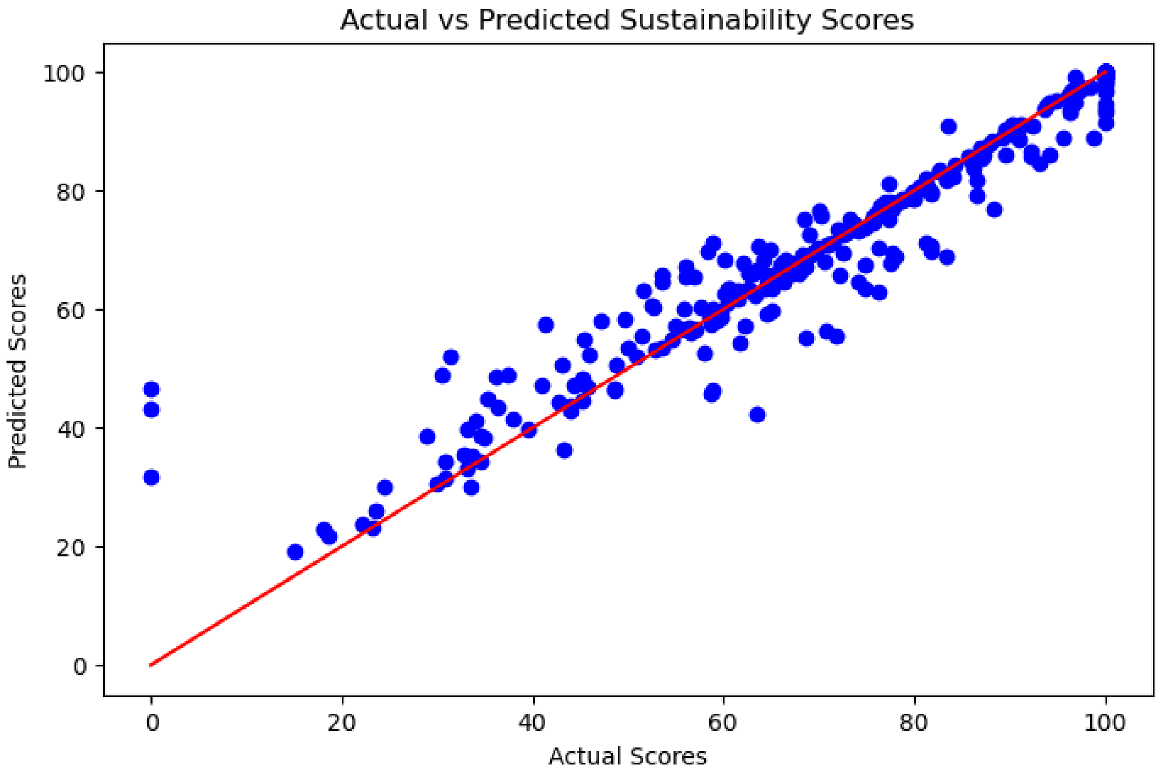
```
In [21]: # Step 6: Model Evaluation
         y_pred = best_rf.predict(X_test)
         mse = mean_squared_error(y_test, y_pred)
```

```
r2 = r2_score(y_test, y_pred)
accuracy = best_rf.score(X_test, y_test) * 100
```

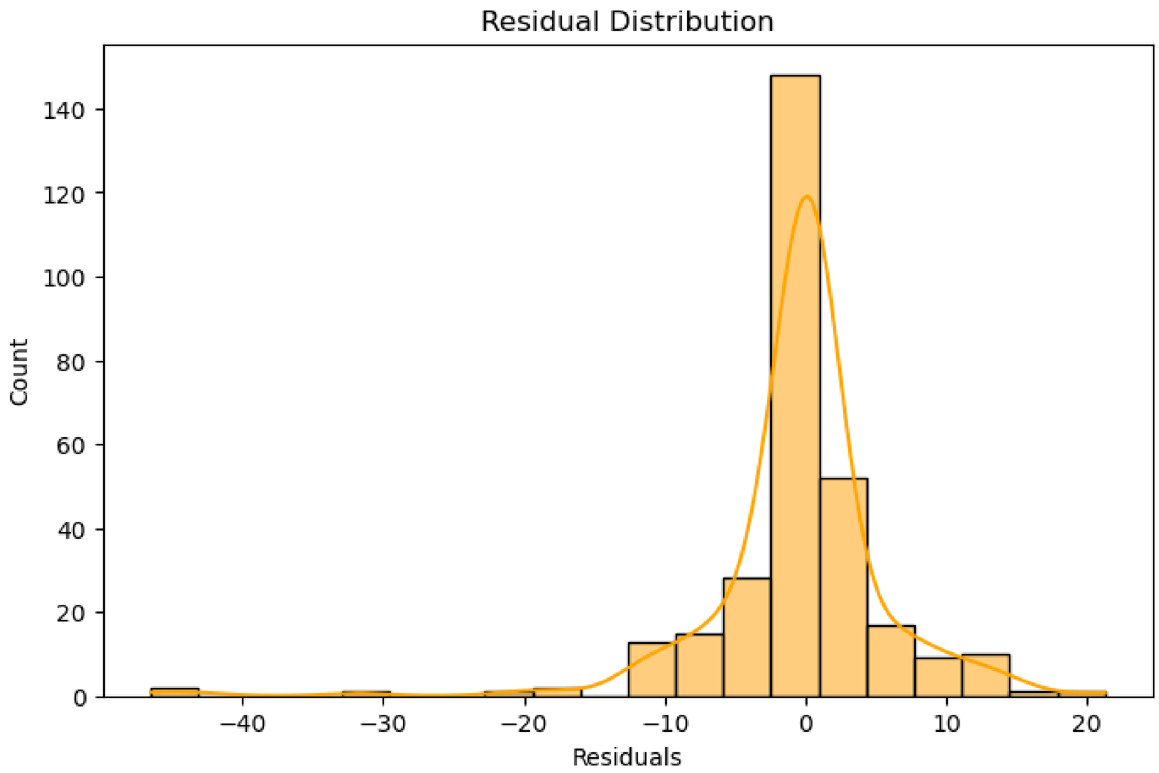
In [22]:
```
print("\n--- Model Performance ---")
print("Mean Squared Error (MSE):", mse)
print("R² Score:", r2)
print("Accuracy:", accuracy, "%")
```

```
--- Model Performance ---
Mean Squared Error (MSE): 42.832928455178845
R² Score: 0.9166630627596599
Accuracy: 91.666306275966 %
```

In [23]:
```
plt.figure(figsize=(8, 5))
plt.scatter(y_test, y_pred, color="blue")
plt.plot([min(y_test), max(y_test)], [min(y_test), max(y_test)], color="r
plt.title("Actual vs Predicted Sustainability Scores")
plt.xlabel("Actual Scores")
plt.ylabel("Predicted Scores")
plt.show()
```

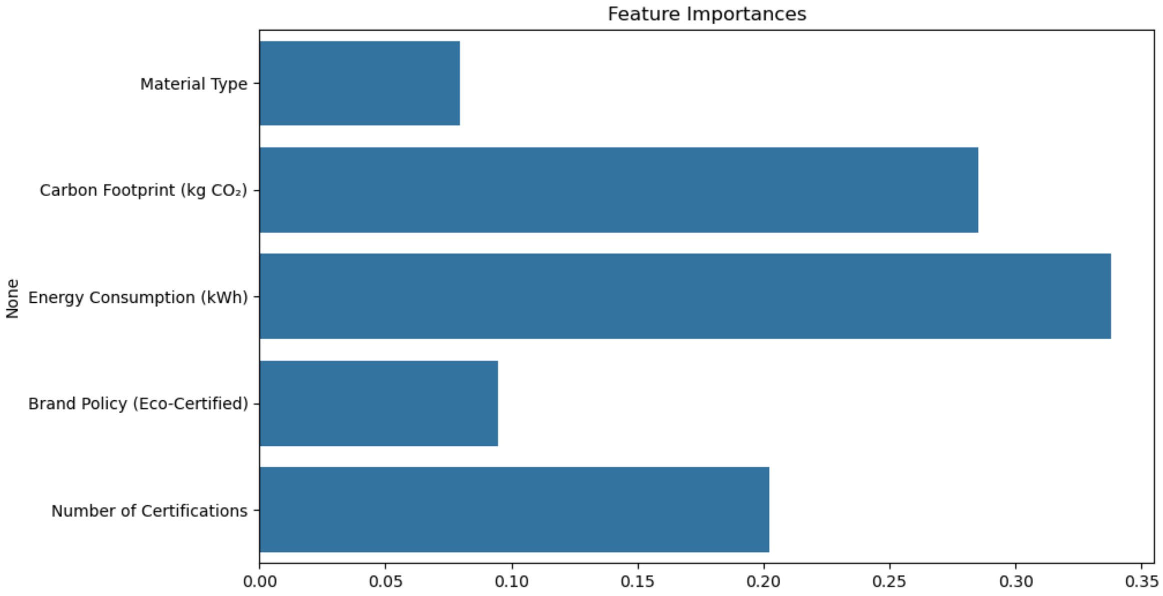


In [24]:
```
residuals = y_test - y_pred
plt.figure(figsize=(8, 5))
sns.histplot(residuals, bins=20, kde=True, color="orange")
plt.title("Residual Distribution")
plt.xlabel("Residuals")
plt.show()
```



In [25]:

```
feature_importances = best_rf.feature_importances_
features = X.columns
plt.figure(figsize=(10, 6))
sns.barplot(x=feature_importances, y=features)
plt.title("Feature Importances")
plt.show()
```



In [26]:

```
import joblib
joblib.dump(best_rf, "sustainability_rf_model.joblib")
```

Out[26]:

```
['sustainability_rf_model.joblib']
```

In [27]:

```
# Example hard-coded input values (replace with actual values)
input_values = np.array([[10, 20, 30, 0.5, 15]])  # Replace with actual f

# Scale the input values using the same scaler
input_values_scaled = scaler.transform(input_values)
```

```
# Predict the sustainability score
predicted_score = best_rf.predict(input_values_scaled)

print("Predicted Sustainability Score:", predicted_score[0])
```

```
Predicted Sustainability Score: 91.51675662420931
```

In [ ]:

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