

# VED ML Data Modelling

ICE, HEV, EV, and PHEV Analysis   **Supervised Learning**   Unsupervised Learning

## Supervised Learning - Regression

- **Model:** Linear Regression.
- **X\_test, y\_test:** Test data for further analysis.
- **y\_pred:** Predictions on test set.
- **Regression Line:** Model for plotting Actual vs Predicted regression line.

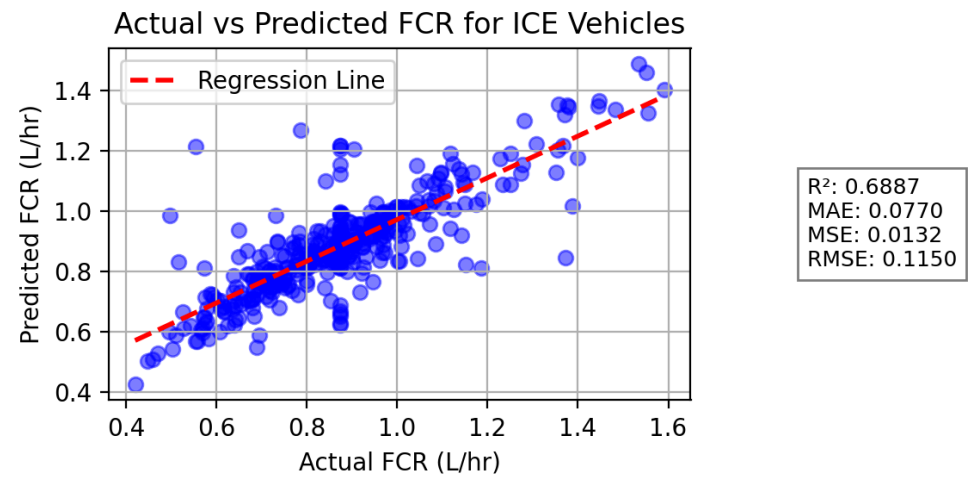
## Linear Regression to Predict Energy Consumption in ICE, HEV, EV and PHEV Vehicles

Predict FCR for ICE vehicles

### Actual vs Predicted Fuel Consumption Rate (FCR) for ICE Vehicles

This scatter plot compares the **actual** FCR values with those predicted by the linear regression model. A red dashed line represents the fitted regression line.

- **Used features:** Vehicle Speed[km/h], Distance[km], Generalized\_Weight, MAF[g/sec], Absolute Load[%], Short Term Fuel Trim Bank 1[%], Short Term Fuel Trim Bank 2[%], Long Term Fuel Trim Bank 1[%], Long Term Fuel Trim Bank 2[%].
- Plotted Actual vs Predicted FCR values and regression line.
- Displayed evaluation metrics:  $R^2$ , MAE, MSE, and RMSE on the plot.



#### Model Coefficients:

```
Vehicle Speed[km/h]: 0.0035
Distance[km]: 0.0002
Generalized_Weight: 0.0001
MAF[g/sec]: 0.0372
Absolute Load[%]: 0.0066
Short Term Fuel Trim Bank 1[%]: -0.0004
Short Term Fuel Trim Bank 2[%]: 0.0029
Long Term Fuel Trim Bank 1[%]: 0.0076
Long Term Fuel Trim Bank 2[%]: 0.0005
```

#### Regression Equation:

```
Slope of the regression line: [ 3.51771144e-03  1.54859609e-04  8.60672719e-05  3
6.57019976e-03 -3.68340265e-04  2.92205509e-03  7.63933480e-03
4.79373945e-04]
Intercept: -0.2424
Target Variable: FCR
FCR = 0.0035*Vehicle Speed[km/h] + 0.0002*Distance[km] + 0.0001*Generalized_Weigh
```

#### Evaluation Metrics:

```
 $R^2$  Score : 0.6887
MAE : 0.0770
MSE : 0.0132
```

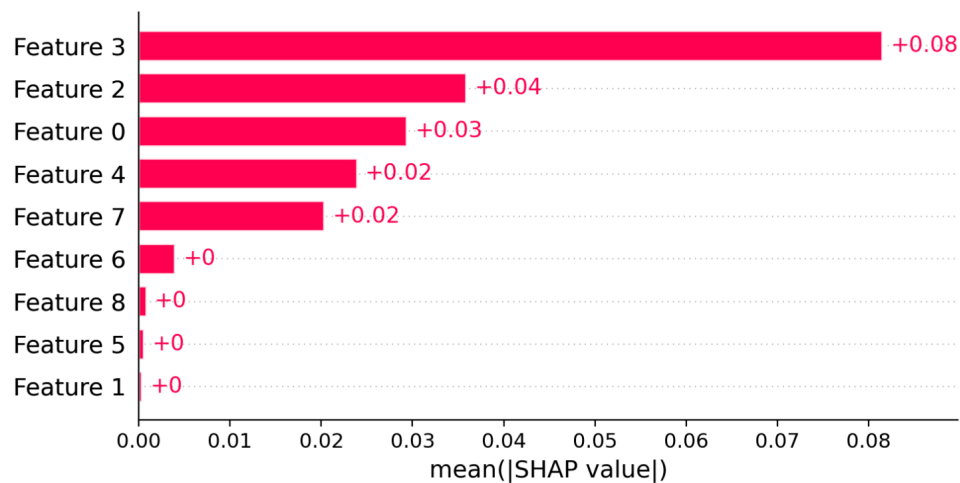
RMSE : 0.1150

## SHAP Feature Importance for ICE Vehicle FCR Prediction

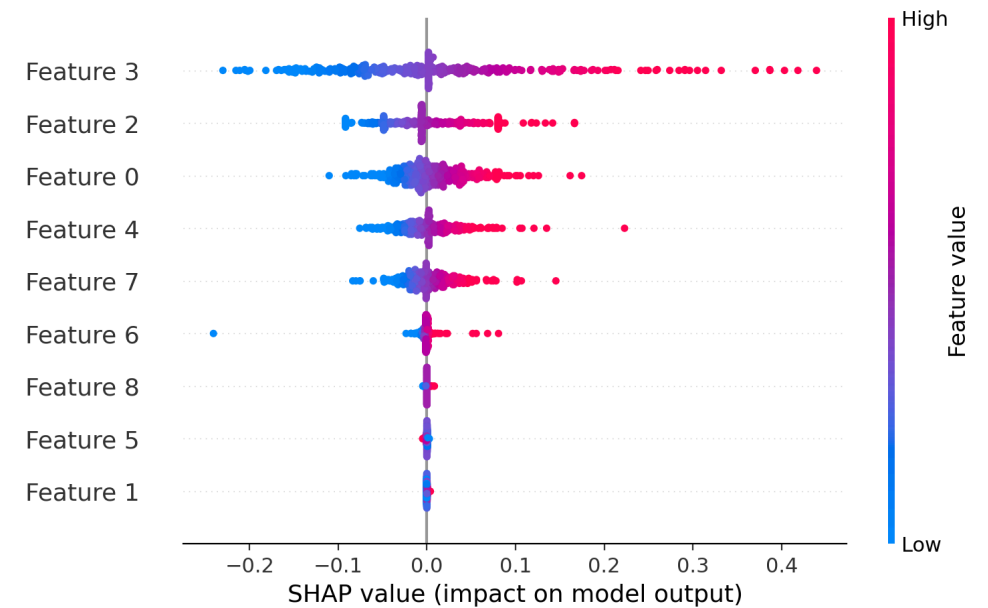
The following visualizations use SHAP (SHapley Additive exPlanations) to interpret the linear regression model predicting Fuel Consumption Rate (FCR) for ICE vehicles.

- **Bar Plot:** Shows mean absolute SHAP value for each feature (global importance).
- **Beeswarm Plot:** Shows the distribution and impact of each feature on model output.
- **Waterfall Plot:** Explains the SHAP values for a single prediction.
- **SHAP Values Table:** Displays the SHAP values for the test set.

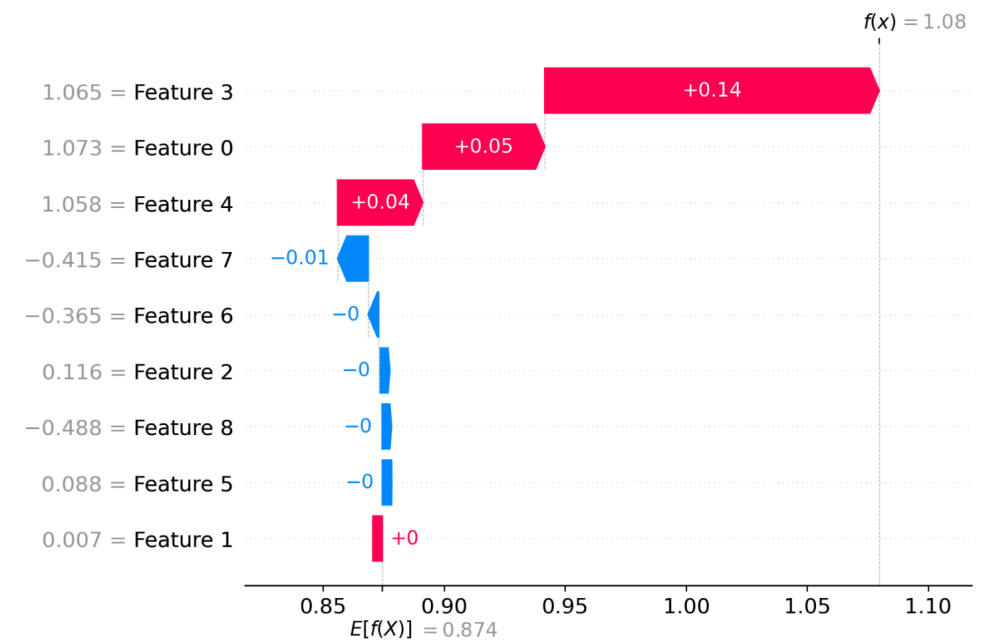
### SHAP Bar Plot (Global Feature Importance)



### SHAP Beeswarm Plot (Feature Impact Distribution)



### SHAP Waterfall Plot (First Test Sample)



### SHAP Values Table (First 10 Test Samples)

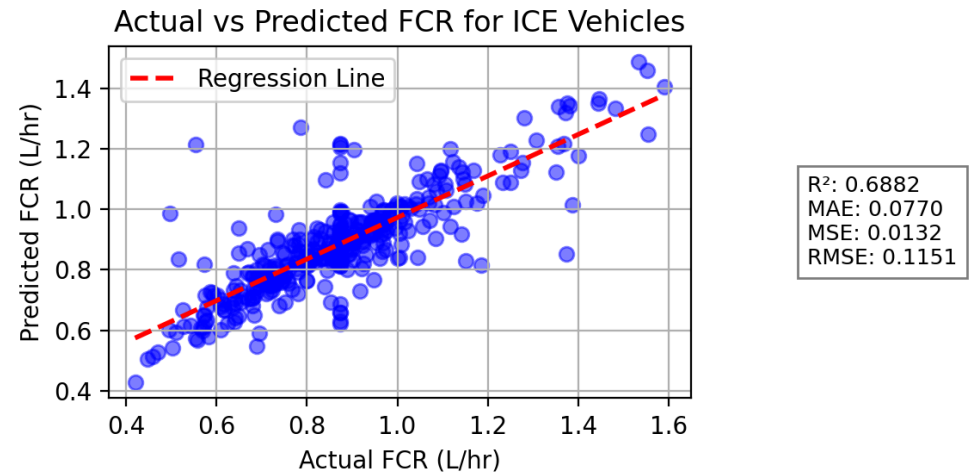
	Vehicle Speed[km/h]	Distance[km]	Generalized_Weight	MAF[g/sec]	Absolute Load[%]	Short Term
0	0.0504	0.00004	-0.0007	0.1381	0.0352	
1	-0.0133	-0.0001	-0.0917	-0.1608	-0.0301	
2	-0.0045	-0.000002	0.0466	0.0512	-0.0083	
3	0.0204	0.0004	-0.0264	0.0199	-0.0069	
4	-0.0243	-0.0001	-0.0266	-0.0718	-0.0219	
5	-0.0799	-0.0004	-0.0917	-0.23	-0.0157	
6	0.0468	-0.00008	-0.0057	0.0018	0.0023	
7	-0.0079	-0.0001	0.0385	-0.0194	-0.0232	
8	-0.0021	0.00005	-0.0023	0.0007	-0.0104	
9	-0.0006	-0.00007	0.0204	0.0025	-0.0179	

Comments:

- The bar plot shows which features have the largest average impact on FCR prediction.
- The beeswarm plot visualizes how each feature's value (high/low) pushes the prediction higher or lower.
- The waterfall plot explains the SHAP value breakdown for a single prediction.
- The SHAP values table provides the actual SHAP values for each feature and test sample.

Actual vs Predicted Fuel Consumption Rate (FCR) for ICE Vehicles after SHAP Analysis

- **Used features:** Vehicle Speed[km/h], Generalized\_Weight, MAF[g/sec], Absolute Load[%], Long Term Fuel Trim Bank 1[%]
- Plotted Actual vs Predicted FCR values and regression line.
- Displayed evaluation metrics: R<sup>2</sup>, MAE, MSE, and RMSE on the plot.



Model Coefficients:

Vehicle Speed[km/h]: 0.0036  
Generalized\_Weight: 0.0001  
MAF[g/sec]: 0.0372  
Absolute Load[%]: 0.0065  
Long Term Fuel Trim Bank 1[%]: 0.0078

Regression Equation:

Slope of the regression line: [3.55961834e-03 8.50345586e-05 3.72454835e-02 6.5177.78615378e-03]  
Intercept: -0.2380  
Target Variable: FCR  
FCR = 0.0036\*Vehicle Speed[km/h] + 0.0001\*Generalized\_Weight + 0.0372\*MAF[g/sec]

Evaluation Metrics:

R<sup>2</sup> Score : 0.6882  
MAE : 0.0770  
MSE : 0.0132  
RMSE : 0.1151

The model can predict FCR for ICE vehicles reasonably well, but not as accurately as for HEVs. There is a moderate linear relationship, but other factors may influence FCR in ICE vehicles, or the selected

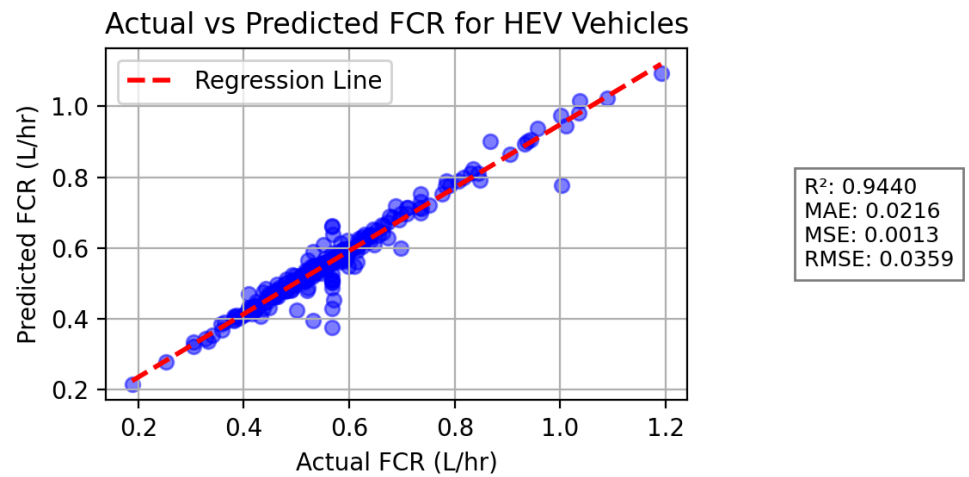
features may not capture all the variability. Further feature engineering or model improvement could enhance prediction accuracy.

## Predict FCR for HEV vehicles

### Actual vs Predicted Fuel Consumption Rate (FCR) for HEV Vehicles

This scatter plot compares the **actual** FCR values with those predicted by the linear regression model. A red dashed line represents the fitted regression line.

- Used features: MAF[g/sec]
- Plotted Actual vs Predicted FCR values and regression line.
- Displayed evaluation metrics: R<sup>2</sup>, MAE, MSE, and RMSE on the plot.



Target Variable: FCR  
FCR = 0.0629 \* MAF[g/sec] + 0.0413

Evaluation Metrics:

R<sup>2</sup> Score : 0.9440  
MAE : 0.0216  
MSE : 0.0013  
RMSE : 0.0359

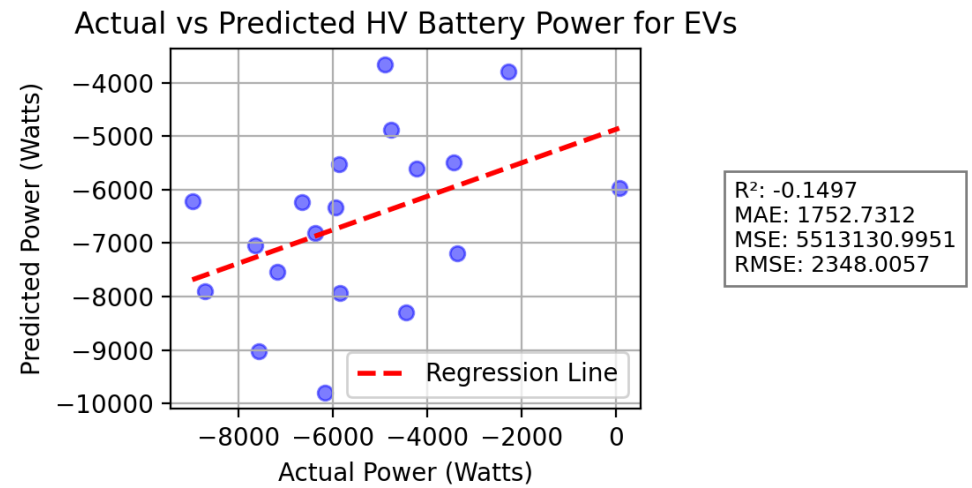
The linear regression model predicts FCR for HEV vehicles with high accuracy using the selected feature(s). The model's predictions are very close to the actual values, as shown by the high R<sup>2</sup> and low error metrics. This suggests that the chosen feature(s) (here, 'MAF[g/sec]') are strong predictors of FCR for HEVs in this dataset.

## Predict Battery Power for EV vehicles

### Actual vs Predicted HV Battery Power for EVs

This scatter plot compares the **actual** Battery Power values with those predicted by the linear regression model. A red dashed line represents the fitted regression line.

- Used features: Air Conditioning Power[Watts], Heater Power[Watts], Vehicle Speed[km/h]
- Plotted Actual vs Predicted Battery Power values and regression line.
- Displayed evaluation metrics: R<sup>2</sup>, MAE, MSE, and RMSE on the plot.



Model Coefficients:

Air Conditioning Power[Watts]: -2.5853  
Heater Power[Watts]: -1.2364  
Vehicle Speed[km/h]: -112.8938

Regression Equation:

Slope of the regression line: [ -2.58530326 -1.23642892 -112.89382874]  
Intercept: -271.2544  
Target Variable: HV Battery Power[Watts]  
HV Battery Power[Watts] = -2.5853\*Air Conditioning Power[Watts] + -1.2364\*Heater

Evaluation Metrics:

R<sup>2</sup> Score : -0.1497  
MAE : 1752.7312  
MSE : 5513130.9951  
RMSE : 2348.0057

The selected features do not adequately explain or predict the HV Battery Power for EVs in this dataset. The model fails to capture the relationship, suggesting the need for better feature selection, more data, or a different modeling approach.

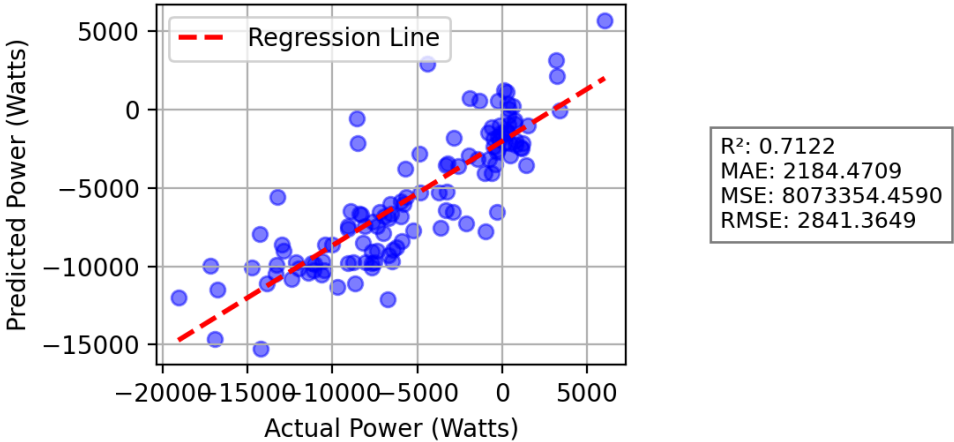
Predict Battery Power for PHEV vehicles

Actual vs Predicted HV Battery Power for PHEVs

This scatter plot compares the **actual Battery Power** values with those predicted by the linear regression model. A red dashed line represents the fitted regression line.

- Used features: Air Conditioning Power[Watts], Heater Power[Watts], Vehicle Speed[km/h]
- Plotted Actual vs Predicted Battery Power values and regression line.
- Displayed evaluation metrics: R<sup>2</sup>, MAE, MSE, and RMSE on the plot.

Actual vs Predicted HV Battery Power for PHEVs



Model Coefficients:

Engine RPM[RPM]: 8.1661  
Air Conditioning Power[Watts]: -0.9029  
Vehicle Speed[km/h]: -203.6183  
OAT[DegC]: 144.2664

Regression Equation:

Slope of the regression line: [ 8.166065 -0.90289333 -203.61834751 144.266  
Intercept: -277.2092  
Target Variable: HV Battery Power[Watts]  
HV Battery Power[Watts] = 8.1661\*Engine RPM[RPM] + -0.9029\*Air Conditioning Power

Evaluation Metrics:

R<sup>2</sup> Score : 0.7122  
MAE : 2184.4709  
MSE : 8073354.4590  
RMSE : 2841.3649

The selected features are effective in predicting HV Battery Power for PHEVs. The model captures the relationship well, making it suitable for estimating power consumption in PHEV vehicles.

