**Studying of the Impact of road, environment, driver, and traffic characteristics on CO2 vehicles emissions on Egypt**

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**دراسة تأثير خصائص الطرق, البيئة, السائق وحركة المرور على انبعاثات ثاني أكسيد الكربون للمركبات في مصر**

 **الملخص:**

**الهدف من هذا البحث هو دراسة العوامل التي تؤثر على انبعاثات ثاني أكسيد الكربون من المركبات على الطرق المصرية. تمت معايرة النماذج باستخدام سجلات انبعاثات المركبات التي تم جمعها خلال الدراسة للفترة (نوفمبر 2017). سجلت البيانات لثماني مركبات ، وتم تصنيف بيانات الانبعاث حسب نوع الوقود إلى ثلاث فئات (ديزل ، وغاز طبيعي ، ومركبات بنزين) ، ولإجراء تحليل مقارن لمختلف تقنيات النمذجة الإحصائية ، تم استخدام نماذج الانحدار الخطي المعممة مثل "الانحدار الخطي" مع وظيفة الارتباط للهوية ، والانحدار الخطي. مع وظيفة الارتباط من السجل ، وانحدار جاما مع وظيفة الارتباط من السجل وانحدار Tweedy مع وظيفة الارتباط في السجل "للتنبؤ بمعدلات انبعاث السيارة كدالة للمتغيرات المستقلة. تم الحصول على قياسات انبعاثات المركبات CO2 (g / s) المستخدمة في هذه الدراسة من جهاز شؤون البيئة المصري (EEAA) المسجلة للفترة (نوفمبر 2017) ، تم اختيار سبعة متغيرات مستقلة في هذا البحث (سرعة السيارة ، الزاوية بين المحاذاة الأفقية ، الملف الشخصي الدرجة ودرجة الحرارة المحيطة والضغط المحيط والرطوبة النسبية المحيطة وعدد الدوران في الدقيقة لمحرك السيارة) والتي تؤثر بشكل مباشر على انبعاثات المركبات لفئات المركبات المختلفة ثم مقارنة هذه النتائج التي تم الحصول عليها من النموذج الرياضي (SPSS). أخيرًا ، وجد أن نموذج الانحدار الخطي مع وظيفة الارتباط في السجل كان أفضل نموذج انحدار معمم لتمثيل الارتباط بين انبعاثات ثاني أكسيد الكربون لمركبات الديزل والغاز الطبيعي وانبعاثات مركبات البنزين.**

**ABSTRACT**

The objective of this research is to study factors that effect on the CO2 vehicles emissions on Egyptian roads. The models were calibrated using vehicles emission records collected during the study for the period (November 2017). Data recorded for eight vehicles, emission data were classified according to the fuel type to three categories (Diesel, Natural Gas and Petrol Vehicles), and to conduct a comparative analysis of various statistical modeling techniques generalized linear regression models were used such as "Linear Regression with Link Function of Identity, Linear Regression. with Link Function of Log, Gamma Regression with Link Function of Log and Tweedy Regression with Link Function of Log " to predict vehicle emission rates as a function of the independent variables.

Vehicles emission measurements CO2 (g/s) used in this study were obtained from Egyptian Environmental Affairs Agency (EEAA) recorded for the period (November 2017), Seven independent variables were selected in this research (vehicle speed, angle between horizontal alignments, profile grade, ambient temperature, ambient pressure, ambient relative humidity and numbers of rotation per minute for vehicle engine) which affect directly on the vehicle emissions for the different vehicles categories then a comparison of these results obtained from the (SPSS) mathematical model.

Finally, it was found that Linear regression model with link function of log was the best generalized regression model to represent the correlation between CO2 emission for Diesel vehicles, Natural Gas and Petrol vehicles emission.

**Keywords:** CO2 emission-Diesel vehicles-Natural Gas vehicles-Petrol vehicles

# Introduction

The road fleet in Egypt consists of various types of vehicles such as cars, taxis, buses and minibuses, trucks, motorcycles, tractors and special purpose vehicles. The number of vehicles registered in Egypt is continuously increasing at a rate much higher the rate of increase of the roads and this causes a sever traffic problems and increased fuel consumption and consequently increased GHG emissions (EEAA, 2016).

In recent years (after 2005) the total number of vehicles began to increase at a very high rate (11.8% annual increase rate in the period 2005/2010 compared to 2.2% in the period 2000/2005) (EEAA, 2016). This results from high increase rate of private cars and motorcycles. The annual increase rate of private cars jumped from 6.1% in the period 2000/2005 to 12.6% in the period 2005/2010 (EEAA, 2016).

The overall fleet composition is continuously changing, the percentage of private cars increase from 44.5% in 2000 to 49.1% in 2010. The percentages of the other types of vehicles such as buses and trucks remain constant or slightly decrease (EEAA, 2016).

# Problem Statement and Research Objectives

The main objective of this study was to analyze factors influence vehicles CO2 emissions. The procedure of the analysis was based on actual continuous speed profiles and emission estimation model. The study focused on vehicles emission measurements of CO2 (g/s) because it was the major contributor to global warming. The underlying hypothesis is that vehicles emissions affected from several variables, these variables categorized to travel-related factors, highway characteristics and vehicle characteristics and other factors. Seven independent variables were selected in this research (vehicle speed, bearing angle between horizontal alignments, profile grade, ambient temperature, ambient pressure, ambient relative humidity and numbers of rotation per minute for vehicle engine) which affect directly on the vehicle CO2 emissions for the different vehicles categories.

# Methodology

This section presents the methodology and techniques which were applied in this research and data sources that were utilized in the modeling approach and the several mathematical approaches to estimate vehicle CO2 emissions relationship with the independent variables which categorized to travel-related factors, highway characteristics and vehicle characteristics and other factors

# Data Description

In this research, the available data for vehicles emissions were obtained from Egyptian Environmental Affairs Agency (EEAA) recorded for the period (November 2017), On-board Portable Emission Measurement System (PEMS) was used to collect the data of second-by-second emissions and speed variation of the vehicle under real-world conditions at any location traveled by the vehicle (Cicero-Fernández, P. 1997).

These data are in the form of look-up tables for microscopic emission rates measurements CO2 (g/s), Temperature, Pressure, Relative Humidity, Numbers of Rotation per Minute for Vehicle Engine and vehicle speed. The raw data was collected every second during various driving cycles for each individual vehicle, Figure 1showed sample of the received data and Table 1 represents the different types for the eight vehicles which used in this research.



Figure 1. Sample of Received Data for Vehicle Emissions, (EEAA, 2017).

Table 1 Vehicle data brand, engine capacity, model year, fuel type and usage (EEAA, 20017).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Car No | Car brand | Engine Capacity CC | Model Year | Fuel Type | Usage |
| 1 | Mercedes | 6,000 | 2,006 | Diesel | Bus |
| 2 | Chevrolet | 4,500 | 2,009 | Diesel | Minibus |
| 3 | Toyota | 2,500 | 2,010 | Diesel | Microbus |
| 4 | Daewoo | 6,000 | 2,010 | Natural Gas | Bus |
| 5 | Foton | 2,500 | 2,013 | Natural Gas | Microbus |
| 6 | Speranza | 1,600 | 2,010 | Petrol | Taxi |
| 7 | Isuzu | 2,000 | 1,989 | Petrol | Private Car |
| 8 | Jeep Cherokee | 3,700 | 2,008 | Petrol | Private Car |

A total reading of 48489 of vehicle emission exhaust were recorded for the eight vehicles, the number of emission readings for each vehicle was indicated in Figure 2

Figure 2: Emission readings for each vehicle, (EEAA, 2017).

# Data Classification

The eight vehicles were classified according the fuel type to three categories the first was for Diesel Vehicles including the first three vehicles (Mercedes Bus, Chevrolet Minibus and Toyota Microbus), while the second category was for Natural Gas Vehicles containing the fourth and fifth vehicles (Daewoo Bus and Foton Microbus), at last category for Petrol Vehicles (Speranza Taxi, Isuzu Private Car and Jeep Cherokee Private Car). The total no of vehicle emission exhaust were illustrated in Figure 3.

Figure 3 Total Emission Readings for Each Vehicle Category, (EEAA, 2017).

# Dependent Variable

In previous researches it was found that CO2 emission one of the main important vehicles emissions exhaust which represent dependent variables measurements.

# Independent Variable

Seven independent variables were selected in this research which affect directly on vehicle emissions from transportation, Design speed is an essential parameter in the highway geometric design, and affects other design features (Harikishan, P 2018). Vehicle speed was chosen as essential element of travel related factors effect on vehicle emissions in this research. The bearing angle between horizontal alignment tangents and longitudinal road grades were selected to study the effect of highway characteristics on vehicle emissions. Numbers of rotation per minute for vehicle engine, ambient temperature, ambient pressure and ambient relative humidity were selected to study the effect of vehicle characteristics and weather conditions on vehicle emission as shown in Table 2.

Table 2 Dependent Variables.

|  |  |  |  |
| --- | --- | --- | --- |
| **No.** | **Variables** | **Symbol** | **Measure** |
| 1 | Vehicle Speed | V | Kilometer Per Hour (KPH) |
| 2 | Angle between horizontal alignments  | β | Degree (°) |
| 3 | Profile Grade | G | Percent (%) |
| 4 | Ambient Temperature | T | Celsius (Co) |
| 5 | Ambient Pressure | P | kilopascal (kPa) |
| 6 | Ambient Relative Humidity | RH% | Percent (%) |
| 7 | Numbers of Rotation Per Minute for Vehicle Engine | RPM | Value |

# Generalized Linear Emission Models

Generalized Linear Models were introduced by (Nelder, J. A. and Wedderburn , 1972), in an attempt to make the assumptions of traditional regression models more realistic in order to suit the practical reality. The generalized linear model is a regression model, in which the dependent variable follows one of the probability distributions belonging to the exponential family, and these models are considered less restrictive than the traditional regression models.

# Simple Regression Analysis

Simple Regression Analysis gives the correlation between dependent variable which represent vehicle CO2 (g/s) emission for the three categories according to fuel type and the seven selected independent variables.

The correlation between dependent variables of Diesel vehicles emission and independent variables were discussed, Single regression show a strong relation between CO2 emission with the independent variables RPM as illustrated in SPSS output tables and figures, The coefficient of determination (R2) was found to be 0.638 which showed the good relation between CO2 and RPM,.

The same procedure was conducted to test the relation between CO2 emission for diesel vehicle and rest of independent variables, Single regression showed a strong relation between CO2 emission with the independent variables V, β, T, P and RH while a poor relation with profile road grade G as the selected roads were almost flat grades.

Table 4 provide the summary of single regression for CO2 Emission of Natural Gas Vehicles which represent the dependent variable and the independent variables, Single regression showed a strong relation between CO2 emission with the independent variables RPM, T, P and RH while a poor relation with vehicle speed V, Bearing β and road profile grade G. Petrol vehicle CO2emission showed a poor relation between CO2 emission with all independent variables unless RPM variable.

Table 3 Single regression between CO2 for diesel vehicles and RPM.

|  |
| --- |
| **Model Description** |
| Model Name | Co2 and RPM |
| Dependent Variable | 1 | Co2  |
| Equation | 1 | Quadratic |
| Independent Variable | RPM |
| Constant | Not included |
| Variable Whose Values Label Observations in Plots | Unspecified |
| Tolerance for Entering Terms in Equations | 0.0001 |
|  |  |

|  |
| --- |
| **Case Processing Summary** |
|  | N |
| Total Cases | 19082 |
| Excluded Casesa | 0 |
| Forecasted Cases | 0 |
| Newly Created Cases | 0 |

a. Cases with a missing value in any variable are excluded from the analysis.

|  |
| --- |
| **Variable Processing Summary** |
|  | Variables |
| Dependent | Independent |
| CO2 | RPM |
| Number of Positive Values | 19081 | 19082 |
| Number of Zeros | 1 | 0 |
| Number of Negative Values | 0 | 0 |
| Number of Missing Values | User-Missing | 0 | 0 |
| System-Missing | 0 | 0 |

**CO2 - Quadratic**

|  |
| --- |
| **Model Summary a** |
| R | R Square | Adjusted R Square | Std. Error of the Estimate |
| 0.799 | 0.638 | 0.638 | 1.905 |

The independent variable is RPM a

a. The equation was estimated without the constant term.

|  |
| --- |
| **ANOVAa** |
|  | Sum of Squares | df | Mean Square | F | Sig. |
| Regression | 121856.115 | 2 | 60928.057 | 16790.027 | .000 |
| Residual | 69237.968 | 19080 | 3.629 |  |  |
| Total | 191094.082 | 19082 |  |  |  |

The independent variable is RPM a

a. The equation was estimated without the constant term.

|  |
| --- |
|  **Coefficients** |
|  | Unstandardized Coefficients | Standardized Coefficients | t | Sig. |
| B | Std. Error | Beta |  |
| RPM | 0.002 | 0.000 | 0.672 | 47.462 | 0.00 |
| RPM | 1.761E-7 | 0.000 | 0.132 | 9.360 | 0.00 |



Figure 4 Scatter plot for CO2 Emission with RPM.

Table 4 Simple regression analysis for diesel vehicles.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Dependent Variable** | **Independent Variables** | **Equation** | **Adjusted R2** | **Relation**  |
| **Diesel Vehicles** | **CO2 Emission for Diesel Vehicles** | V | CO2 (D) = 1.531\*V | 0.594 | Good |
| β | CO2 (D) = 1.804\*β | 0.507 | Good |
| G | CO2 (D) = 0.015\*G | 0.084 | Poor |
| T | CO2 (D) = 2.152\*T | 0.523 | Good |
| P | CO2 (D) = 0.722\*P | 0.521 | Good |
| RH% | CO2 (D) = 1.118\*RH | 0.528 | Good |
| RPM | CO2 (D) = 0.672\*RPM | 0.638 | Good |
| **Natural Gas Vehicles** | **CO2 Emission for Diesel Vehicles** | V | CO2 (N) = 1.905\*V | 0.463 | Poor |
| β | CO2 (N) = 1.867\*β | 0.483 | Poor |
| G | CO2 (N) = 0.017\*G | 0.103 | Poor |
| T | CO2 (N) = 1.260\*T | 0.623 | Good |
| P | CO2 (N) = 0.745\*P | 0.555 | Good |
| RH% | CO2 (N) = 3.077\*RH | 0.694 | Good |
| RPM | CO2 (N) = 0.509\*RPM | 0.793 | Good |
| **Petrol Vehicles** | **CO2 Emission for Petrol Vehicles** | V | CO2 (P) = 1.118\*V | 0.437 | Poor |
| β | CO2 (P) = 1.578\*β | 0.34 | Poor |
| G | CO2 (P) = 0.288\*G | 0.083 | Poor |
| T | CO2 (P) = 0.410\*T | 0.392 | Poor |
| P | CO2 (P) = 0.619\*P | 0.383 | Poor |
| RH% | CO2 (P) = 0.902\*RH | 0.384 | Poor |
| RPM | CO2 (P) = 0.323\* RPM | 0.696 | Good |

# Statistical Analysis

Many of parameters contribute together to increase or decrease vehicles CO2 emissions, therefore simple regression analysis may give improper results, So Multiple Regression Models would be the proper one and the combined effect of these parameters on vehicles CO2 emissions must be taken into consideration. Generalized Linear Models used to analyze the relationship between a single dependent variable of vehicles CO2 emissions and several independent variables.

# Results of Diesel Vehicle Emission Models

The relation between Diesel vehicles emission CO2 (D) and independent variables were investigated by four models of generalized linear regression models as follow:

# Linear Regression with Link Function of Identity

Linear regression model with Link Function of Identity (LRMLFI) was used based on the normal distribution by linking the independent variables with the expected value of the dependent variables CO2 (D) through the Identity link function.

The goodness of fit indicators was given in Table 5, while the Omnibus test used to find out whether the model was significant or not was given in Table 6. The model was significant as the level of significance was less than 0.01

Table 5: Goodness of Fit indicators (LRMLFI of CO2 (D))

|  |
| --- |
| **Goodness of Fita** |
|  | Value | df | Value/df |
| Deviance | 45514.690 | 19074 | 2.386 |
| Scaled Deviance | 19082.000 | 19074 |  |
| Pearson Chi–Square | 45514.690 | 19074 | 2.386 |
| Scaled Pearson Chi–Square | 19082.000 | 19074 |  |
| Log Likelihoodb | –35370.078 |  |  |
| Akaike's Information Criterion (AIC) | 70758.155 |  |  |
| Finite Sample Corrected AIC (AICC) | 70758.165 |  |  |
| Bayesian Information Criterion (BIC) | 70828.864 |  |  |
| Consistent AIC (CAIC) | 70837.864 |  |  |

Table 6: Omnibus Test (LRMLFI of CO2 (D))

|  |
| --- |
| **Omnibus Testa** |
| Likelihood Ratio Chi–Square | df | Sig. |
| 27377.532 | 5 | 0.000 |

All the variables were significant, as the level of significance was less than 0.05. We also find that R–square value was 50.1%, which was the percentage of the effect of the independent variables on CO2 (D) emissions as given in Table 7, the model was as follow:

CO2 (D) = 0.003\* RPM + 0.009\* V + 0.001\* β + 0.426\*P + 0.043\*G

Table 7: Model Parameters (LRMLFI of CO2 (D))

|  |
| --- |
|  **Parameter Estimates** |
| Parameter | B | Std. Error | Wald Chi–Square | df | sig | R–square |
| RPM | .003 | 3.1942E–5 | 8119.773 | 1 | .000 | 0.501 |
| V | 0.009 | .0009 | 88.075 | 1 | .000 |
| β | 0.001 | .0001 | 26.455 | 1 | .000 |
| P | 0.426 | .0708 | 36.154 | 1 | .000 |
| G | 0.043 | .0038 | 126.294 | 1 | .000 |

# Linear Regression with Link Function of Log

Linear regression with Link Function of log model (LRMLFL) was used based on the normal distribution by linking the independent variables with the expected value of the dependent variable CO2 (D) through the log link function.

 Table 8 provide the goodness of fit indicators and Table 9 showed the Omnibus test that used to find out whether the model was significant or not. The model was significant as the level of significance was less than 0.01.

All the variables were significant, as the level of significance was less than 0.05. We also find that R–square value was 51.30 %, which was the percentage of the effect of the independent variables on CO2 (D) Emissions as given in Table 10, the model was as follow:

Log CO2 (D) = 0.001\* RPM+ 0.007\* V + 0.000\* β –0.004\*T + 0.133\*P + 0.022\*G

Table 8: Goodness of Fit indicators (LRMLFL CO2 (D))

|  |
| --- |
| **Goodness of Fita** |
|  | Value | df | Value/df |
| Deviance | 44613.709 | 19073 | 2.339 |
| Scaled Deviance | 19082.000 | 19073 |  |
| Pearson Chi–Square | 44613.709 | 19073 | 2.339 |
| Scaled Pearson Chi–Square | 19082.000 | 19073 |  |
| Log Likelihoodb | –35179.316 |  |  |
| Akaike's Information Criterion (AIC) | 70378.631 |  |  |
| Finite Sample Corrected AIC (AICC) | 70378.643 |  |  |
| Bayesian Information Criterion (BIC) | 70457.196 |  |  |
| Consistent AIC (CAIC) | 70467.196 |  |  |

Table 9: Omnibus Test (LRMLFL CO2 (D))

|  |
| --- |
| **Omnibus Testa** |
| Likelihood Ratio Chi–Square | df | Sig. |
| 19341.579 | 6 | .000 |

Table 10: Model Parameters (LRMLFL CO2 (D))

|  |
| --- |
| **Parameter Estimates** |
| Parameter | B | Std. Error | Wald Chi–Square | df | sig | R–square |
| RPM | .001 | 9.1779E–6 | 11030.716 | 1 | .000 | 0.513 |
| V | .007 | .0003 | 394.946 | 1 | .000 |
| β | .000 | 4.4021E–5 | 125.075 | 1 | .000 |
| T | –.004 | .0013 | 7.506 | 1 | .006 |
| P | .133 | .0289 | 21.156 | 1 | .000 |
| G | .022 | .0015 | 218.716 | 1 | .000 |

# Gamma Regression with Link Function of Log

Gamma Regression with Link Function of Log model (GRMLFL) used based on gamma distribution by linking the independent variables with the expected value of the dependent variable CO2 (D) through the link function of log.

The goodness of fit indicators was given in Table 11, while Table 12 provide the Omnibus test. The model was significant as the level of significance was less than 0.01

Table 11: Goodness of Fit indicators (GRMLFL CO2 (D))

|  |
| --- |
| **Goodness of Fita** |
|  | Value | df | Value/df |
| Deviance | 7654.733 | 19073 | .401 |
| Scaled Deviance | 20266.072 | 19073 |  |
| Pearson Chi–Square | 6194.508 | 19073 | .325 |
| Scaled Pearson Chi–Square | 16400.095 | 19073 |  |
| Log Likelihoodb | –26050.806 |  |  |
| Akaike's Information Criterion (AIC) | 52119.612 |  |  |
| Finite Sample Corrected AIC (AICC) | 52119.621 |  |  |
| Bayesian Information Criterion (BIC) | 52190.320 |  |  |
| Consistent AIC (CAIC) | 52199.320 |  |  |

Table 12: Omnibus Test for (GRMLFL CO2 (D))

|  |
| --- |
| **Omnibus Testa** |
| Likelihood Ratio Chi–Square | df | Sig. |
| 32660.688 | 5 | .000 |

All the variables were significant, as the level of significance was less than 0.05. We also find that R–square value was 32.90%, which was the percentage of the effect of the independent variables on CO2 (D) emissions as given in Table 13, the model was as follow:

Log CO2 (D) = 0.001\* RPM+ 0.005\* V + 0.000\* β + 0.081\*P + 0.018\*G

Table 13: Model Parameters (GRMLFL CO2 (D))

|  |
| --- |
| **Parameter Estimates** |
| Parameter | B | Std. Error | Wald Chi–Square | df | sig | R–square |
| RPM | .001 | 1.3964E–5 | 11035.817 | 1 | .000 | 0.329 |
| V | .005 | .0004 | 178.741 | 1 | .000 |
| β | .000 | 4.7782E–5 | 15.251 | 1 | .000 |
| P | .081 | .0285 | 8.174 | 1 | .004 |
| G | .018 | .0015 | 137.350 | 1 | .000 |

# Tweedy Regression with Link Function of Log

Tweedy Regression with Link Function of Log model (TRMLFL) was used by linking the independent variables with the expected value of the dependent variables CO2 (D) through the log link function.

Table 14 provide the goodness of fit indicators, Table 15 present Omnibus test that used to find out whether the model was significant or not, the model was significant as the level of significance was less than 0.01

Table 14: Goodness of Fit indicators (TRMLFL CO2 (D))

|  |
| --- |
| **Goodness of Fita** |
|  | Value | df | Value/df |
| Deviance | 10105.084 | 19074 | .530 |
| Scaled Deviance | 21011.393 | 19074 |  |
| Pearson Chi–Square | 8885.452 | 19074 | .466 |
| Scaled Pearson Chi–Square | 18475.425 | 19074 |  |
| Log Likelihoodb | –27240.356 |  |  |
| Akaike's Information Criterion (AIC) | 54498.713 |  |  |
| Finite Sample Corrected AIC (AICC) | 54498.722 |  |  |
| Bayesian Information Criterion (BIC) | 54569.421 |  |  |
| Consistent AIC (CAIC) | 54578.421 |  |  |

Table 15: Omnibus Test (TRMLFL CO2 (D))

|  |
| --- |
| **Omnibus Testa** |
| Likelihood Ratio Chi–Square | df | Sig. |
| 34810.592 | 5 | .000 |

All the variables were significant, as the level of significance was less than 0.01. We also find that R–square value was 25.9%, which was the percentage of the effect of the independent variables on CO2 (D) emissions as given in Table 4–15, the model was as follow:

Log CO2 (D) = 0.001\* RPM+ 0.006\* V + 0.000\* β + 0.128\*P + 0.021\*G

Table 16: Model Parameters (TRMLFL CO2 (D))

|  |
| --- |
| **Parameter Estimates** |
| Parameter | B | Std. Error | Wald Chi–Square | df | sig | R–square |
| RPM | .001 | 1.1535E–5 | 12443.649 | 1 | .000 | 0.259 |
| V | .006 | .0003 | 336.957 | 1 | .000 |
| β | .000 | 4.5814E–5 | 37.799 | 1 | .000 |
| P | .128 | .0268 | 22.646 | 1 | .000 |
| G | .021 | .0015 | 191.885 | 1 | .000 |

# Summary of CO2 Emission for Diesel Vehicles

Analysis of statistics using the generalized regression model by different types of models show that Gamma and Tweedy Regression with Link Function of Log were not appropriated enough in analyzing CO2 emission for diesel vehicles while Linear regression model with Link Function of Identity (LRMLFI) and Linear Regression Model with Link Function of Log (LRMLFL) models provide a better results.

The results showed that Linear Regression Model with Link Function of Log (LRMLFL) was the best generalized regression model as it had account a goodness of fit with a highest percent of correlation R2 = 51.30%.

Log CO2 (D) = 0.001\*RPM + 0.007\*V – 0.004 \* T + 0.133 \* P + 0.022 \* G

# Results of Natural Gas Vehicle Emission Models

Four models of generalized linear regression models were used to investigate the relation between Natural Gas vehicles emission CO2 (g/s) and each of independent variables as shown in Table 17.

As we illustrate before for CO2 emission for diesel vehicles, the same procedure was conducted to test the relation between CO2 emission for Natural Gas vehicle and the independent variables, Analysis of statistics using the generalized regression models showed that all used generalized regression models had given acceptable account a goodness of fit with a high percent of correlation R2 value.

The results showed that Linear Regression Model with Link Function of Log (LRMLFL) was the best generalized regression model as it had account a goodness of fit with a highest percent of correlation R2 = 92.50%.

Log CO2 (N) = – 0.001\* V – 9.007E–5\* β – 0.035 \* P + 0.002 \* RH

# Results of Petrol Vehicle Emission Models

Table 17 provide the analysis of statistics using the four models of generalized linear regression models, all used generalized regression models had given acceptable account a goodness of fit with a high percent of correlation R2 value.

The results showed that Linear Regression Model with Link Function of Log (LRMLFL) was the best generalized regression model as it had account a goodness of fit with a highest percent of correlation R2 = 62.20%.

Log CO2 (P) = – 0.001\* V – 0.018\*T – 0.05\*P – 0.013\*RH + 0.018\*G

Table 17: Generalized linear models for CO2 emission for different vehicle categories.

|  |  |  |
| --- | --- | --- |
|  | **Dependent Variable** | **Generalized Linear Regression Models** |
| **Linear Regression with Link Function of Identity** | **Linear Regression with Link Function of Log** | **Gamma Regression with Link Function of Log** | **Tweedy Regression with Link Function of Log** |
| **Petrol Vehicles** | **CO2 Emission** | CO2 (P) = 0.002 \* RPM– 0.018 \* V – 0.001 \* β – 0.064 \* T – 0.052 \* RH + 0.012 \* GR2 = 0.600 | Log CO2 (P) = – 0.001 \* V – 0.018 \* T – 0.05 \* P – 0.013 \* RH + 0.018 \* GR2 = 0.622 | Log CO2 (P) = 0.001\* PM – 0.004 \* V – 0.024 \* T – 0.159 \* P – 0.021 \* RH + 0.006 \* GR2 = 0.579 | Log CO2 (P) = 0.001 \* RPM– 0.002 \* V – 0.029 \* T – 0.143 \* P – 0.018 \* RH + 0.009 \* GR2 = 0.599 |
| **Natural Gas Vehicles** | **CO2 Emission** | CO2 (N) = 0.004 \* RPM – 0.019 \* V – 0.001 \* β + 0.483 \* P + 0.013 \* RH R2 = 0.896 | Log CO2 (N) = – 0.001 \* V – 9.007E–5 \* β – 0.035 \* P + 0.002 \* RHR2 = 0.925 | Log CO2 (N) = 0.001 \* V – 0.006 \* T – 0.003 \* RH + 0.012 \* G R2 = 0.891 | Log CO2 (N) = 0.001 \* V – 0.009 \* T – 0.005 \* RH + 0.012 \* GR2 = 0.896 |
| **Diesel Vehicles** | **CO2 Emission**  | CO2 (D) = 0.003 \* RPM + 0.009 \* V + 0.001 \* β + 0.426 \* P + 0.043 \* G R2 = 0.501  | Log CO2 (D) = 0.001 \* RPM + 0.007 \* V –0.004 \* T + 0.133 \* P + 0.022 \* GR2 = 0.513 | Log CO2  (D) = 0.001 \* RPM + 0.005 \* V + 0.081 \* P + 0.018 \* GR2 = 0.329 | Log CO2  (D) = 0.001 \* RPM + 0.006 \* V + 0.128 \* P + 0.021 \* GR2 = 0.259 |

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# General Conclusion for CO2 Vehicle Emissions

* CO2 emission for Diesel vehicles showed a good relation with vehicle speed, horizontal alignment bearing angle, ambient temperature, ambient pressure, ambient relative humidity and numbers of rotation per minute for vehicle engine while a poor relation with profile road grade as the selected roads were almost flat grades.
* CO2 Emission for Natural Gas vehicles provided a good representative relation with ambient temperature, ambient pressure, ambient relative humidity and numbers of rotation per minute for vehicle engine while a poor relation with vehicle speed, horizontal alignment bearing angle and profile road grade.
* CO2 emission for Petrol vehicles showed a good representative relationship with numbers of rotation per minute for vehicle engine while a poor relation with vehicle speed, horizontal alignment bearing angle, ambient temperature, ambient pressure, ambient relative humidity and profile road grade.
* Linear regression model with link function of log (LRMLFL) was the highest generalized regression model to represent the correlation between CO2 emissions for Diesel vehicles.
* Natural Gas vehicles CO2 emission measurements were well presented with generalized regression model, where the best model was the Linear Regression Model with Link Function of Log (LRMLFL).
* Linear regression model with link function of log (LRMLFL) was the best generalized regression model to represent the correlation between Petrol vehicles CO2 emission with factors affecting it.

# Recommendations

* For further studies in the field of vehicle emissions rates it is recommended to apply the Linear regression model with link function of log (LRMLFL), as it proved to be the best generalized regression models technique for CO2 vehicle emission.
* CO2 emission showed different performance in relation to the studied vehicle according to fuel types of Diesel, Natural Gas and Petrol vehicles.
* CO2 emission showed different performance in relation to the studied vehicle types of private car, Microbus, Minibus and public Bus vehicles.
* Highway geometric design features/criteria that were not considered in this research, such as combinations of horizontal and vertical alignment, intersection, or interchange.
* The environmental impact of heavy-duty vehicles cannot be ignored in the modeling process. Heavy-duty gasoline and diesel engines should be modeled separately.
* Investigate the effect of traffic congestion on vehicle CO2 emission rates on other major roads in Egypt.
* Studies should be made to find out how to increase awareness among drivers in terms of vehicles emission causes and how to be always in focus to safe environment.

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