**Energy efficiency trade-offs in small to large electric vehicles**

Martin Weiss, Kira Christina Cloos, Eckard Helmers

**Additional file**

**Table S1** of the Supplementary Material is an Excel sheet containing the raw data of vehicle attributes.

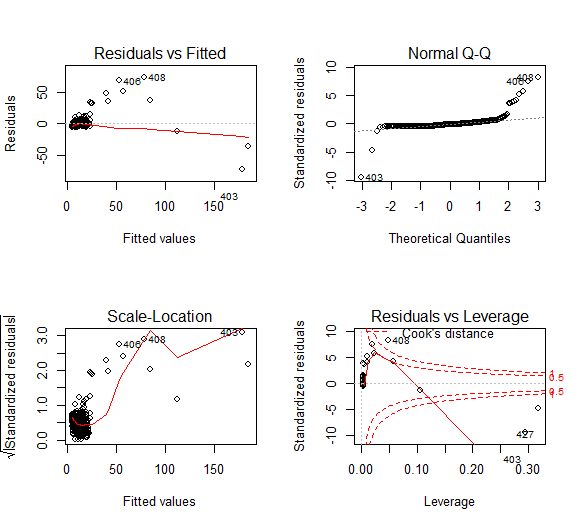


Figure S1: Diagnostic residuals plot - Model 1, certified energy consumption

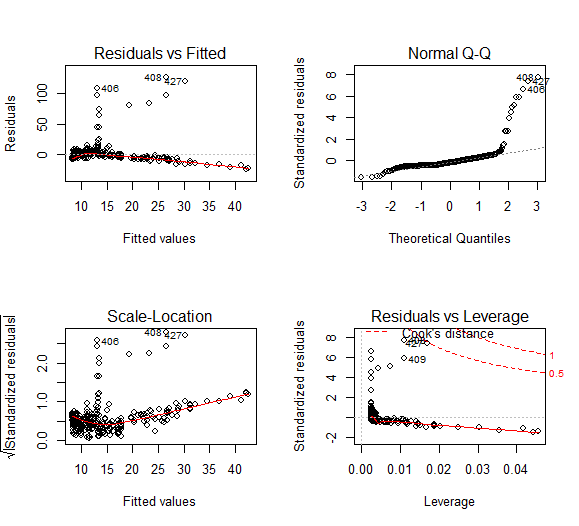


Figure S2: Diagnostic residuals plot - Model 2, certified energy consumption

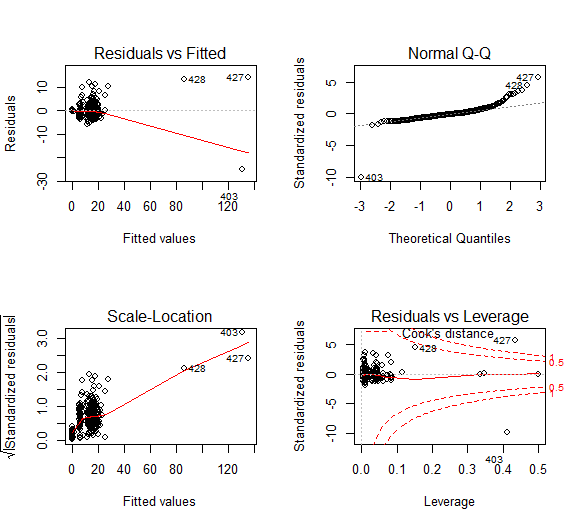


Figure S3: Diagnostic residuals plot - Model 3, certified energy consumption

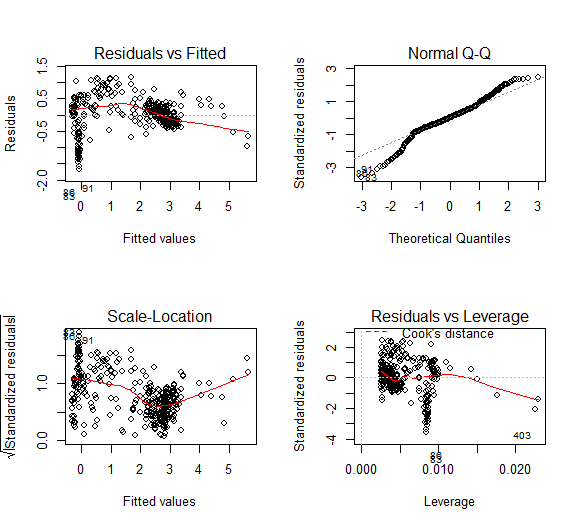


Figure S4: Diagnostic residuals plot - Model 4, certified energy consumption

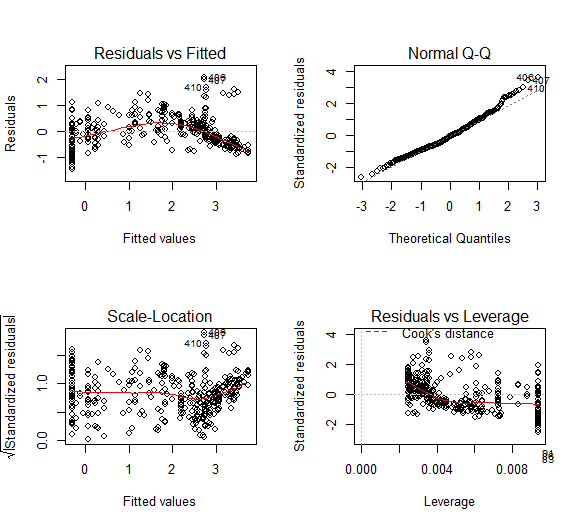


Figure S5: Diagnostic residuals plot - Model 5, certified energy consumption

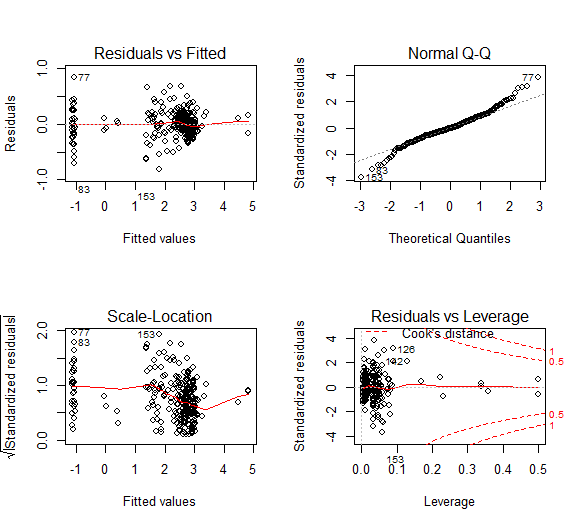


Figure S6: Diagnostic residuals plot - Model 6, certified energy consumption

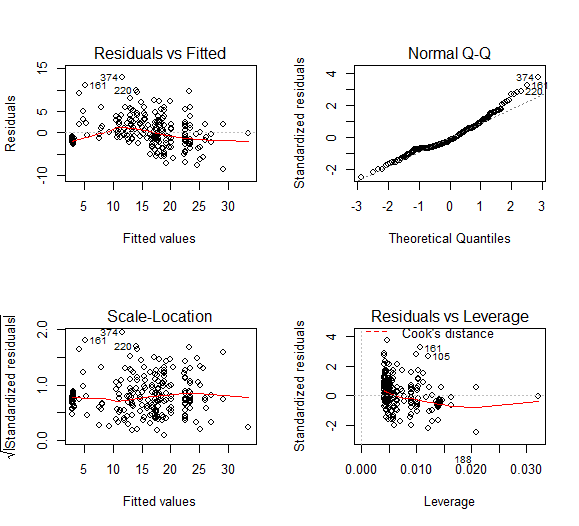


Figure S7: Diagnostic residuals plot - Model 1, real-word energy consumption

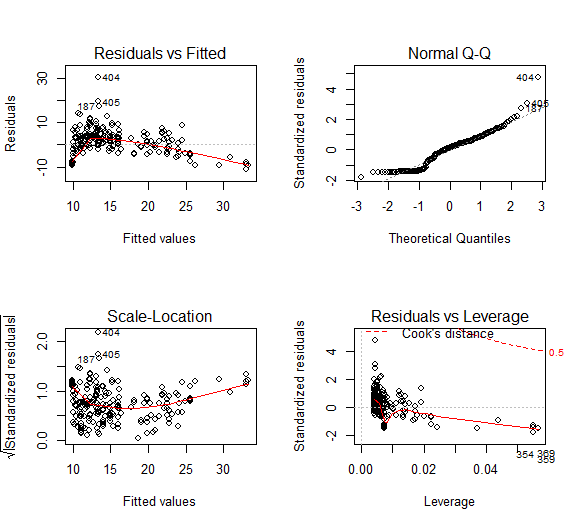


Figure S8: Diagnostic residuals plot - Model 2, real-world energy consumption

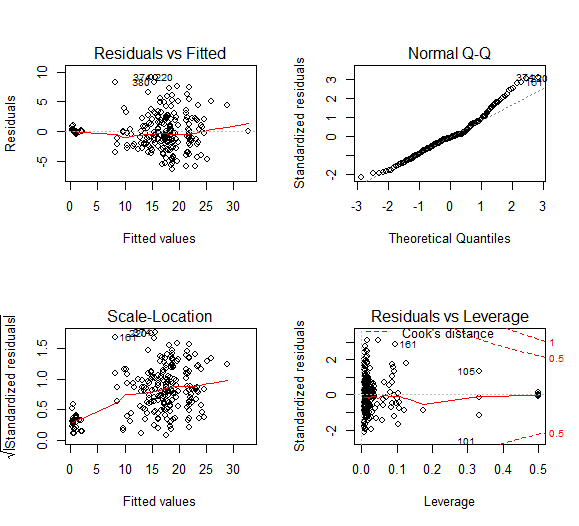


Figure S9: Diagnostic residuals plot - Model 3, real-world energy consumption

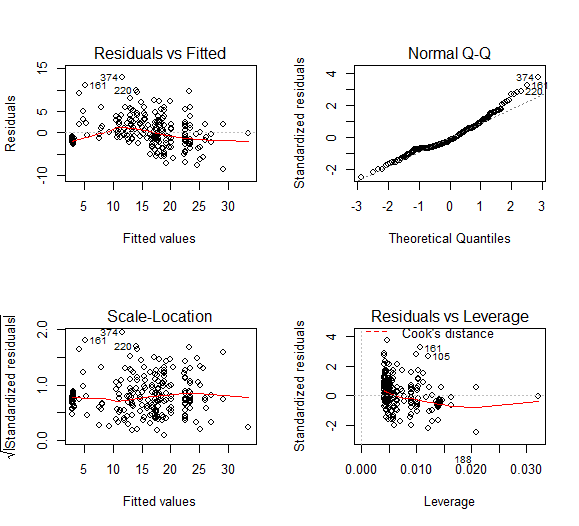


Figure S10: Diagnostic residuals plot - Model 4, real-world energy consumption

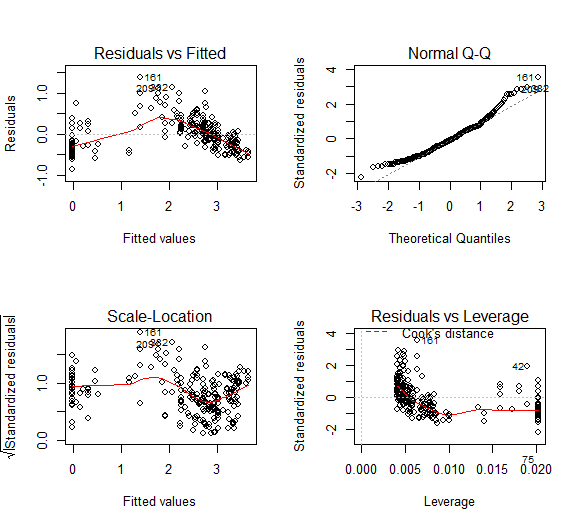


Figure S11: Diagnostic residuals plot - Model 5, real-world energy consumption

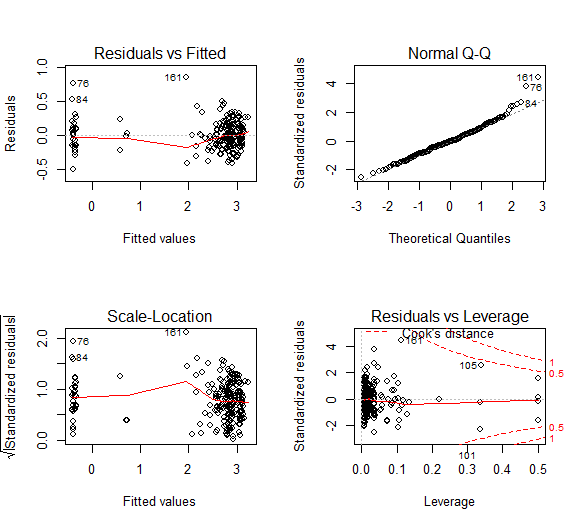


Figure S12: Diagnostic residuals plot - Model 6, real-world energy consumption

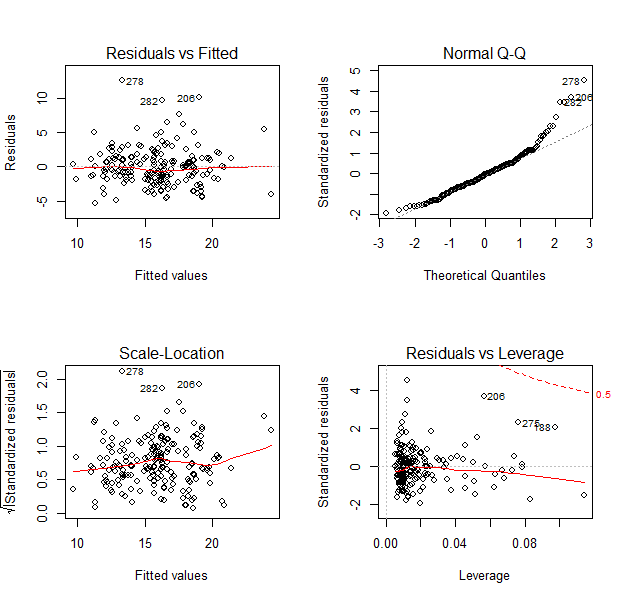


Figure S13: Diagnostic residuals plot - Model 3, certified energy consumption of passenger cars

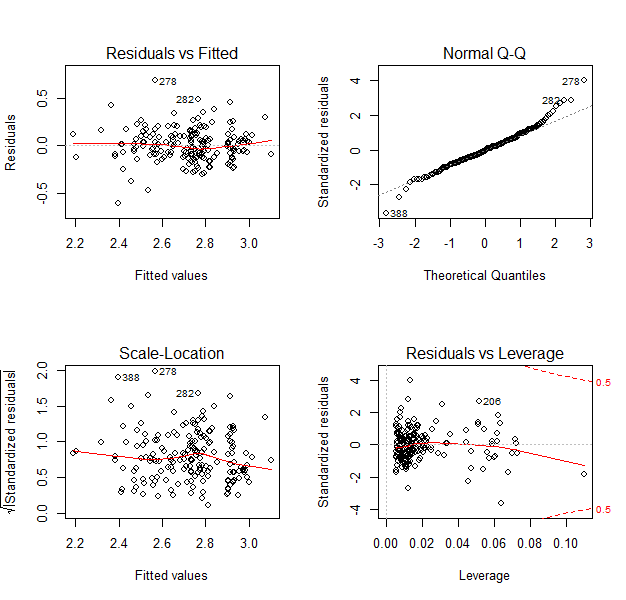


Figure S14: Diagnostic residuals plot - Model 6, certified energy consumption of passenger cars

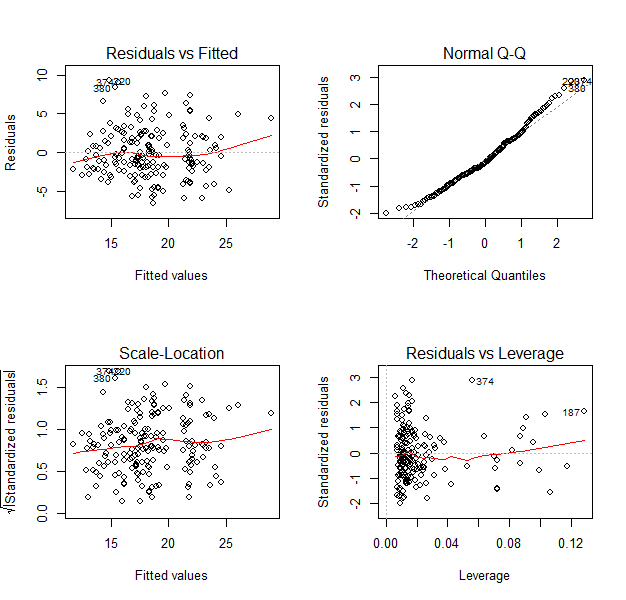


Figure S15: Diagnostic residuals plot - Model 3, real-world energy consumption of passenger cars

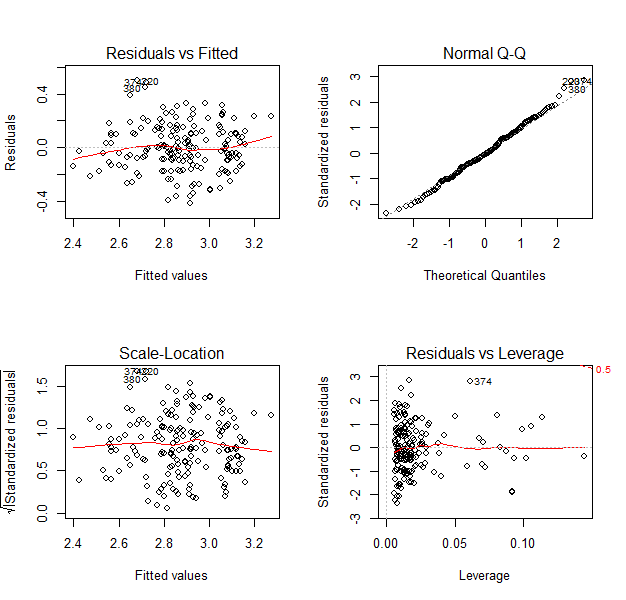


Figure S16: Diagnostic residuals plot - Model 6, real-world energy consumption of passenger cars

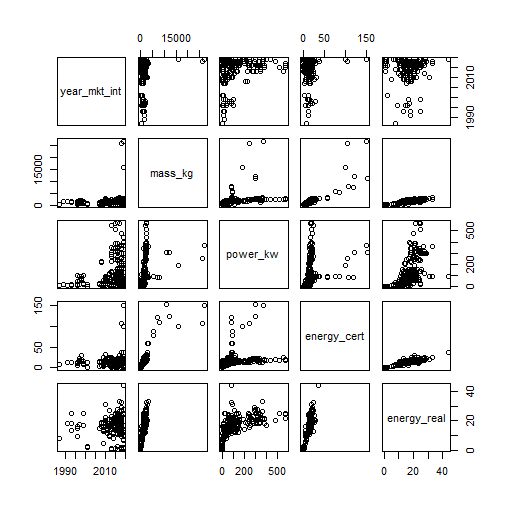


Figure S17: Pairplot - all electric vehicles captured in our analysis; year\_mkt\_int - year of market introduction, mass\_kg - vehicle mass [kg], power\_kw - rated motor power [kW], energy\_cert - certified energy consumption [kWh/100 km], energy\_real - real-world energy consumption [kWh/100 km]

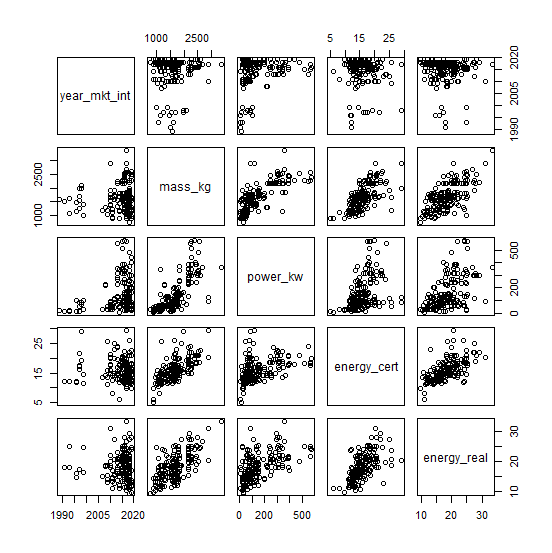


Figure S18: Pairplot - electric passenger cars; year\_mkt\_int - year of market introduction, mass\_kg - vehicle mass [kg], power\_kw - rated motor power [kW], energy\_cert - certified energy consumption [kWh/100 km], energy\_real - real-world energy consumption [kWh/100 km]

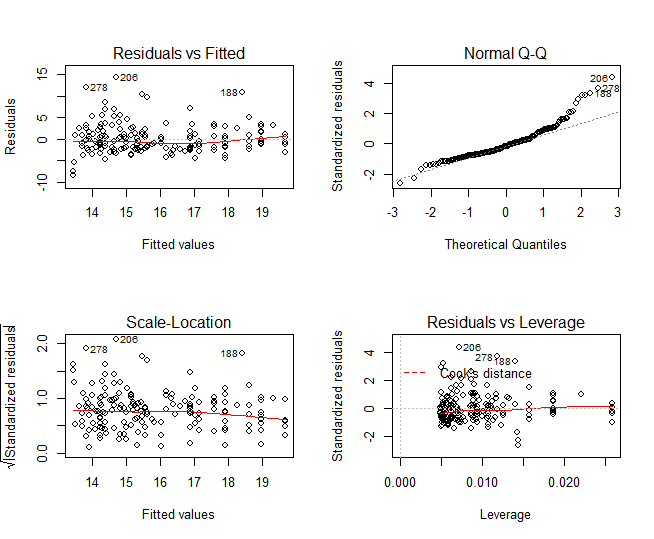


Figure S19: Diagnostic residuals plot - regression analysis of certified energy consumption of passenger cars as a function of battery capacity

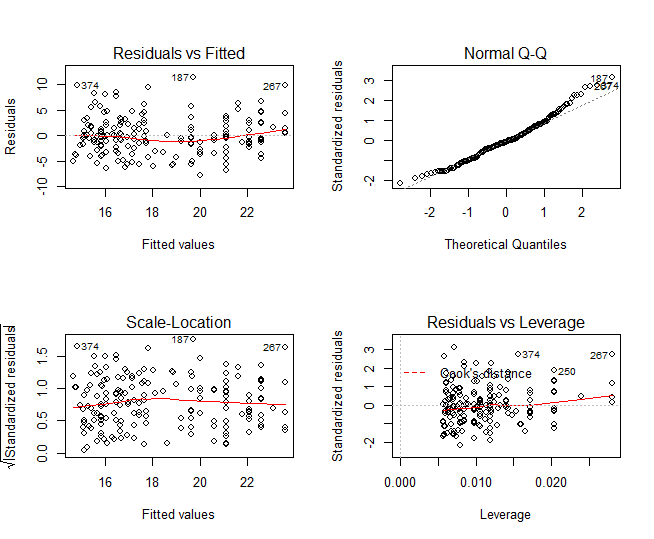


Figure S20: Diagnostic residuals plot - regression analysis of real-world energy consumption of passenger cars as a function of battery capacity

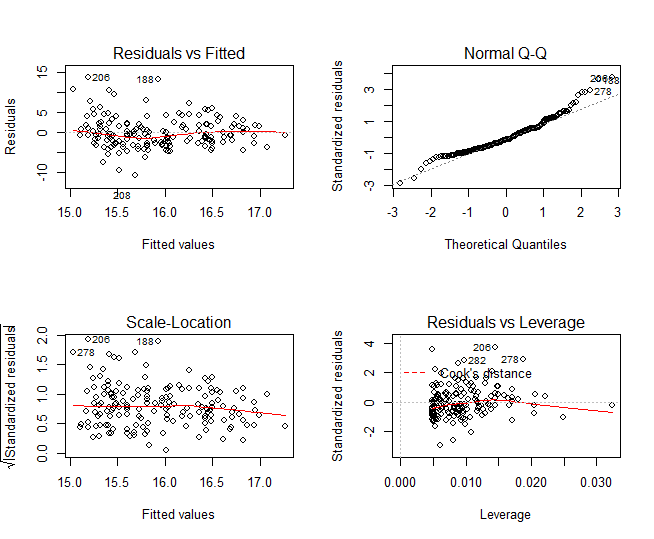


Figure S21: Diagnostic residuals plot - regression analysis of certified energy consumption of passenger cars as a function of (certified) drive range

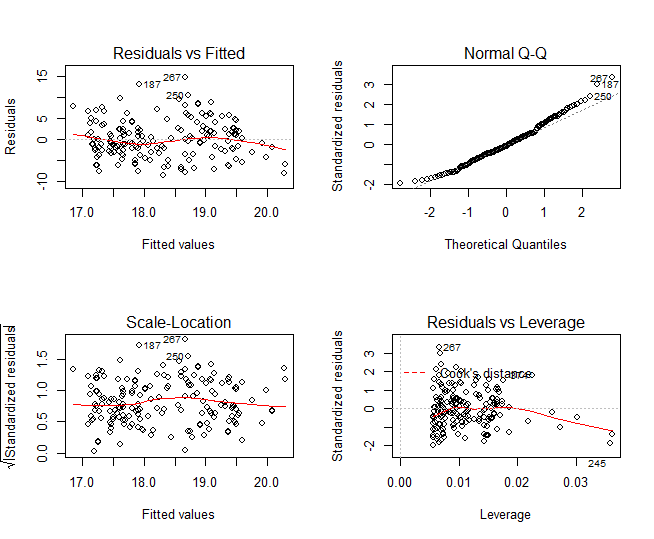


Figure S22: Diagnostic residuals plot - regression analysis of real-world energy consumption of passenger cars as a function of (real-world) drive range

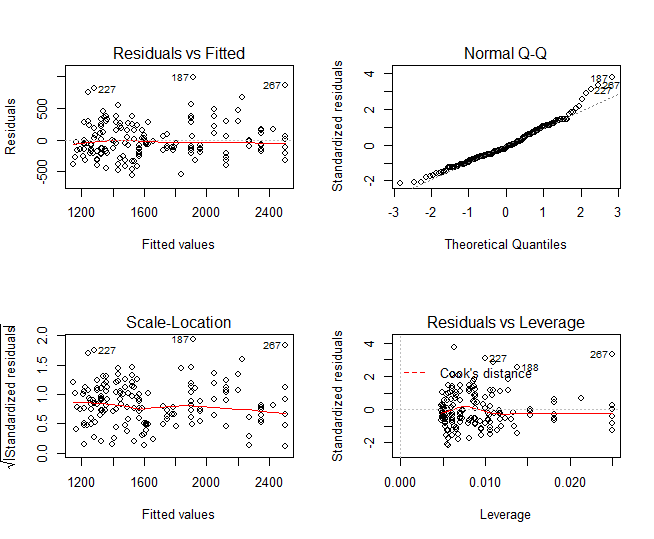


Figure S23: Diagnostic residuals plot - regression analysis of the mass of passenger cars as a function of battery capacity

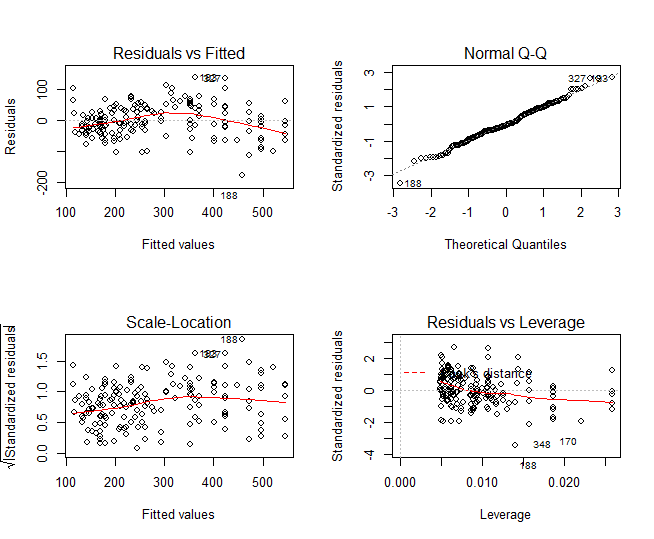


Figure S24: Diagnostic residuals plot - regression analysis of drive range of passenger cars (certified energy consumption) as a function of battery capacity

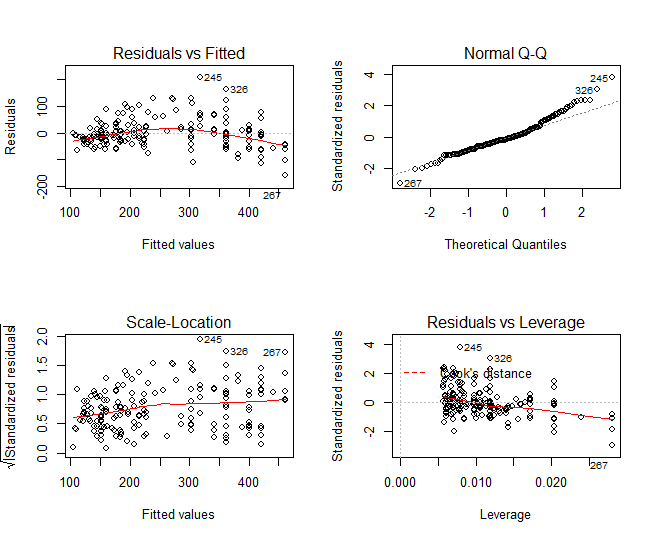


Figure S25: Diagnostic residuals plot - regression analysis of drive range of passenger cars (real-world energy consumption) as a function of battery capacity

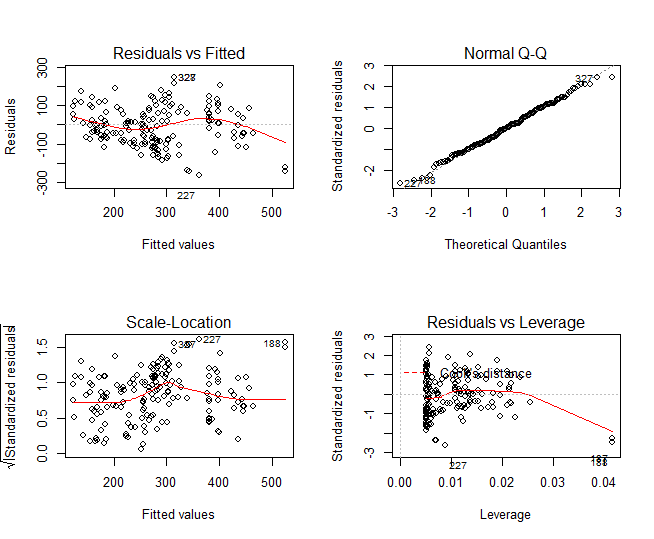


Figure S26: Diagnostic residuals plot - regression analysis of drive range (based on certified energy consumption) of passenger cars as a function of vehicle mass

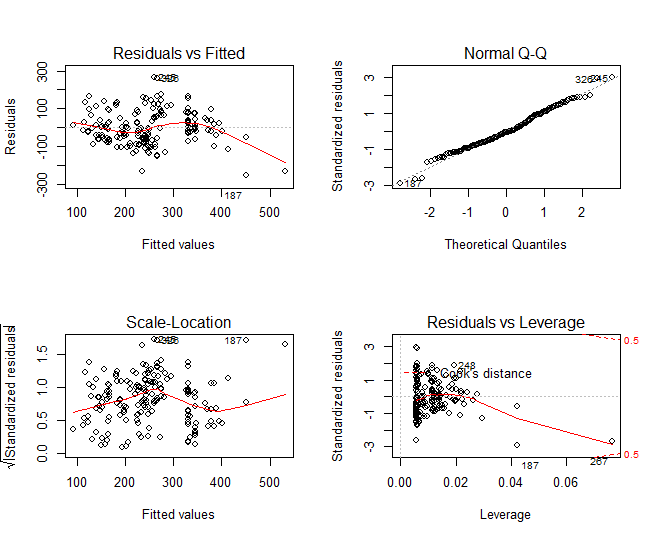


Figure S27: Diagnostic residuals plot - regression analysis of drive range (based on real-world energy consumption) of passenger cars as a function of vehicle mass

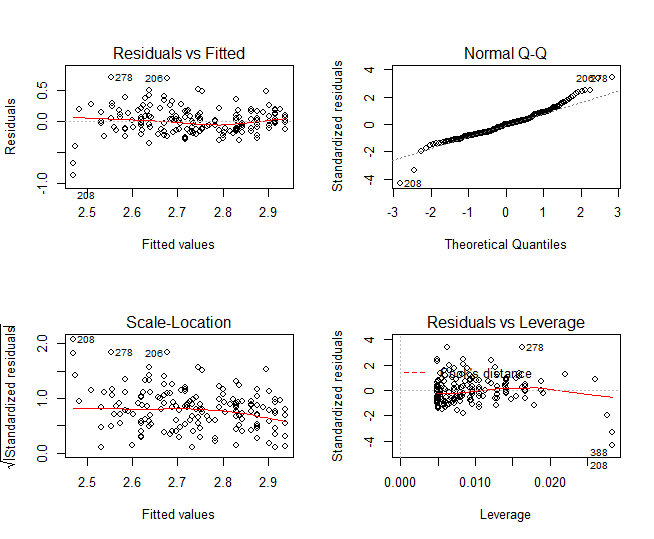


Figure S28: Diagnostic residuals plot - regression analysis of log(certified energy consumption) of passenger cars as a function of log(battery capacity)

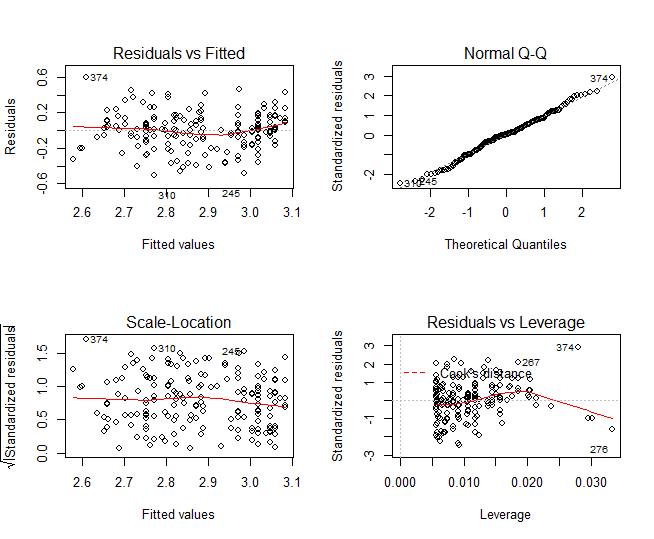


Figure S29: Diagnostic residuals plot - regression analysis of log(real-world energy consumption) of passenger cars as a function of log(battery capacity)

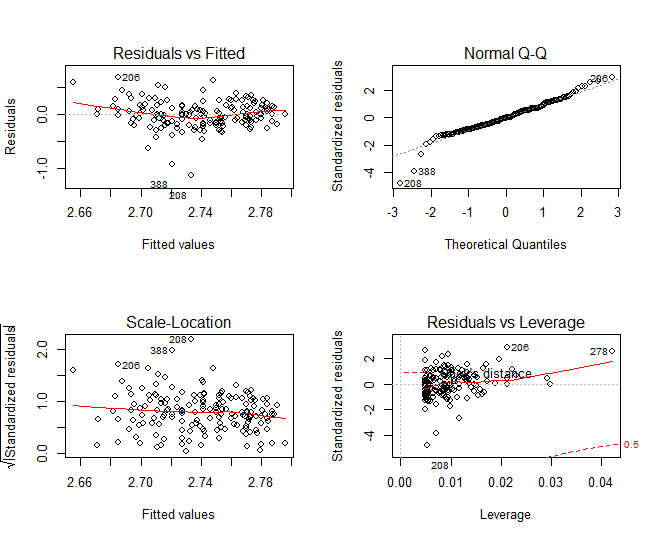


Figure S30: Diagnostic residuals plot - regression analysis of log(certified energy consumption) of passenger cars as a function of log(drive range, assuming certified energy consumption)

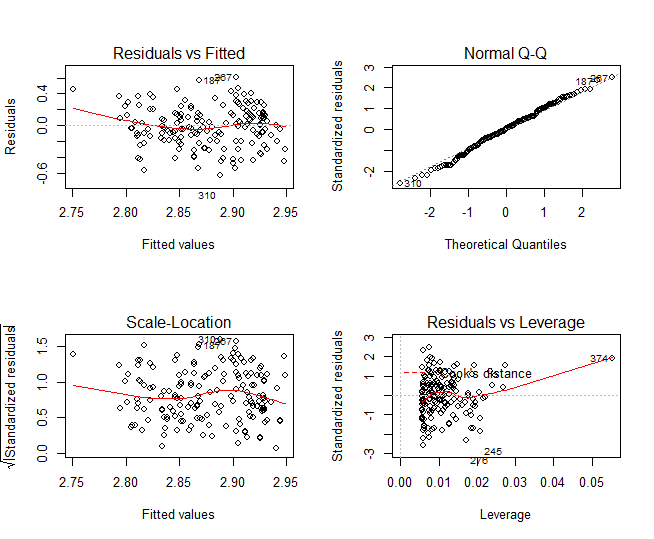


Figure S31: Diagnostic residuals plot - regression analysis of log(real-world energy consumption) of passenger cars as a function of log(drive range, assuming real-world energy consumption)

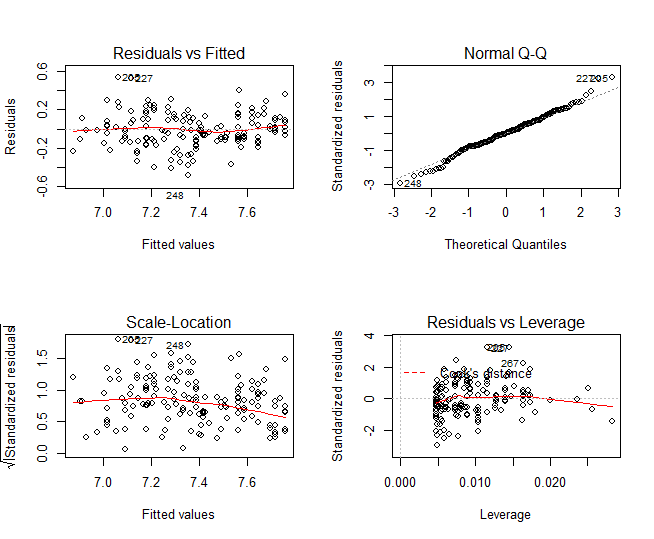


Figure S32: Diagnostic residuals plot - regression analysis of log(vehicle mass) of passenger cars as a function of log(battery capacity)

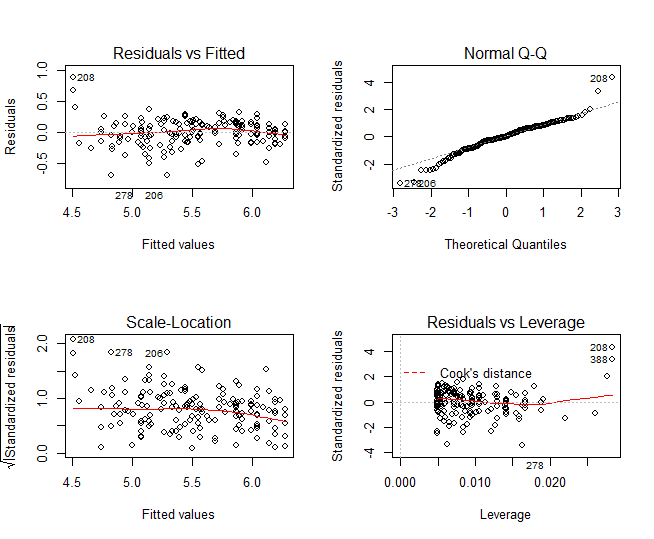


Figure S33: Diagnostic residuals plot - regression analysis of log(drive range, assuming certified energy consumption) of passenger cars as a function of log(battery capacity)

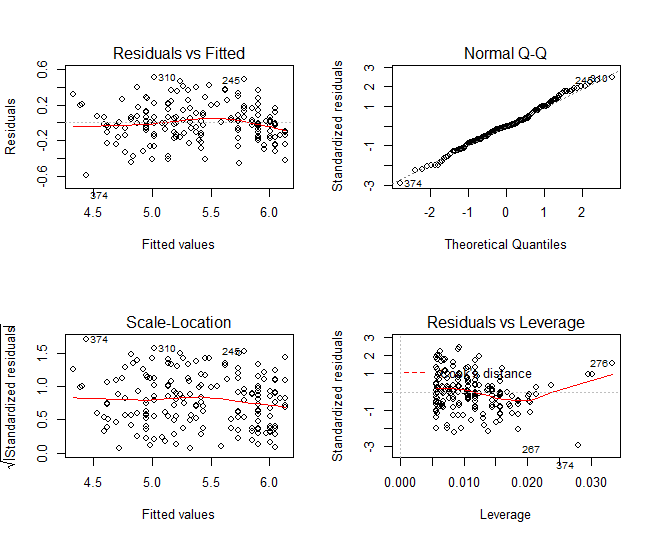


Figure S34: Diagnostic residuals plot - regression analysis of log(drive range, assuming real-world energy consumption) of passenger cars as a function of log(battery capacity)

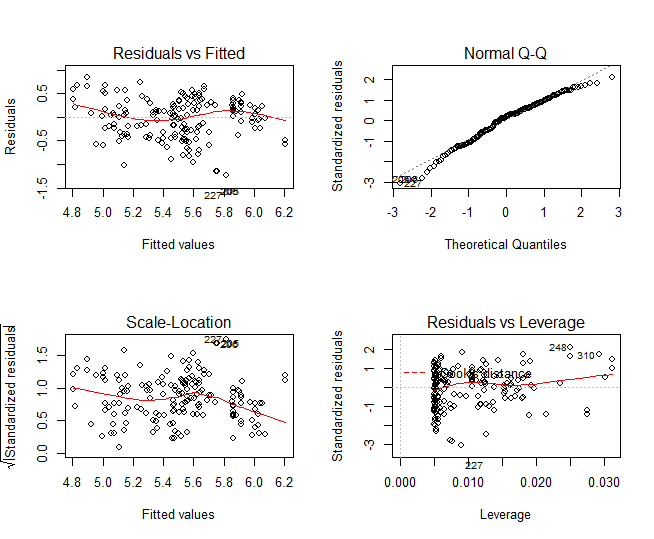


Figure S35: Diagnostic residuals plot - regression analysis of log(drive range, assuming certified energy consumption) of passenger cars as a function of log(vehicle mass)

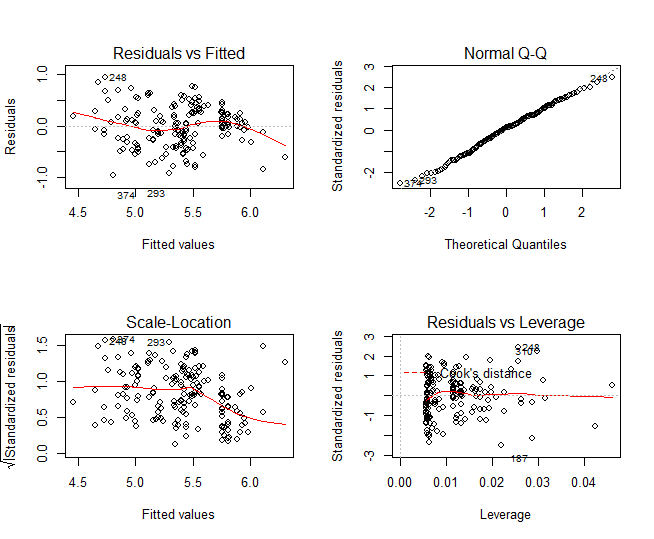


Figure S36: Diagnostic residuals plot - regression analysis of log(drive range, assuming real-world energy consumption) of passenger cars as a function of log(vehicle mass)

Table S2: Regression analysis - certified and real-world energy consumption, vehicle mass, battery capacity, and drive range of electric passenger cars; significance at 1% level (\*\*\*), 5% level (\*\*), and 10% level (\*)

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Energy consumption | Coefficient | Value | Standard error | *t* value | | Pr (>abs *t*) | *p* value | | Adjusted *R2* |
|  | *energy consumption = α7+β13battery capacity* | | | | | | | | |
| Certified | (Intercept)\*\*\* | 13 | 0.51 | 25 | | 6.10e-64 | <0.001 | | 0.22 |
| Battery capacity\*\*\* | 6.97e-02 | 8.42e-03 | 8.28 | | 1.64e-14 |
| Real-world | (Intercept)\*\*\* | 14 | 0.55 | 25 | | 3.66e-19 | <0.001 | | 0.34 |
| Battery capacity\*\*\* | 9.91e-02 | 1.02e-02 | 6.26 | | 1.52e-03 |
|  | *energy consumption = α7+β13drive range* | | | | | | | | |
| Certified | (Intercept)\*\*\* | 15 | 0.69 | 21 | | 3.40e-54 | 0.032 | | 0.02 |
| Drive range\*\* | 4.10e-03 | 1.90e-03 | 2.16 | | 3.24e-02 |
| Real-world | (Intercept)\*\*\* | 17 | 0.72 | 23 | | 3.99e-55 | 0.008 | | 0.03 |
| Drive range\*\*\* | 7.12e-03 | 2.64e-03 | 2.70 | | 7.68e-03 |
|  | *mass = α8+β14battery capacity* | | | | | | | | |
|  | (Intercept\*\*\* | 999 | 37 | 27 | 2.46e-70 | | <0.001 | 0.69 | |
| Battery capacity\*\*\* | 15.0 | 0.6 | 22 | 3.29e-55 | |
|  | *drive range = α8+β14battery capacity* | | | | | | | | |
| Certified | (Intercept)\*\*\* | 63 | 6 | 9 | 3.21e-19 | | <0.001 | 0.85 | |
| Battery capacity\*\*\* | 4.8 | 0.1 | 33 | 3.71e-83 | |
| Real-world | (Intercept)\*\*\* | 66 | 7 | 10 | 4.44e-18 | | <0.001 | 0.79 | |
| Battery capacity\*\*\* | 3.9 | 0.2 | 24 | 2.19e-58 | |
|  | *drive range = α9+β15mass* | | | | | | | | |
| Certified | (Intercept)\*\* | -54 | 27 | -2.00 | 4.72e-02 | | <0.001 | 0.44 | |
| Mass\*\*\* | 0.20 | 1.63e-2 | 12 | 6.57e-26 | |
| Real-world | (Intercept) | -33 | 27 | -1.21 | 0.23 | | <0.001 | 0.45 | |
| Mass\*\*\* | 0.17 | 1.65e-2 | 10 | 3.11e-19 | |
|  | *log(energy consumption) = α7+β13log(battery capacity)* | | | | | | | | |
| Certified | (Intercept)\*\*\* | 1.97 | 0.12 | 17 | | 6.57e-41 | <0.001 | | 0.26 |
| log(Battery capacity)\*\*\* | 0.21 | 2.96e-02 | 7 | | 2.15e-11 |
| Real-world | (Intercept)\*\*\* | 2.08 | 9.70e-02 | 21 | | 6.61e-51 | <0.001 | | 0.29 |
| log(Battery capacity)\*\*\* | 0.22 | 2.53e-03 | 9 | | 4.26e-15 |
|  | *log(energy consumption) = α7+β13log(rive range)* | | | | | | | | |
| Certified | (Intercept)\*\*\* | 2.40 | 0.19 | 12 | | 1.41e-26 | 0.070 | | 0.01 |
| log(Drive range)\* | 6.15e-02 | 3.38e-03 | 1.82 | | 7.01e-02 |
| Real-world | (Intercept)\*\*\* | 2.44 | 0.19 | 13 | | <2e-16 | 0.020 | | 0.02 |
| log(drive range)\*\* | 8.14e-02 | 3.48e-02 | 2.34 | | 2.04e-02 |
|  | *log(mass) = α8+β14log(battery capacity)* | | | | | | | | |
|  | (Intercept\*\*\* | 5.99 | 6.87e-02 | 87 | 4.01e-165 | | <0.001 | 0.67 | |
| Battery capacity\*\*\* | 0.38 | 1.75e-02 | 22 | 8.14e-56 | |
|  | *log(drive range) = α8+β14log(battery capacity)* | | | | | | | | |
| Certified | (Intercept)\*\*\* | 2.63 | 0.12 | 23 | 9.95e-58 | | <0.001 | 0.84 | |
| log(Battery capacity)\*\*\* | 0.79 | 2.96e-02 | 27 | 1.34e-68 | |
| Real-world | (Intercept)\*\*\* | 2.53 | 9.70e-02 | 26 | 2.67e-62 | | <0.001 | 0.84 | |
| log(Battery capacity)\*\*\* | 0.78 | 2.53e-2 | 31 | 6.444-73 | |
|  | *log(drive range) = α9+β15llog(mass)* | | | | | | | | |
| Certified | (Intercept)\*\*\* | -3.23 | 0.78 | -4.14 | 5.24e-05 | | <0.001 | 0.38 | |
| log(Mass)\*\*\* | 1.18 | 0.10 | 11.3 | 4.16e-23 | |
| Real-world | (Intercept)\*\*\* | -3.81 | 0.81 | -4.73 | 4.64e-06 | | <0.001 | 0.45 | |
| log(Mass)\*\*\* | 1.25 | 0.11 | 11.6 | 2.73e-23 | |

Table S3: Sensitivity analysis - regression analysis of medians per vehicle type; significance at 1% level (\*\*\*), 5% level (\*\*), and 10% level (\*); light-commercial and heavy-duty vehicles are excluded from the regression analysis of real-world fuel consumption in Model 6 as sample size is insufficient; Models 3 and 6 include vehicle type as categorical variable

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Energy consumption | Coefficient | | Value | | Standard error | | *t* value | | Pr (>abs *t*) | *p* value | | Adjusted *R2* |
|  | *Model 1: energy consumption = α1+β1mass* | | | | | | | | | | | |
| Certified | (Intercept) | 0.30 | | | | 0.59 | 0.50 | | 0.64 | <0.001 | | 0.97 |
| Mass\*\*\* | 1.04e-02 | | | | 1.07e-03 | 9.66 | | 2.02e-04 |
| Real-world | (Intercept) | 1.44 | | | | 1.41 | 1.02 | | 0.35 | 0.002 | | 0.91 |
| Mass\*\*\* | 1.27e-02 | | | | 2.02e-03 | 6.26 | | 1.52e-03 |
|  | *Model 2: energy consumption = α2+β2power* | | | | | | | | | | | |
| Certified | (Intercept | 1.56 | | | | 1.12 | 1.39 | 0.22 | | 0.06 | 0.71 | |
| Power\* | 0.18 | | | | 7.41e-02 | 2.41 | 6.08e-02 | |
| Real-world | (Intercept) | 3.02 | | | | 1.62 | 1.86 | 0.12 | | 0.10 | 0.65 | |
| Power\* | 0.22 | | | | 0.11 | 2.04 | 9.67e-02 | |
|  | *Model 3: energy consumption = α3+β3mass+ β4power + β5year + β6type* | | | | | | | | | | | |
| Certified | (Intercept) | | | 125 | | 199 | 0.63 | 0.59 | | 0.04 | 0.94 | |
| Mass | | | 1.10e-02 | | 3.85e-03 | 2.87 | 0.10 | |
| Power | | | -3.04e-02 | | -6.30e-02 | -0.48 | 0.68 | |
| Year | | | -6.24e-02 | | 9.91e-02 | -0.63 | 0.59 | |
| Type | | | 0.41 | | 0.91 | 0.45 | 0.69 | |
| Real-world | (Intercept) | | | 240 | | 429 | 0.56 | 0.63 | | 0.11 | 0.83 | |
| Mass | | | 1.23e-02 | | 8.22e-03 | 1.50 | 0.76 | |
| Power | | | -4.79e-02 | | 0.13 | -0.36 | 0.76 | |
| Year | | | -1.12 | | 0.21 | -0.56 | 0.63 | |
| Type | | | 1.33 | | 1.92 | 0.69 | 0.56 | |
|  | *Model 4: log(energy consumption) = α4+β7log(mass)* | | | | | | | | | | | |
| log(Certified) | (Intercept)\*\*\* | | | -5.09 | | 1.05 | -4.84 | 4.72e-03 | | <0.001 | 0.87 | |
| log(Mass)\*\*\* | | | 1.08 | | 0.15 | 7.22 | 7.96e-04 | |
| log(Real-world) | (Intercept)\*\*\* | | | -3.94 | | 0.94 | -4.19 | 8.61e-03 | | <0.001 | 0.85 | |
| log(Mass)\*\*\* | | | 0.96 | | 0.14 | 7.05 | 8.90e-04 | |
|  | *Model 5: log(energy consumption) = α5+β8log(power)* | | | | | | | | | | | |
| log(Certified) | (Intercept) | | | 3.48e-02 | | 0.24 | 0.15 | 0.89 | | <0.001 | 0.92 | |
| log(Power)\*\*\* | | | 0.61 | | 7.88e-02 | 7.68 | 5.96e-04 | |
| log(Real-world) | (Intercept)\* | | | 0.60 | | 0.24 | 2.47 | 5.67e-02 | | <0.001 | 0.90 | |
| log(Power)\*\*\* | | | 0.54 | | 7.58e-02 | 7.16 | 8.27e-04 | |
|  | *Model 6: log(energy consumption) = α6+β9log(mass)+ β10log(power)+ β11year +β12type* | | | | | | | | | | | |
| log(Certified) | (Intercept) | | | -51 | | 146 | -0.35 | 0.76 | | 0.06 | 0.90 | |
| log(Mass) | | | 0.83 | | 0.58 | 1.44 | 0.29 | |
| log(Power) | | | 0.37 | | 0.16 | 2.32 | 0.15 | |
| Year | | | 2.36e-02 | | 7.18e-02 | 0.33 | 0.77 | |
| Type | | | -0.26 | | 0.50 | -0.52 | 0.66 | |
| log(Real-world) | (Intercept) | | | -64 | | 152 | -0.42 | 0.71 | | 0.07 | 0.86 | |
| log(Mass) | | | 0.30 | | 0.63 | 0.47 | 0.68 | |
| log(Power) | | | 0.44 | | 0.17 | 2.56 | 0.13 | |
| Year | | | 3.17e-02 | | 7.47e-02 | 0.42 | 0.71 | |
| Type | | | -6.63e-02 | | 0.53 | -0.13 | 0.91 | |