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An approach towards comprehensive Life Cycle Assessment (LCA) for surface transport automotive fuels

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Abstract. Life Cycle Assessment (LCA) of fuel is commonly known as 'Well to Wheel' (WTW) analysis, which is divided into two stages, viz. the 'Well to Tank' (WTT) or fuel stage, and the 'Tank to Wheel' (TTW) or vehicle stage. In both these stages, the physico-chemical of the fuel as well as the technical attributes of the vehicle are taken into consideration to assess the environmental impacts of an automotive fuel. There are also several factors that are exclusive of the internal fuel characteristics and the vehicle propulsion system that influence the emissions. These factors can be either natural or environmental (e.g., local topography, wind parameters, average ambient temperature, etc.) or man-made (health of the road network, traffic density and traffic management system, customer attitude, etc.). These factors along with the vehicle design-based attributes impact the rolling resistance, the aerodynamic drag resistance, and the inertial resistance. The power supplied to the wheels needs to be manifested into the distance covered by a wheel depending upon these independent external factors. Therefore, the WTW approach has been extended to have the complete LCA of a fuel and this extension is named 'Wheel to Miles' (WHTM). In the TTW part, the quantity of the fuel consumed is assessed, whereas, in the WHTM part, the quality of the consumed fuel is analyzed in terms of the mileage realized. All three major resistances (rolling, air drag, and inertial) are impacted by natural, man-made, and vehicle design-based factors, and in turn, they impact the vehicle fuel economy. A change in rolling resistance has a high impact on the fuel economy among all the three resistances analyzed. The fuel economy of a freight vehicle is majorly impacted by a change in the coefficient of rolling resistance, while that of a passenger vehicle is more sensitive towards a change in the drag coefficient.

Keywords: Life-cycle assessment, Well to Wheel, Well to Miles, Wheel to Miles, Transport fuel

1. Introduction

Life-cycle Assessment (LCA) has emerged as a reliable analytical decision support tool to evaluate the environmental footprints of any commodity during its whole life cycle i.e., from cradle to grave [1]. LCA is defined by ISO 14040:2006 as "a technique for assessing the environmental aspects and potential impacts associated with a product, by compiling an inventory of relevant inputs and outputs of a product system, evaluating the potential environmental impacts, and interpreting the results of the inventory analysis and impact assessment phases" [2]. It is an assessment of all the processes involved in the entire life-cycle of a product, starting from the extraction of the raw materials to manufacturing, transportation, distribution, usage, maintenance, reprocessing, recycling, reuse and final disposal, if needed [3].

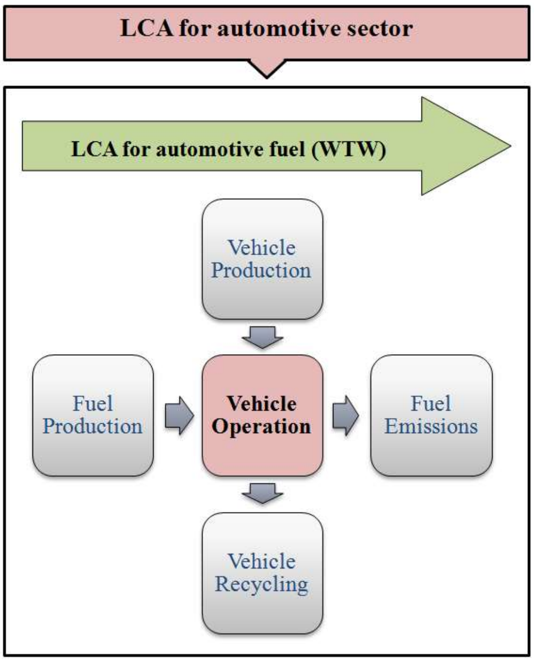

Figure 1: Life-cycle assessment framework of automotive sector and automotive fuel

Life-cycle Assessment (LCA) is one of the widely used methodologies to analyse the emissions emanating from a transport fuel starting from its extraction at the source to the final release from vehicular exhausts as tailpipe emissions. As the different fuels have different volumetric energy content values, it is prudent to quantify the emissions released per unit of energy manifested by the individual transport fuels [4]. The LCA of the automotive fuel is a sub-set of the LCA of the automotive sector as shown in **Figure 1** [2]. The life cycle of an automotive fuel is commonly referred to as the 'Well to Wheel' (WTW) in the reported literature, which deals with the emission analysis of automotive fuels.

For the convenience of analysis, the WTW analysis is divided into two parts, viz. 'Well to Tank' (WTT) and 'Tank to Wheel' (TTW). The 'Well to Tank' part is commonly referred to as the fuel production part (or fuel part) while the 'Tank to Wheel' part is called as fuel use part (or vehicle part) [5]. The WTT or fuel part is further divided into three sub-parts i.e., upstream, mid-stream and downstream as seen in **Figure 2**. In the upstream part, the emissions emanating from the exploration of the fuel source and the extraction of the raw form of the fuel from its natural reserves are considered. It also considers the emissions attributed to the transportation of the raw form to a place (such as a refinery) where it would undergo several stages of processing (or refinement) and get converted to a form that is ready for final consumption. Subsequently, in the mid-stream part, the emissions from the transportation of the refined fuel to the distribution channels via tankers or pipelines or any other means are accounted for. In the downstream part, the refined fuel is distributed through the retail outlets into a commercial freight or passenger vehicle tank and the associated emissions are considered.

Figure 2: Sub-parts of the Well to Tank (WTT) part

The TTW or the vehicle part is the stage at which the automotive fuel loaded in the vehicle tank is utilized by the vehicle drive-train to provide power to the wheels of the vehicle. In this part, the emissions associated with the vehicle-fuel combinations are considered where the energy-rich fuel goes through various stages of the drive-train and the electrical or chemical energy contained in the fuel (in the tank) gets converted into the mechanical energy of the wheels [6]. Different vehicles have different drive-train configurations and the paths of energy flow differ accordingly, leading to different energy efficiencies at the TTW stage.

1.1 A Re-look into the WTW approach

The two parts of the ‘Well to Wheel’ (WTW) approach, i.e. ‘Well to Tank’ (WTT) and ‘Tank to Wheel’ (TTW), consider the emissions emanating due to the internal properties and characteristics of the fuel and the vehicle respectively. They do not consider the impact of the attributes that are independent of the fuel and the vehicle drive-train characteristics. These factors include vehicle design parameters (e.g., kerb weight, rolling resistance, aerodynamic drag, inertial acceleration, and tank losses), natural as well as environmental parameters (e.g., wind force, temperature etc.), and various man-made factors (road quality, traffic, length of trip). It necessitates the extension of the WTW approach by the inclusion of a new ‘Wheel to Miles’ (WHTM) segment after the TTW part, thus making the complete approach a ‘Well to Miles’ (WTM) as can be seen in **Figure 3**.

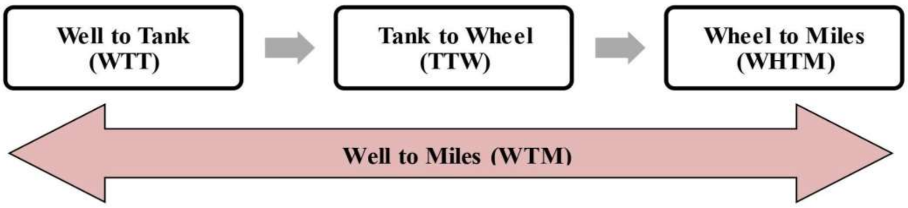

Figure 3: Well to Miles approach and its components

The WTM approach has been explored for the first time in a review article published in 2019 where the wheel power is considered to be dependent upon the vehicle-specific characteristics such as the rolling friction, the aerodynamic drag, and the vehicle mass [7]. The aerodynamic drag and the rolling friction are independent of the characteristics of the fuel and the vehicle propulsion system. Such independent parameters are evaluated in the ideal factory conditions based on the simulated impact data and other necessary technical information. In real-life conditions, there are some other factors as well that impact the power conversion by the wheels once the power is delivered to the wheels. The fuel life cycle methodology in the WTM can be expressed through the mathematical expression given in **Equation 1**. The expression shown in **Equation 1** is an improvement over the formula mentioned in *Ganguly et al.* [8] which considers the WTW life-cycle emission assessment of a fuel.

$$\frac{\begin{matrix}GHG\\ Pollution\\ (lbs\ CO_{2,eq})\end{matrix}}{\begin{matrix}Unit\ of\ fuel\\ (gallon\ or\ kg)\end{matrix}} * \frac{\begin{matrix}Unit\ of\ fuel\\ (gallon\ or\ kg)\end{matrix}}{\begin{matrix}Energy\ in\ fuel\\ (MU\ gge)\end{matrix}} * \frac{\begin{matrix}Energy\ in\ fuel\\ (MU\ gge)\end{matrix}}{\begin{matrix}Energy\ delivered\\ to\ wheels\\ (MU\ gge)\end{matrix}} * \frac{\begin{matrix}Energy\ delivered\\ to\ wheels\\ (MU\ gge)\end{matrix}}{\begin{matrix}Energy\ converted\\ by\ wheels\\ (MU\ gge)\end{matrix}} * \frac{\begin{matrix}Energy\ converted\\ by\ wheels\\ (MU\ gge)\end{matrix}}{\begin{matrix}vehicle\ distance\\ travelled\\ (miles)\end{matrix}} = \frac{lbs\ CO_{2,eq}}{miles} \quad \textbf{(1)}$$

The greenhouse gas (GHG) emission quantified as lbs $CO_{2,eq}$ considers the emissions emanating from fuel production and fuel use phase in the WTT and TTM segments, respectively. The volumetric energy content in the fuel depends upon the fuel quality while the delivery of energy to the wheels depends upon the vehicle drive-train and propulsion system. The energy delivered to the wheels gets converted into useful mechanical energy depending upon the vehicle characteristics i.e., aerodynamic drag, rolling friction and vehicle mass, etc. The energy converted by the vehicle wheels manifests itself in the distance travelled by the vehicle and it depends on the natural as well as the man-made environmental parameters as enumerated in **Table 1**.

Table 1: Factor influencing the fuel economy in the 'Well to Miles' (WTM) phase

Vehicle Design	Natural Environment	Man-made Environment
- Vehicle mass - Rolling resistance - Aerodynamic drag - Inertial acceleration - Tank losses	- Geographical terrain - Temperature - Wind action - Location of emission concentrate	- Road quality - Road traffic & Traffic Management System - Tank load - Vehicle Maintenance - Driving pattern and behaviour

The present analysis is limited to the quantification of the impact of the vehicle design parameters (that are independent of the vehicle propulsion system) and the natural environment-related parameters. Their influence on fuel consumption and fuel economy is assessed and quantified under different circumstances. The human factors that depend upon the behaviour of the driver to cause a change in the fuel economy of the vehicle and impact WHTM emissions are out of the scope of this study.

1.2 Vehicle design influencing factors

The propulsion system of the vehicle is responsible for impacting the fuel economy of a vehicle. However, there are a few design-based factors of a vehicle as well, that indirectly impact the fuel consumption of the vehicle, viz. the mass of the vehicle, the rolling resistance by the tyres, the aerodynamic drag by the vehicle body and the inertial acceleration. Other factors such as tank losses due to evaporation also play a role in the fuel loss and, thereby increasing the overall fuel consumption and impacting the TTM emissions. **Equation 2** represents the equation of motion based on the factors that are independent of the vehicle propulsion system [9].

$$m\frac{d}{dt}v(t) = F_t(t) - (F_r(t) + F_a(t) + F_i(t) + F_g(t)) \quad \textbf{(2)}$$

Where m is the vehicle kerb weight, v(t) is the vehicle velocity, F_t is the traction force generated by the propulsion system, F_r is the rolling friction force, F_a is the aerodynamic drag force, F_i is the force due to the inertia, and F_g is the force caused by gravity on the vehicle when it is driven on the roads with slopes.

Evidently, the energy consumption by a vehicle depends on rolling resistance, air resistance, inertial resistance, and gravity. The corresponding mathematical expression is depicted in **Equation 3**.

$$E_{vehicle} = \mu_r.m.g.v + \frac{1}{2}\rho.C_D.A.v^3 + m.v.a + m.g.\nabla z \quad \textbf{(3)}$$

The present study considers that there is no increase in the elevation, and therefore ∇z (altitude gained per unit time) is zero. The modified expression for energy consumption is given in **Equation 4**.

$$E_{vehicle} = \mu_r.m.g.v + \frac{1}{2}\rho.C_D.A.v^3 + m.v.a \quad \textbf{(4)}$$

Where, $E_{vehicle}$ is the mechanical energy consumed by a vehicle (at a particular instant) for overcoming the abovementioned resistances to move from its inertial position. μ_r is the coefficient of rolling resistance, m is the mass of the vehicle (with/without load), g is the acceleration due to gravity, v is the instantaneous velocity of the vehicle, ρ is the air density (at the given temperature), C_D is vehicle shape-dependent drag coefficient, A is the frontal cross-sectional area, and a is the instantaneous acceleration of the vehicle.

1.2.1 Vehicle mass

The fuel consumption of a vehicle increases with an increase in the mass of the vehicle. It is also important to increase the vehicle mass to an optimum level as an increased vehicle mass generally results in increased safety of the vehicle in the event of a vehicle crash. This results in a trade-off between these dual requirements of the fuel economy as well as the safety requirements [10]. *Tolouei et al.* (2009) have found that vehicle mass impacts diesel cars more than petrol cars and it also impacts automatic cars more as compared to manual cars [10]. The load volume on the vehicle adds to the weight of the vehicle. This factor along with the load distribution in the vehicle is responsible for the optimum fuel economy of the vehicle.

1.2.2 Rolling resistance

About 33% of the fuel consumed by a passenger car is utilized towards overcoming friction generated in the engine, by the braking system, by the transmission system, or by tyres [11]. The friction generated by tyres is known as rolling friction and about 11% of the total fuel consumed by a passenger car goes towards overcoming the driving resistance generated from the tyre-road contact [11]. The rolling friction in the tyre-road contact is impacted by multiple factors such as tyre design (bias-ply v/s radial-ply) and micro-topographical changes. The radial-ply tyres offer about 17% lower mean rolling friction as compared to that in the 18-inch bias-ply tyres. The undulations on the road surface (viz. bumps and potholes) result in enhanced fuel consumption due to the heating up of the tyres from increased hysteresis. The hysteresis loss is impacted by various factors viz., vehicle load, wheel alignment, ambient temperature and several tyre-related attributes viz. rotational speed, constituent materials, geometry, tread depth (tyre wear), and inflation pressure. For example, the sifter wheels generate low hysteresis energy loss while the stiffer wheels generate higher hysteresis loss.

The rubber from which a tyre is made contains numerous additives which have different purposes. Collectively, all these additives influence the rolling resistance induced by a tyre. Apart from the chemical composition, the shape, size and overall geometry (viz., outer diameter, rim diameter, and tyre width) affect the rolling resistance. More than 50% of the rolling resistance in a tyre originates from the deformation in the tread; hence, the rubber used in the tread is particularly important. Therefore, the wear and tear of the tyre reduces the rolling resistance leading to safety concerns. The rolling resistance of a tyre is related to the air pressure inside it. Nearly 25% of all vehicles drive with pressure 25% below the pressure recommended by the manufacturer in at least one tyre, due to infrequent tyre pressure checks in the vehicles. On average, 1 psi of air pressure is lost per month and this loss increases sharply with the change in ambient temperature (1.7 psi for a 10°C drop) [12]. With the constant checking of the tyre's air pressure, significant savings on money and fuel can be achieved by the end-users. In contrast, an increase in tyre pressure also reduces the rolling resistance. A change in the tyre pressure from 24 psi to 29 psi reduces rolling resistance by 10%. Therefore, for tyres inflated to pressures 36 psi, a 1.4% increase in the rolling resistance is achieved by each unit drop of pressure (in psi) [13].

1.2.3 Aerodynamic drag

A vehicle experiences the air drag from both internal and external fronts. The internal air drag has a minor share (20%) in the total aerodynamic drag experienced by a vehicle. The internal air drag is produced as a resistance to the air circulation inside the vehicle for purposes such as heating, cooling, and ventilation. The air circulation inside the engine compartment is also considered a part of the internal air drag. Therefore, it is observed that a vehicle with its windows open produces higher drag than the one with all windows closed due to the increased flow of air inside the vehicle compartment [14]. A vehicle in motion experiences external air drag due to the air resistance provided by its body. The external air drag is proportional to the square of the driving speed and area of the vehicle. The effective area of the vehicle is calculated by multiplying the drag coefficient (C_D) and the projected frontal cross-sectional area (A) which depends on the shape and size of the vehicle [15]. In addition, the local head and tail winds also influence the external aerodynamic drag and, therefore the energy consumption. However, the impact of the local head and tail winds is assumed to be negligible for carrying out the air drag studies.

As per a study, close following-in between the two vehicles results in drag saving, leading to reduced fuel consumption for the trailing vehicle as the trailing vehicle experiences a diminished dynamic pressure. Therefore, two vehicles collectively have less drag than each one being driven in isolation. This is regarded as a decrease in drag coefficient [16]. Skin friction by the vehicle body also has a minor role in impacting the aerodynamic drag, but most (more than 90%) of the external drag is generated by the pressure differences. Therefore, a number of vehicle design changes viz, built-in aero shield, reduction in the radiator size, more rounded corners, recessed lamps and tanks, and base flaps etc. are incorporated to reduce the drag coefficient and the frontal cross-sectional area of the vehicle.

1.2.4 Inertial acceleration

Inertia is induced in a vehicle due to its own mass as well as by rotating parts (cause fictitious d'Alembert forces) present inside the vehicle. A vehicle that is not in motion experiences the force emanating out of inertia and an extra needs to be provided to overcome it. For calculation and simulation purposes, it is convenient for the researchers to add the inertia of the rotating masses to the vehicle mass [9]. The energy required to overcome the inertial acceleration is equal to the energy used for braking purposes which is nearly 5% of the fuel energy consumed by a passenger car.

1.2.5 Tank losses

Oil and gasoline evaporate over a period from the tanks and other containers in which they are stored. This leads to the physical loss of fuel as well as qualitative deterioration (e.g., physicochemical characteristics), of the fuel. This results in an increase in the specific fuel consumption of a vehicle over a period of time [17]. These evaporation losses can be caused by multiple factors viz., daily fluctuations in the ambient temperature, atmospheric pressure, and the partial pressure of fuel vapour in the tank. These evaporation losses are minimised by different ways viz., specially designed complex tanks and systems to capture light hydrocarbons and low-cost additives in the fuel which modify the chemical characteristics of the fuel.

2. Methodology:

In this study, the impact of the various factors is assessed by calculating the change in the fuel requirement for different combinations of the parametric values. **Equation 4** is used to calculate the energy consumed by the vehicle while overcoming the three main resistance contributors viz. rolling resistance, drag resistance and inertial resistance. As per *Holmberg et al. (2012) [11]*, the energy required for overcoming these resistances is necessary to move a vehicle and result in distance covered i.e. miles. The energy required for overcoming the major resistances amounts to about 21.5% of the total energy in the fuel that goes into the vehicle tank. The effect of change in vehicle mass on fuel economy is assessed by changing the value of 'm' in **Equation 4**. Similarly, the change in the consumption of the energy due to changing values of rolling resistance, air drag resistance and inertial resistance is evaluated by changing 'μ_r', 'C_D' and 'a', respectively in the same equation. The study has been carried out for two chosen vehicle models, one each from the passenger and the freight segment. The relevant vehicle attributes and parameters are presented in **Table 2**.

Table 2: Vehicle details and the standard conditions

Model No.	**Toyota Corolla LE 2020**	**Tata 1012 LPT**
Class	Passenger	Freight
Vehicle Mass (m) (kg)	1340	3250
Frontal area (A_f) (m^2)	2.172	3.302
Air density at 10°C (ρ_{air}) (kg/m^3)	1.246	1.246
Acceleration due to gravity (g) (m/s^2)	9.81	9.81
Rolling resistance coefficient (μ_r)	0.01	0.01
Aerodynamic drag coefficient (C_D)	0.29	0.608
Acceleration (a) (m/s^2)	0.5 for the first 30 seconds 0 for the next 30 seconds -0.5 for the last 30 seconds	0.25 for the first 30 seconds 0 for the next 30 seconds -0.25 for the last 30 seconds
Initial speed (u) (m/s)	0	0
Maximum Vehicle speed (v_{max}) (m/s)	15	7.5

Toyota Corolla LE 2020 is chosen as the reference variant in the passenger segment and the vehicle mass in the simulations is changed based on the other variants of the same model. This change in variants is also responsible for a slight change in the frontal area and the aerodynamic drag coefficient. The frontal area is calculated by multiplying the width and height of the car with a factor of 0.85 as suggested in reported literature [18]. The aerodynamic drag coefficient value is obtained from the manufacturer's datasheet [19]. The rolling resistance coefficient is 0.01 for new asphalt roads and it keeps on increasing with reducing road quality. The illustrative acceleration profile (see **Table 2**) for the passenger vehicle is chosen such that the average performance of the vehicle is reflected over long-term use. In the freight segment, Tata Motors 1012 LPT (Long Platform Truck) has been chosen as the base variant. This variant was considered without the trailer attached and without any load. The standard aerodynamic drag coefficient value of 0.608 is taken from *Bayındırlı et al. (2016)* [20] and it increases by 15.8% when a trailer is attached to the vehicle. The illustrative acceleration profile (see **Table 2**) emulates the average performance expected from a commercial vehicle.

3. Result and Discussion

As mentioned in Section 2, the total energy required to overcome the three resistances is calculated using **Equation 4**. This energy amounts to 21.5% of the total energy going into the vehicle tank as fuel. Subsequently, using the calorific value of the fuel, the required fuel mass is estimated (over a distance based on the respective acceleration profile mentioned in **Table 2)**. The calculations were performed considering standard conditions, and the salient values are summarized in **Table 3**.

Table 3: Calculations based on the vehicle under standard conditions

	Toyota Corolla LE 2020	**Tata 1012 LPT**
Distance covered (based on acceleration profile)	900 meters	450 meters
Maximum velocity attained	15 m/s	7.5 m/s
The total energy required to overcome resistance (E)	479406 J	350028 J
Total energy in the fuel (TE=E/0.215)	2229794 J	1628039 J
Fuel Calorific Value (FCV)	Petrol (34.2 MJ/litre)	Diesel (38.6 MJ/litre)
Fuel required to overcome resistances (F=TE/FCV) [base case value]	0.0652 litres	0.0422 litres
Normalized fuel (N_f) = Fuel required/base case value	1	1

The normalized fuel amount (N_f) is calculated by dividing the total fuel required (F) by 0.0652 litres for Toyota Corolla LE 2020 and by 0.0422 litres for Tata 1012 LPT. Therefore, the normalized fuel amount (N_f) assumes a base case value equal to 1 for both the segments, passenger as well as freight. This parameter helps in visualizing the change in the fuel required with changing conditions with respect to the base case.

A higher amount of normalized fuel consumption (more than 1) denotes degradation in vehicle performance, whereas fuel consumption values less than 1 indicate superior vehicle performance. The various simulation scenarios are created by changing the indicators of the various resistances mentioned in **Section 2**. The rolling resistance coefficient (μ_r) and the acceleration (a) are considered the indicators for rolling resistance and inertial resistance, respectively. The air drag resistance (C_D) is considered as the indicator for the drag resistance while the atmospheric density (ρ_{air}) is indicative of the impact of the natural environment on the fuel economy. The density of air depends upon the ambient temperature, and it varies between 1.246 kg /m^3 (at 10°C) and 1.127 (at 40°C) kg/m^3 to study the impact of change in temperature on fuel consumption. As per the US Environmental Protection Agency, the fuel mileage drops with a drop in the air temperature [21]. The impact on fuel consumption is also evaluated by varying the acceleration within the average limits for the chosen representative passenger (from 0.1 m/s^2 to 0.6 m/s^2) and the freight (from 0.05 m/s^2 to 0.3 m/s^2) vehicles.

Figures 4 and **5** depict the change in the overall fuel consumption for changing values of the aforesaid resistance indicators for Toyota Corolla LE 2020 (passenger vehicle) and Tata LPT 1012 (freight vehicle), respectively. From Figures 4(a, b, d) and 5(a, b, d), it is evident that the required amount of fuel varies linearly with the coefficient of rolling resistance, the air-drag coefficient and the atmospheric density. However, the fuel consumption is found to be a quadratic function of the vehicle acceleration.

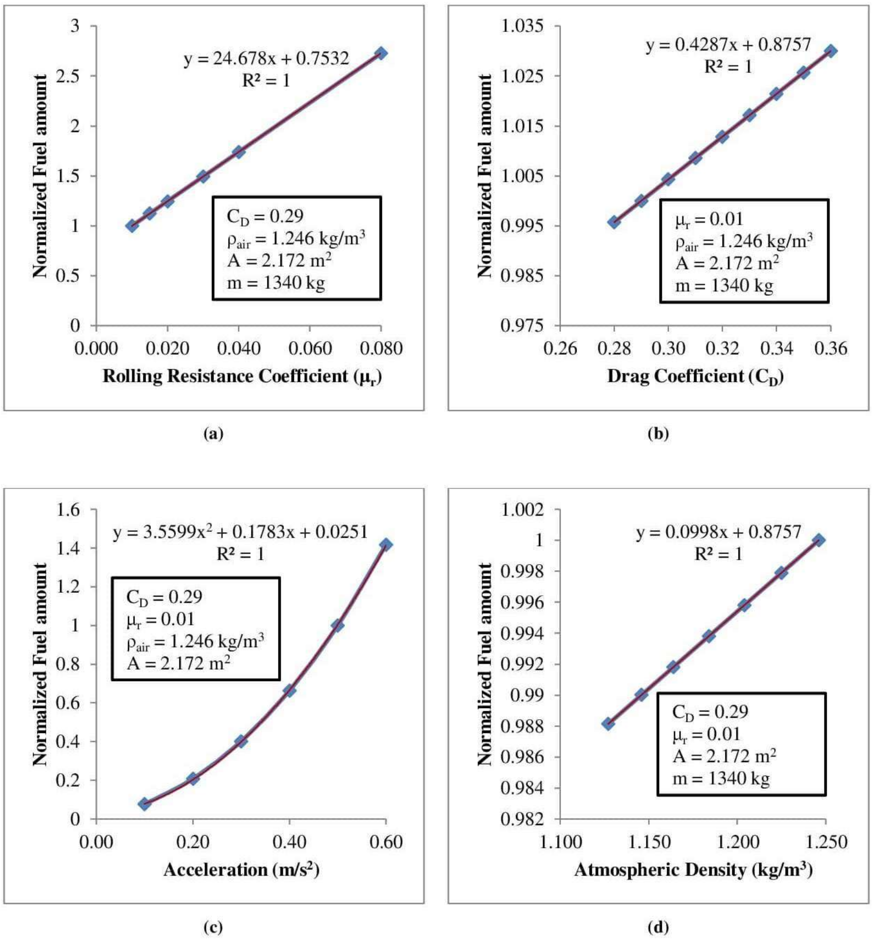

Figure 4: Fuel required by Toyota Corolla LE 2020 (standard) with changing (a) rolling resistance, (b) drag coefficient, (c) acceleration, and (d) atmospheric density

The rate of change of fuel consumption is found to be the highest with changing rolling resistance, and it is found to be impacted minimally by the variations in the density of air. Comparing figures 4(a) and 5(a), it is also observed that the coefficient of rolling resistance has a bigger impact on the fuel consumption of a freight vehicle as compared to the passenger vehicle. Over the terminal limits of μ_r, the required fuel amount changes by about 4 times for the Tata 1012 LPT (freight variant) as compared to 2.7 times observed in the case of the Toyota Corolla LE 2020 (passenger variant). The coefficient of rolling resistance changes with the many factors and one of the foremost among them is the road quality. Its value varies from 0.01 (smooth metalled asphalt conditions) to 0.08 (rough road conditions). The fuel requirement nearly doubles when the road becomes loose as against the new asphaltic surface. The condition of the tyre also impacts the coefficient of rolling resistance in a major way. It also depends upon the traffic conditions as heavy traffic results in multiple starts and stops (resulting in varying velocity profiles). This condition also results in high fuel consumption towards overcoming the inertial resistance. The driving pattern is also important in determining the fuel requirement towards inertial resistance. A change in the acceleration impacts the changes in the fuel requirement in a non-linear (quadratic) fashion for both passenger and freight variants (figures 4(c) and 5(c)).

In contrast, from figures 4(b) and 5(b) the rate of change in the fuel consumption in Toyota Corolla LE 2020 is found to be impacted more by the aerodynamic drag resistance as compared to that in Tata 1012 LPT. As the drag resistance depends upon multiple factors viz. air drag coefficient, air density, frontal area, and vehicle velocity profile (as seen in **Equation 4**), it gets highly influenced by multiple natural and man-made factors. Especially, the frontal design and the frontal area play a major role in reducing the air drag through the reduction in the effective area (C_D.A).

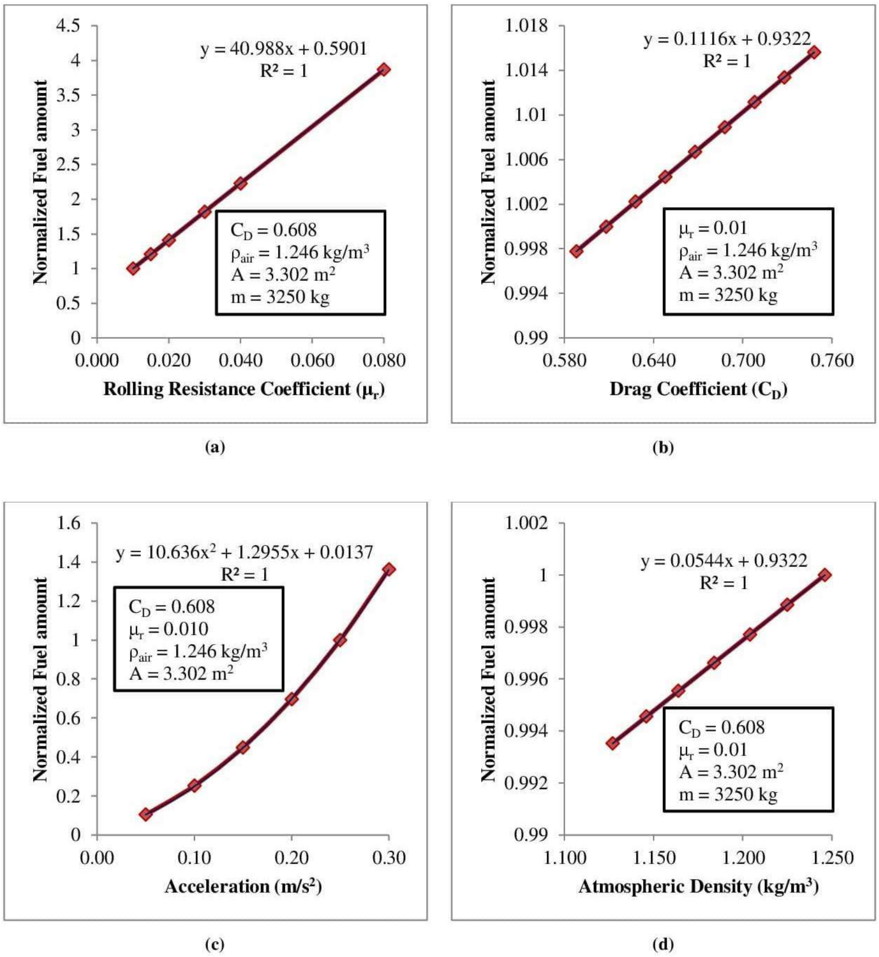

Figure 5: Fuel required by Tata 1012 LPT (standard) with changing (a) rolling resistance, (b) drag coefficient, (c) acceleration, and (d) atmospheric density

4. Conclusion

From the analysis presented in this paper, it can be concluded that there are multiple factors that are independent of the determinants in the vehicle propulsion system and yet they are responsible for determining the fuel economy of a vehicle. Some of the major factors of such category are vehicle mass, air drag resistance, inertial resistance and rolling resistance. These resistances are characterized by both natural conditions and man-made factors. The natural factors are the ambient temperature, wind direction, altitude etc., whereas the man-made factors are the infrastructure conditions, driving behaviour, vehicle maintenance, road traffic and its management etc. These factors need to be considered for estimating the life-cycle emissions of a fuel. This can be effectively achieved by visualising the journey of fuel from the well-to-miles (WTM) approach as against the prevalent well-to-wheels (WTW) framework.

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