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Real World Powertrain Analysis

Powertrain & Sustainability

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1 Acronyms

OBD – On-Board Diagnostics

KERS – Kinetic Energy Recovery System

GPS – Global Positioning System

ICE – Internal Combustion Engine

SI – Spark Ignition

2 Nomenclature

Km – Kilometres

ms – Millisecond

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8 Introduction

This Paper will consist of a Real-World Powertrain Analysis assisted with the use of Microsoft Excel & the Scan XL software package (Palmer Performance Engineering, 2020). Data was provided from three contrasting vehicle types; the data was accumulated from a logging application (Scan XL) which accesses vehicle data from the OBDII port during Dr Williams 30km commute from home to work over an assortment of road types and environments.

The vehicles are as follows;

- 2011 Triumph 800 XC
- 2016 Volvo V40 Cross-Country D2
- 2016 Toyota Aygo 1.0 VVT-i-X-Pression 5dr Hatchback

This study will inhere of Four different tasks. Firstly, the raw data was processed, and the validity of the calculated channels were determined, redundant data was removed. Secondly, a comparative analysis was undertaken of all three vehicles characteristics such as engine load, driveability, efficiency, performance etc. Furthermore, the next task consisted of the author attempting to model an “*ideal*” vehicle regarding the 60km commute, for this section of the report two different studies were undertaken, the first being a fuelling study looking at a Iso-octane (Petrol) & Methanol Fuel blend and also looking at alternative fuels, only the Toyota Aygo and the Triumph Tiger was taken into consideration. The second study was carried out on the Volvo V40 and was regarding KERS. The final section will contain a vehicle specification proposal assuming the author to be a technical director of an automotive company ensuring to adhere to be economically & politically viable for production of a vehicle for an alternative drive cycle that will be ready for production by the year 2028.

9 Interpretation of Data Provided

9.1 Excel

Initially the .csv files for each vehicle were compiled into one spreadsheet, the data had been formulated from the OBDII output of the vehicle and the GPS data which was calculated from the Scan XL app running on Dr Williams mobile phone. The data was then investigated to check its validity and to move any information that could be considered negligible. Moreover, most of the data came in threes; Timestamp, Imperial & Metric.

AUX.GPS.ALTITUDE (timestamp)	AUX.GPS.ALTITUDE ft	AUX.GPS.ALTITUDE m
GPS Altitude	GPS Altitude	GPS Altitude

Figure 1 Altitude (Timestamp, ft, m)

Figure 1 shows how the raw data was provided, the timestamp data consisted of the frame time in ms and would only change on average every 10 frames when the frame time had gone up by an increment of 1,000 ms, this data alongside the data measured in imperial units were removed as they were of no use within the study only the data in metric units was vital.

2016 Volvo V40 Cross-Country D2					2016 Toyota Aygo 1.0 VVT-i-X-Pression 5dr Hatchback				
Engine Displacement	1969.00	cc			Engine Displacement	998.00	cc		
Bore	82.00	mm	0.082	m	Bore	71.00	mm	0.071	m
Stroke	93.20	mm	0.0932	m	Stroke	84.00	mm	0.084	m
Maximum Torque @ 1,500-2,750 RPM	350.00	Nm			Maximum Torque @ 4,300 RPM	95.00	Nm		
Maximum Power @ 3,750 RPM	88.00	kW			Maximum Power @ 6,000 RPM	51.00	kW		
Vehicle Weight	1606.00	kg			Vehicle Weight	860.00	kg		
Total Weight	1687.27	kg			Total Weight	941.27	kg		
Coefficient of Drag	0.34				Coefficient of Drag	0.28			
Frontal Area	2.20	m ²			Frontal Area	2.00	m ²		
Wheel Size	406.40	mm	0.4064	m	Wheel Size	355.60	mm	0.3556	m
Tyre Size	123.00	mm	0.1230	m	Tyre Size	107.25	mm	0.1073	m
Tyre Pressure	34.00	Psi	2.3442	Bar	Tyre Pressure	33.00	Psi	2.2752	Bar
Rolling Radius	316.41	mm	0.3164	m	Rolling Radius	276.50	mm	0.2765	m
2011 Triumph Tiger 800 XC					Density of Air				
Engine Displacement	799.00	cc			kg/m ⁻³				Gravity
Bore	74.00	mm	0.074	m	1.2250				m/s ²
Stroke	61.90	mm	0.0619	m					9.8067
Maximum Torque @ 7,850 RPM	79.00	Nm			Additional Weight				
Maximum Power @ 9,300 RPM	69.10	kW			kg				
Vehicle Weight	214.50	kg			Dr Williams	80.00			
Total Weight	295.77	kg			MacBook	1.27			
Coefficient of Drag	0.70								
Frontal Area	0.91	m ²							
Front Wheel Size	533.40	mm	0.5334	m					
Rear Wheel Size	431.80	mm	0.4318	m					
Front Tyre Size	81.00	mm	0.0810	m					
Rear Tyre Size	105.00	mm	0.1050	m					
Front Rolling Radius	337.27	mm	0.3373	m					
Rear Rolling Radius	311.27	mm	0.3113	m					
Tyre Pressure Front	40.00	Psi	2.7579	Bar					
Tyre Pressure Rear	42.00	Psi	2.8958	Bar					

Figure 2 Specifications Page

Figure 2 shows the specification sheet for each vehicle and some constants. Most of the data was provided from the vehicle manufacturers specification sheets. Furthermore, even though the commute started early in the morning and the altitude changed throughout the journey an assumption on the density of air was made as 1.2250 kg/m^3 , which is the standard density of air at sea level and the rate of acceleration for gravity was assumed as 9.80665 m/s^2 . The total weight of the vehicle was expressed as;

$$\begin{aligned} \text{Total Weight} = & \text{Mass of Vehicle} + \text{Mass of Dr Williams} \\ & + \text{Mass of Dr Williams Macbook Air} \end{aligned}$$

Equation 1 Total Weight

The Frontal Area of the Volvo V40 was provided within the specification sheet, although it was not for the Triumph or the Aygo, so the following equation was utilised in order to calculate them;

$$\text{Frontal Area} = \text{Width} \times \text{Height} \times 0.85$$

Equation 2 Frontal Area

9.1.1 Route

In order to validate the longitude and latitude figures, the values from the first frame and the final frame were utilised in Google Maps to plot the journey, as shown in figure 3. The end destination was known by the author as the end location shown in figure 3. therefore proving the validity of the GPS data.

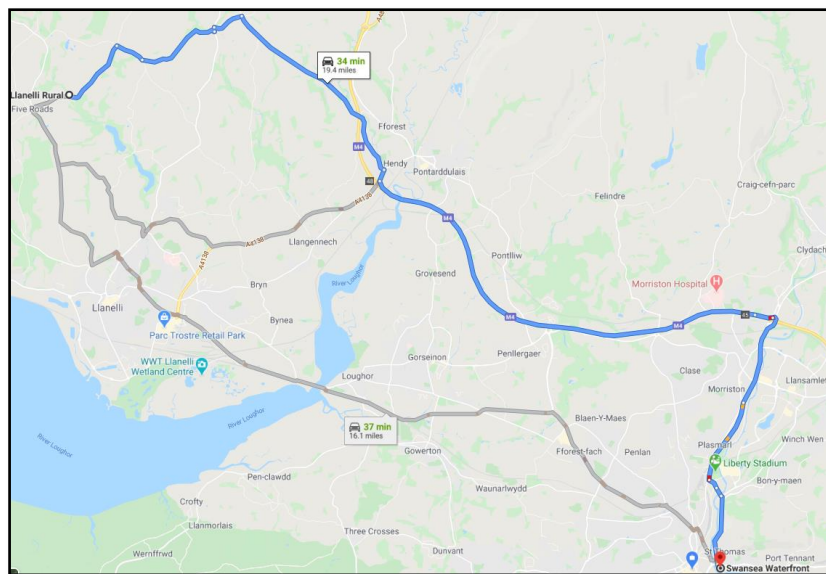


Figure 3 Google Maps Direction Showing Journey (Google, 2020)

Furthermore, figure 3 also displays that Google suggests three viable routes with the “quickest” being highlighted blue, to find out which of these routes was taken or to see if an alternative route was taken the Longitude & Latitude values were plotted on a scatter graph and the same map as previously

displayed in figure 3 was placed behind and scaled until it fitted showing the route taken, this can be found in graph 1 below.



Graph 1 Longitude Plotted Against Latitude Showing the Journey (Google, 2020)

Graph 1 also shows that each vehicle followed an identical route ensuring consistency with all three commutes.

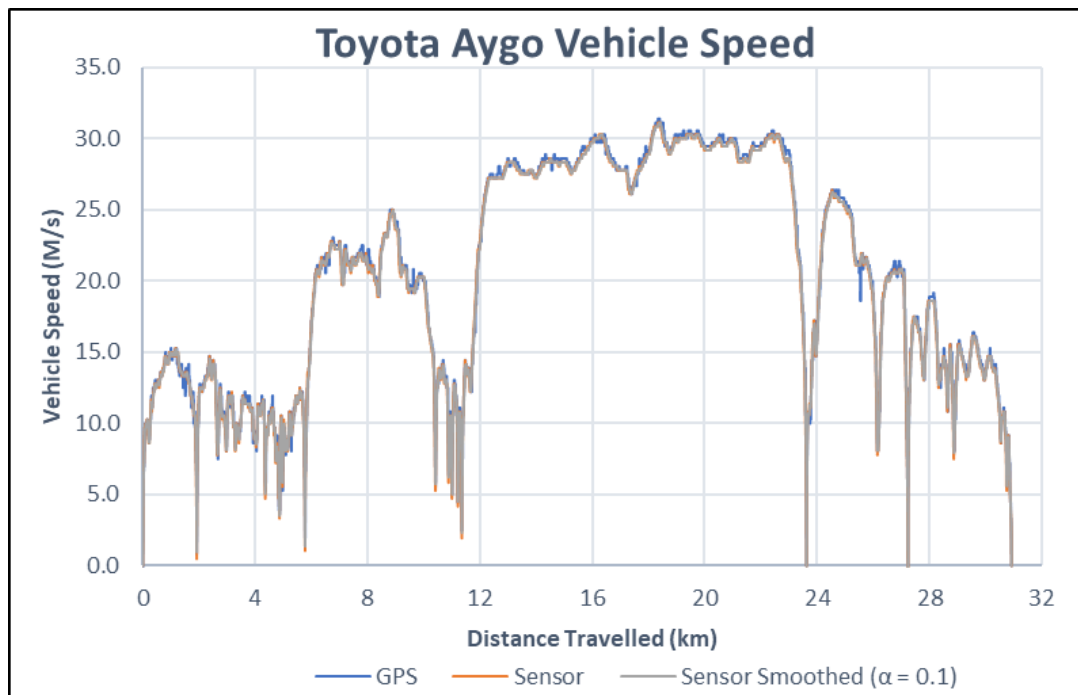
9.1.2 Vehicle Speed

In the Provided data, there were two available linear velocities;

- GPS Speed
- Wheel Sensor Speed

GPS is a network of around 30 satellites which orbit the earth at an altitude 20,000km, on average at least four satellites are available at any one-time and each one transmits information about its position and time at regular intervals, these signals travel at the speed of light and are intercepted by a GPS receiver, which in this case is the phone of Dr Williams. (Physics.Org, n.d.). In addition to this, both the GPS Speed and speed recorded from the sensor were relatively close with a difference of 2.54% between them both at max speed. Furthermore, for the purpose of continuing with the study one of the speeds needed to be used for further calculations throughout this paper. Both can be considered accurate, but the Sensor speed was used with the assumption being made that none of the vehicles were to lose traction at any point during their journey. Moreover, this decision was made because even though GPS

is considered reliable, and GPS-enabled smartphones are typically accurate to within a 4.9m radius under open sky. However their accuracy can worsen near buildings, bridges etc (GPS.gov, n.d.).



Graph 2 Toyota Aygo Vehicle Speed

Graph 2 also shows a third vehicle speed “*Sensor Smoothed ($\alpha = 0.1$)*”. Basically, when using the normal sensor speed to further calculate information out it was generating a lot of noise on the graphs, so an exponential data smoothing tool was applied in excel to smooth out the irregularities.

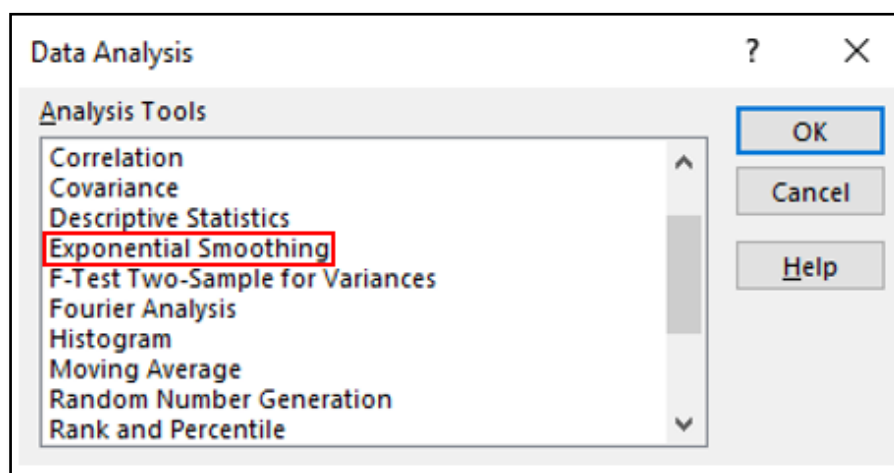


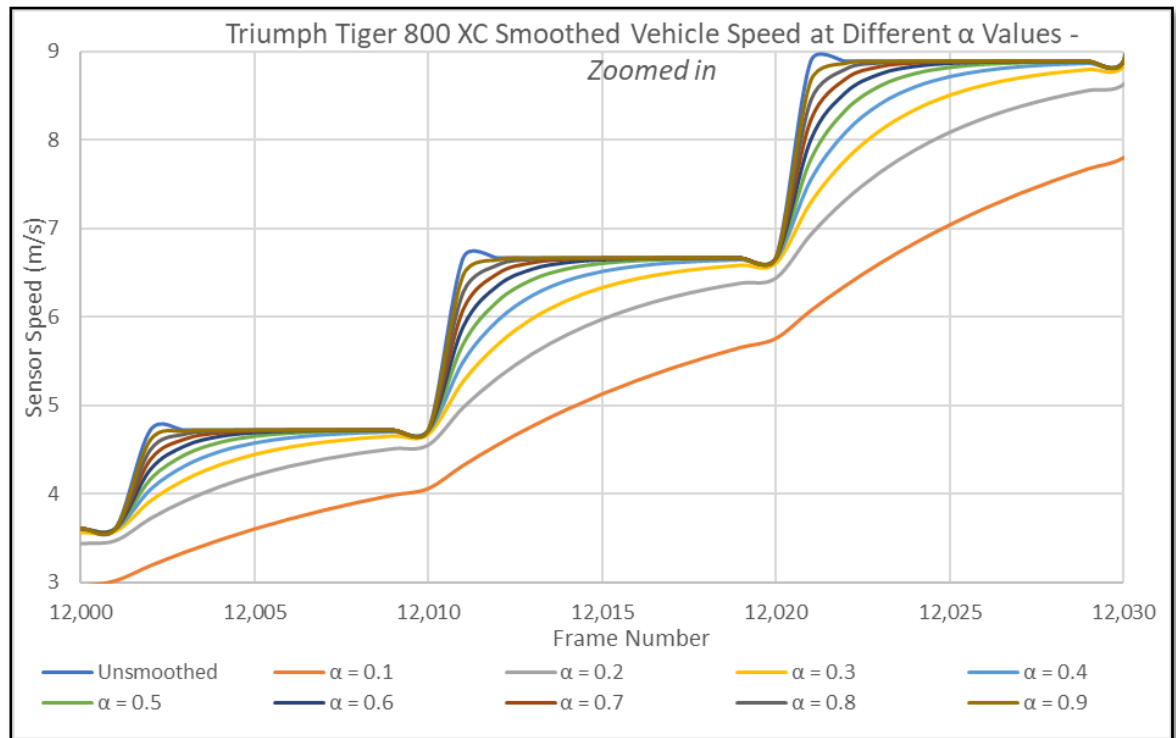
Figure 4 Exponential Smoothing

A damping factor needed to be added between 0.1-0.9, the damping factor is written as;

$$\text{Damping Factor} = 1 - \alpha$$

Equation 3 Damping Factor (Excel Easy, 2018)

Where Alpha (α) is the smoothing constant. This method was carried out for each available damping factor from 0.1 & 0.9.



Graph 3 Triumph Tiger 800 XC Smoothed Vehicle Speed at Different α Values - Zoomed In

“The smaller alpha (larger damping factor), the more peaks and valleys are smoothed out. The larger alpha (smaller damping factor), the closer the smoothed values are the actual data” (Excel Easy, 2018). The decision was made to use $\alpha = 1$ as it still followed the correct trend and at maximum speed only had a difference of 0.24% for the v40, 0.03% for the Aygo and 0.83% for the Triumph.

Maximum Vehicle Speed (m/s)	
GPS	33.61
Sensor	32.78
Sensor Smoothed $\alpha = 0.1$	32.70

Table 1 Volvo V40 Maximum Vehicle Speed

9.1.3 Vehicle Acceleration

Time derivatives are the standard way of representing instantaneous velocities and accelerations, velocity is the derivative of position with respect to time and acceleration is the derivative of velocity with respect to time and can be more simply expressed as;

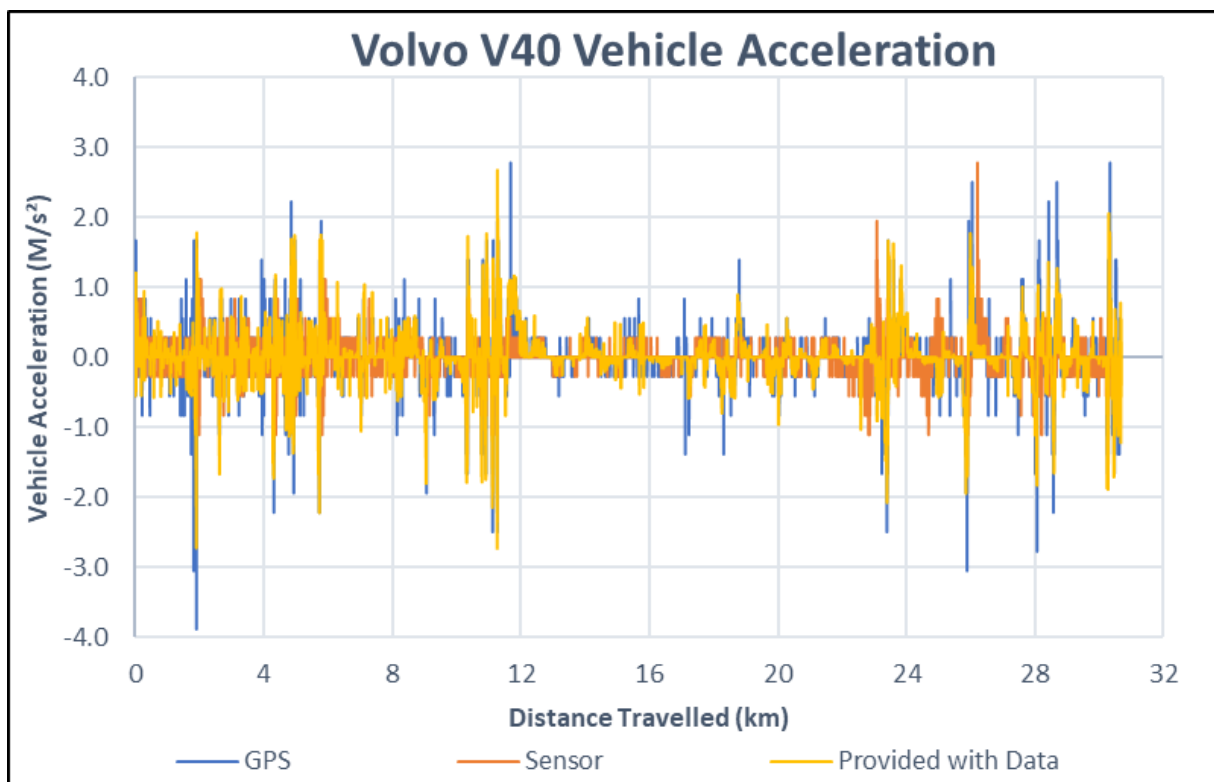
$$v = \frac{dy}{dt}$$

Equation 4 Velocity

$$a = \frac{dv}{dt} = \frac{d^2y}{dt^2}$$

Equation 5 Acceleration

Where y represents position and t represents time. Using this method the accelerations could then be calculated from the vehicle speed from the GPS and the Sensor, also from the provided data from Scan XL there was a column was labelled “*Current Acceleration Based on the last two speed readings*”.



Graph 4 Volvo V40

Graph Four Shows each vehicle acceleration whilst their similar and all follow the same trend there are some differences. Table 2 below shows the accelerations for the Volvo V40, the same table for the Triumph and the Aygo can be found in the Microsoft Excel Spreadsheet.

Maximum Vehicle Acceleration (m/s ²)	
Acceleration from Provided Data	2.67
GPS	2.78
Sensor	2.22

Table 2 Toyota Aygo

9.1.4 Distance Travelled

From the Scan XL data there was a column called “*distance Travelled since last fuel consumption reset*”. From all three vehicles undertaking the same commute the average distance was 30.93 km, which is 19.22 Miles. As previously discussed in section 4.1.1 as the start and end co-ordinates are known to the author, they were plotted in google maps which states the journey is 19.4 miles, that’s only an error margin of 0.93% which is most definitely within tolerance. Furthermore from the vehicle Speed and time the distance could also be calculated as a validation tool to double check that the values from “Distance travelled since last fuel consumption reset” was as accurate as possible.

- Time was given in ms, so;

$$seconds = ms \times 10^{-3}$$

Equation 6 ms to s

- Then distance was calculated as;

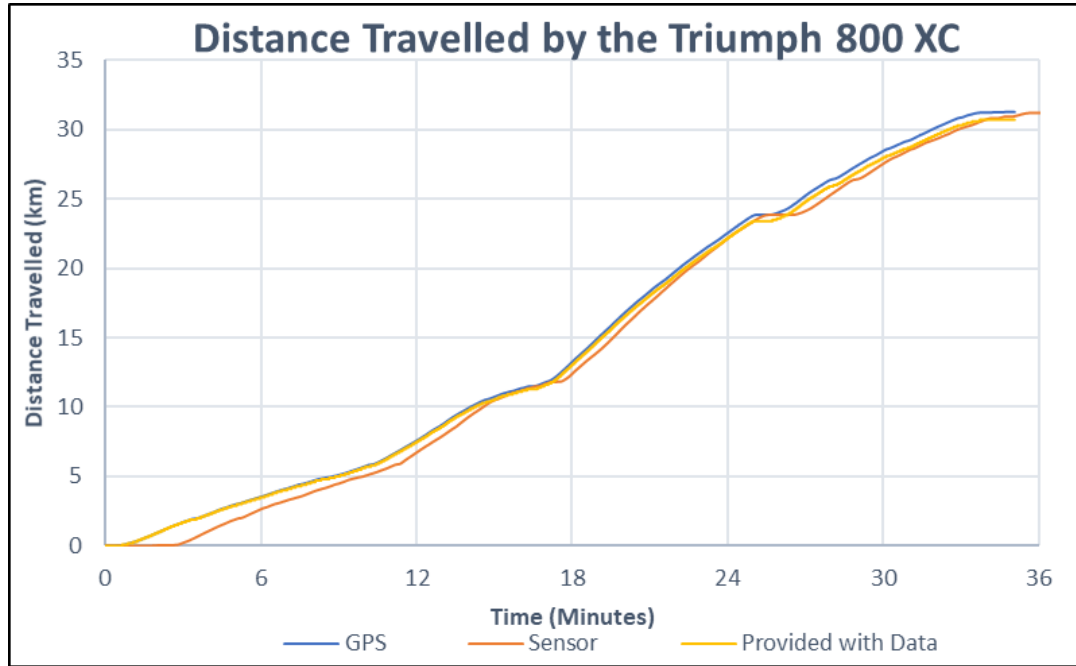
$$Distance\ Per\ Frame = \frac{v \times \Delta t}{1000}$$

Equation 7 Distance Per Frame

Where velocity was in m/s, time in seconds, and the division of a thousand was done for the purpose of units, putting the answer in kilometres. Next, to get the collective distance a sum of the distance travelled for each frame was taken. The answers for the distance from Scan XL, and distance calculated from GPS and Sensor Speed for the Triumph can be found in table 3 below. Once again, for the other two vehicles please refer to the Spreadsheet.

<i>Distance Travelled (km)</i>	
Distance Travelled since Last Fuel Consumption	31.20
From GPS Data	31.18
From Sensor <i>Smoothed $\alpha = 0.1$</i> Data	31.23

Table 3 Distance Travelled



Graph 5 Distance Travelled by the Triumph 800 XC

To further maintain consistency as previously stated any further work that requires distance as a product of its equation will be using the distance from the sensor.

9.1.5 Angular Velocity

9.1.5.1 Engine

The RPM of the engine for each vehicle during the commute was also provided in the raw Scan XL data from the OBDII to then calculate the angular velocity of the engine in radians per second the following equation was used;

$$\text{Angular Velocity} = 2 \times \pi \times \left(\frac{\text{RPM}}{60} \right)$$

Equation 8 Engine Angular Velocity

9.1.5.2 Wheel

Then to calculate angular velocity at the wheels the following equation was used;

$$\text{Angular Velocity} = \frac{\text{Linear Velocity}}{\text{Rolling Radius}}$$

Equation 9 Wheel Angular Velocity

9.1.6 Forces

First, the road slope angle needed to be calculated. The first method was to attempt to use basic trigonometry, as shown in figure 5 and equation 11 below.

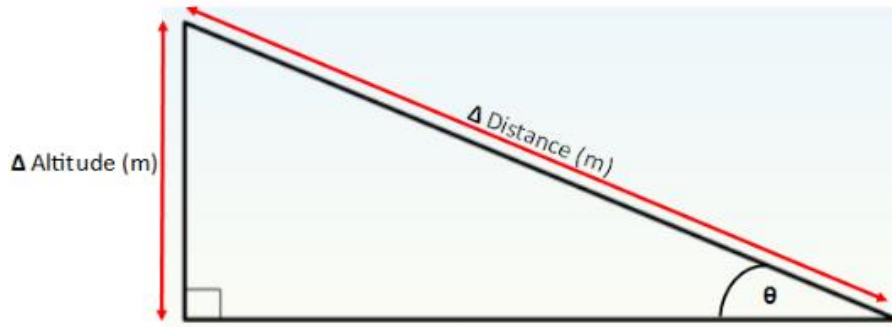


Figure 5 Trigonometry Diagram for Road Slope angle

$$\sin \theta = \frac{\text{Opposite}}{\text{Hypotenuse}}$$

$$\therefore \theta = \sin^{-1} \times \frac{\text{Opposite}}{\text{Hypotenuse}}$$

$$\therefore \theta = \sin^{-1} \times \frac{\Delta \text{ Altitude}}{\Delta \text{ Distance}}$$

Equation 10 Road Slope Angle One

Unfortunately, since the rate of change of altitude and distance was 0 at various point throughout the cycle there was usually either a 0 dividing or divided by which would then result in Microsoft Excel displaying an error code. To attempt eradicate this issue an if statement was used removing all cells with a value of 0 unfortunately this did not work as even when both variables contained actual numbers excel would just display errors every time the inverse-sin function was used. Therefore, research was conducted, and a new equation was found in accordance to Euler's Theorem.

$$\theta = \cos^{-1} \sqrt{\frac{1}{1 + \tan^2(\text{Pitch}) + \tan^2(\text{roll})}}$$

Equation 11 Road Slope Angle Two (R.N. Barbosa, 2012)

The Pitch and Roll Values were also from the raw excel data from Scan XL. The answer was given in radians, so with use of the "DEGREES" function put in excel they were converted to degrees. Furthermore, this was done for the Aygo and V40, but as triumph is a motorcycle and for the purpose of this study lean angle, etc is not considered. This may result in an inaccurate result regarding the angle of the road therefore an average of the V40 and Aygo's road slope angle was used in the hope of maintaining consistency.

Next, the Inertial Force was calculated using equation 13 below following newtons second law.

$$\text{Inertial Force} = \text{Mass} \times \text{Acceleration} \times \sin(\theta)$$

Equation 12 Inertial Force

Where Mass is the total weight, acceleration is the linear acceleration of the vehicle and theta is the road slope angle. Then, Drag Force was calculated using;

$$Drag\ Force = \frac{1}{2} \times \rho \times CD \times A \times v^2$$

Equation 13 Drag Force

Where ρ is density of air, CD is the drag coefficient, A is frontal Area and v is the vehicles linear velocity. Next the rolling resistance needed to be calculated, Firstly, as the rolling resistance coefficient was not considered a constant, it was expressed as;

Rolling Resistance Coefficient

$$= 0.005 + \left(\frac{1}{Tyre\ Pressure} \right) \times \left(0.001 + 0.0095 \times \left(\frac{velocity}{100} \right)^2 \right)$$

Equation 14 Rolling Resistance Coefficient (Engineering ToolBox, 2008)

Next, the rolling resistance was calculated using equation 16 below.

$$Rolling\ Resistance = RR_{Coefficient} \times Total\ Weight \times Gravity$$

Equation 15 Rolling Resistance

Now the total required driving force of each vehicle at each time frame during the commute cycle could be calculated as;

$$Total\ Driving\ Force = Inertial\ Force + Drag\ Force + Rolling\ Resistance$$

Equation 16 Total Driving Force

9.1.7 Energy

The Energy generated through the cycle for each vehicle at each point was calculated using the following equations;

$$Potential\ Energy = Mass \times Gravity \times Height$$

Equation 17 Potential Energy

$$Kinetic\ Energy = \frac{1}{2} \times Mass \times Velocity^2$$

Equation 18 Kinetic Energy

Where the height required to calculate the potential energy was the altitude of the vehicle at each specific time frame.

Then using the Sum of Function and the Max function within Excel the total energy and maximum energy values throughout the cycle were calculated, which will be discussed further in depth later within the report.

9.1.8 Power & Torque

The power and Torque were then calculated using the following the two equations

$$\text{Power} = \text{Total Driving Force} \times \text{Vehicle Speed}$$

Equation 19 Power

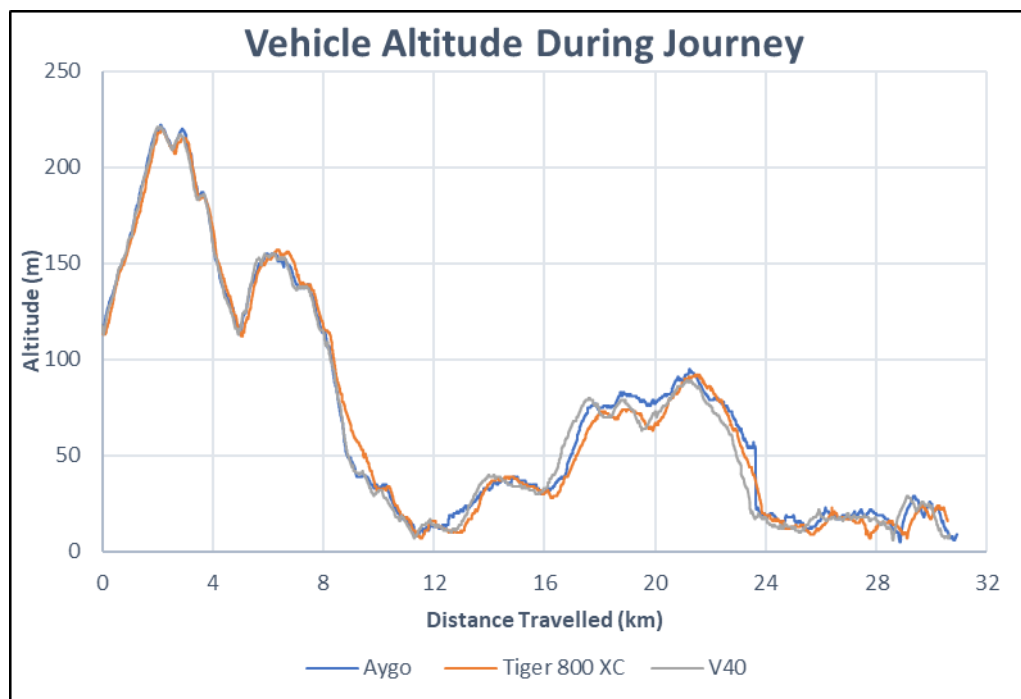
$$\text{Torque} = \text{Total Driving Force} \times \text{Rolling Radius}$$

Equation 20 Torque

For the triumph there was two different rolling radiuses on account of the front and rear wheel being different sizes, but when calculating the torque the rear wheel radius was used as that's the wheel which is being driven. Furthermore, the power is what is required to overcome the resistive forces and move the vehicles. This will be further analysed within the comparative analysis section of the paper.

10 Comparative analysis

10.1 Altitude

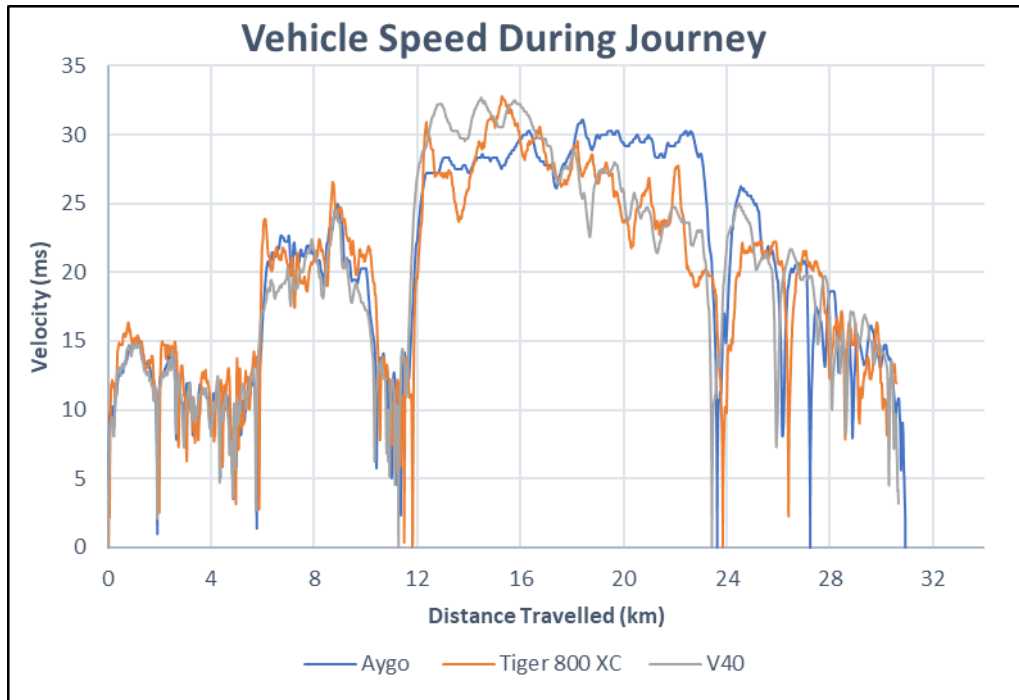


Graph 6 Vehicle Altitude

Graph Six shows the altitude of each vehicle plotted against the distance travelled, it's clear to see that they are all consistently following the same trend. This proves that all three vehicles took the same

route, which will ensure consistency throughout the study. Further validation that the vehicles took the same route can be found in appendix 10.1 where the longitude is plotted against latitude as previously stated in section 4.1.1 for all three vehicles.

10.2 Vehicle Speed



Graph 7 Vehicle Speed During Journey

Graph 7 shows the linear velocity of each vehicle plotted against distance travelled. It can be seen from around 12 to 20km's each vehicle seems to have its fastest period, this is taking place on the motorway. At maximum velocity of Each vehicle the Triumph is fastest and the Aygo is the slowest but even then, there is only percentage difference of 5.28%.

<i>Maximum Vehicle Speed (m/s)</i>	
Volvo V40	32.70
Toyota Aygo	31.10
Triumph Tiger 800 XC	32.78

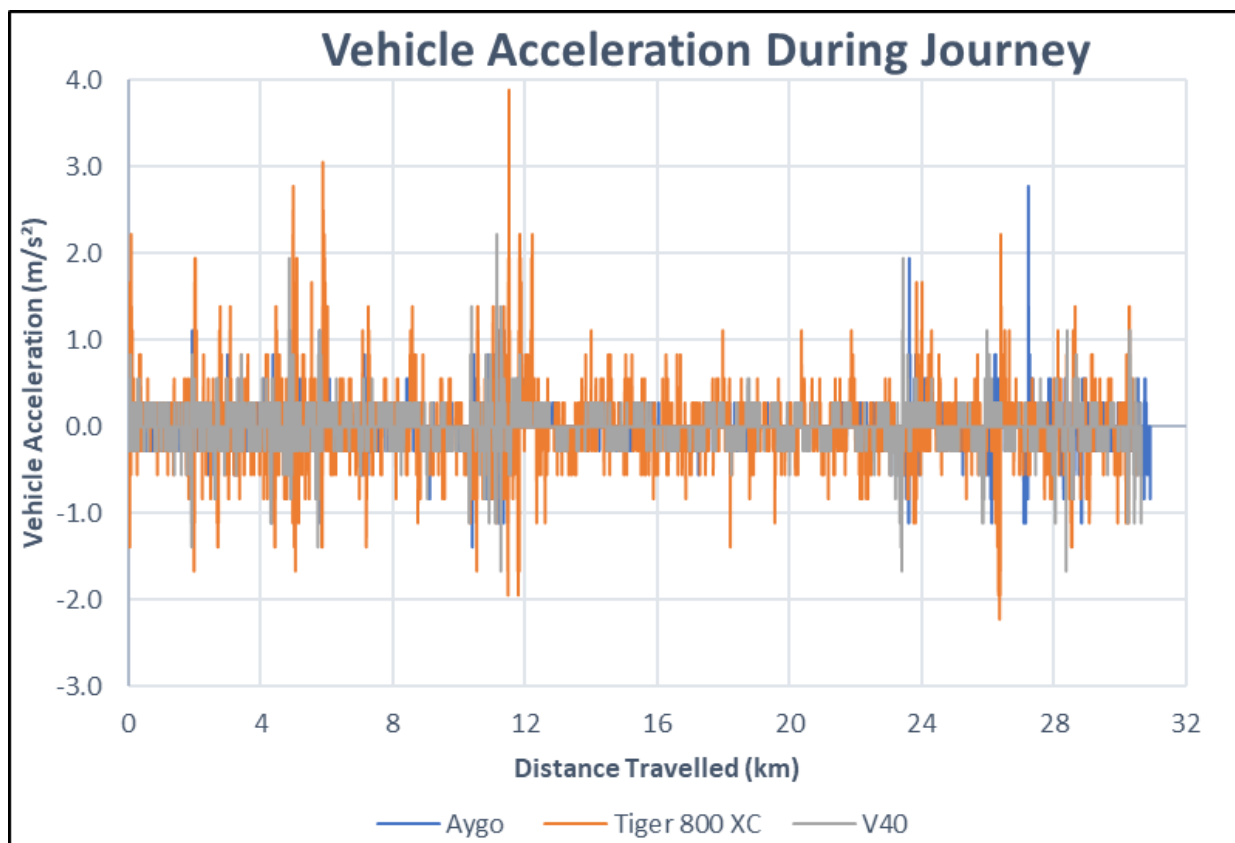
Table 4 Maximum Vehicle Speed

Furthermore, from reviewing graph 7 it shows that at certain points during the journey each vehicle would come to a complete stop it was pretty consistent with each vehicle where these points were happening so therefore, it can be assumed there is a set of traffic lights or a junction etc at these points. This is where the start stop system should kick in for the V40, from further reviewing the data the RPM only drops to 0 at one point during the commute, the assumption was made that this is when the stop start kicks in this is further proved as the vehicle is at a complete standstill at this point as the distance

travelled remains at 23.4km. This period commences for 23.0460 seconds so most likely, during a set of traffic lights.

The idea behind Stop/Start Technology is that it saves fuel and emissions that might be generated when the car is sat at idle at a set of traffic lights. On the other hand with that being said, Taking into consideration that the total journey is 32 minutes and 30 seconds so the stop start technology is only active for a minuscule part of that timescale.

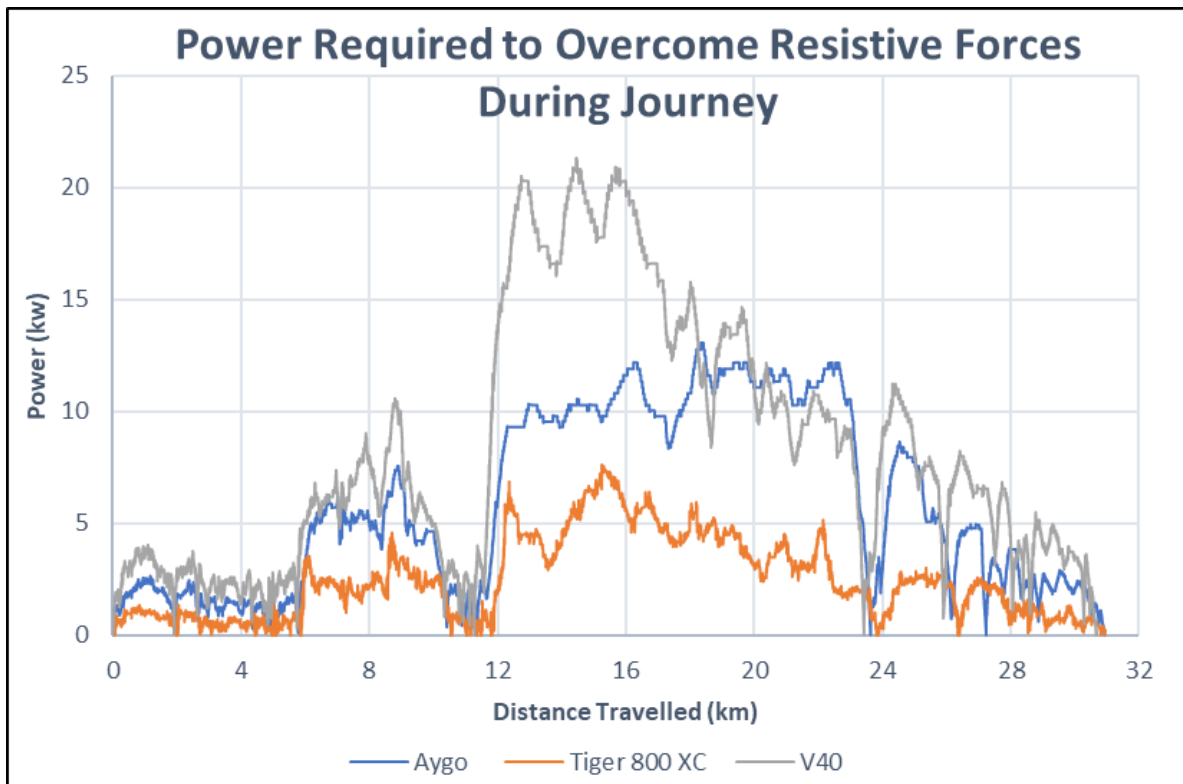
10.3 Acceleration



Graph 8 Vehicle Acceleration During Journey

Graph 8 shows the vehicle acceleration for each vehicle throughout the cycle, the graph has a lot of noise this is because, as previously stated acceleration is the derivative of velocity therefore any noise on the speed graph is then amplified. The triumph accelerates faster than both the cars this is also shown in graph 8, by rearranging $F = ma$ to make acceleration the subject, it states that acceleration is inversely proportional to mass and the triumph which is only 18.42% of the Volvos mass and 31.43% of the algos mass. Furthermore, this is why motorcycles tends to have higher power-to-weight ratios than cars.

10.4 Power



Graph 9 Power Required to Overcome Resistive forces During journey

Graph 9 shows the power required to overcome resistive forces during the drive cycle and follows same trends as linear velocity which is a factor of the power equation. Furthermore, the Volvo has the highest value throughout the commute whereas the Triumph has the smallest, this is due to vehicle mass, as vehicle mass is a product of inertial force, which in turn is used to calculate total force. Therefore at the same or similar speeds the heaviest vehicle will need more power to overcome the resistive forces being exerted upon it.

	Power (kW)		
	V40	Aygo	Tiger 800 XC
Maximum Power Needed to overcome resistive forces during	21.32	13.07	7.60
Max Power Output of the Vehicle	88.00	51.00	69.10

Table 5 Power

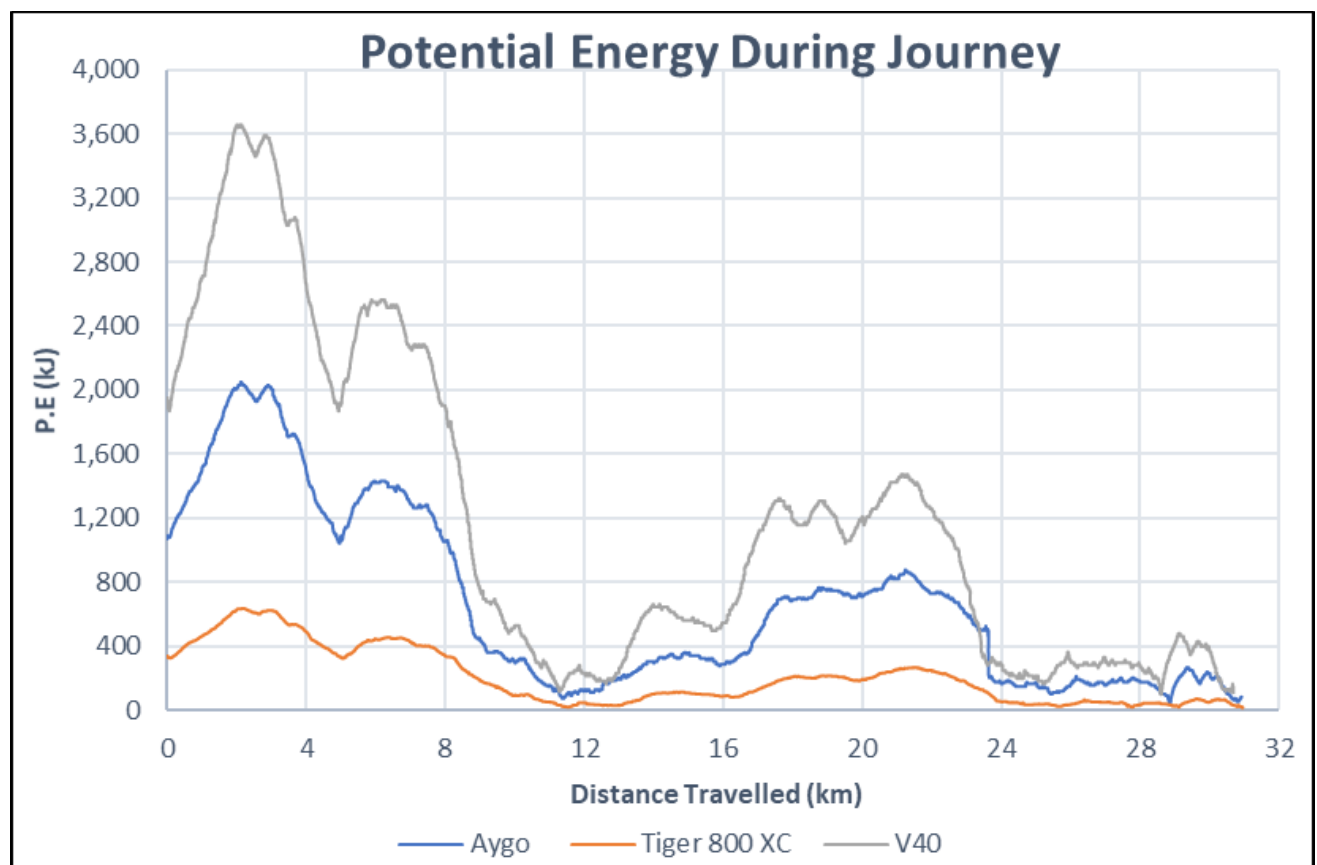
Table 5 shows the maximum power needed to overcome resistive forces during the commute. Furthermore, table 6 below then shows what percentage of the vehicles available power is being utilized during this time.

Maximum amount of available power being used to overcome resistive forces during commute		
V40	Aygo	Tiger 800 XC
24.23%	25.62%	11.00%

Table 6 Maximum amount of Available Power Being Used to Overcome Resistive Forces During Commute

10.5 Energy

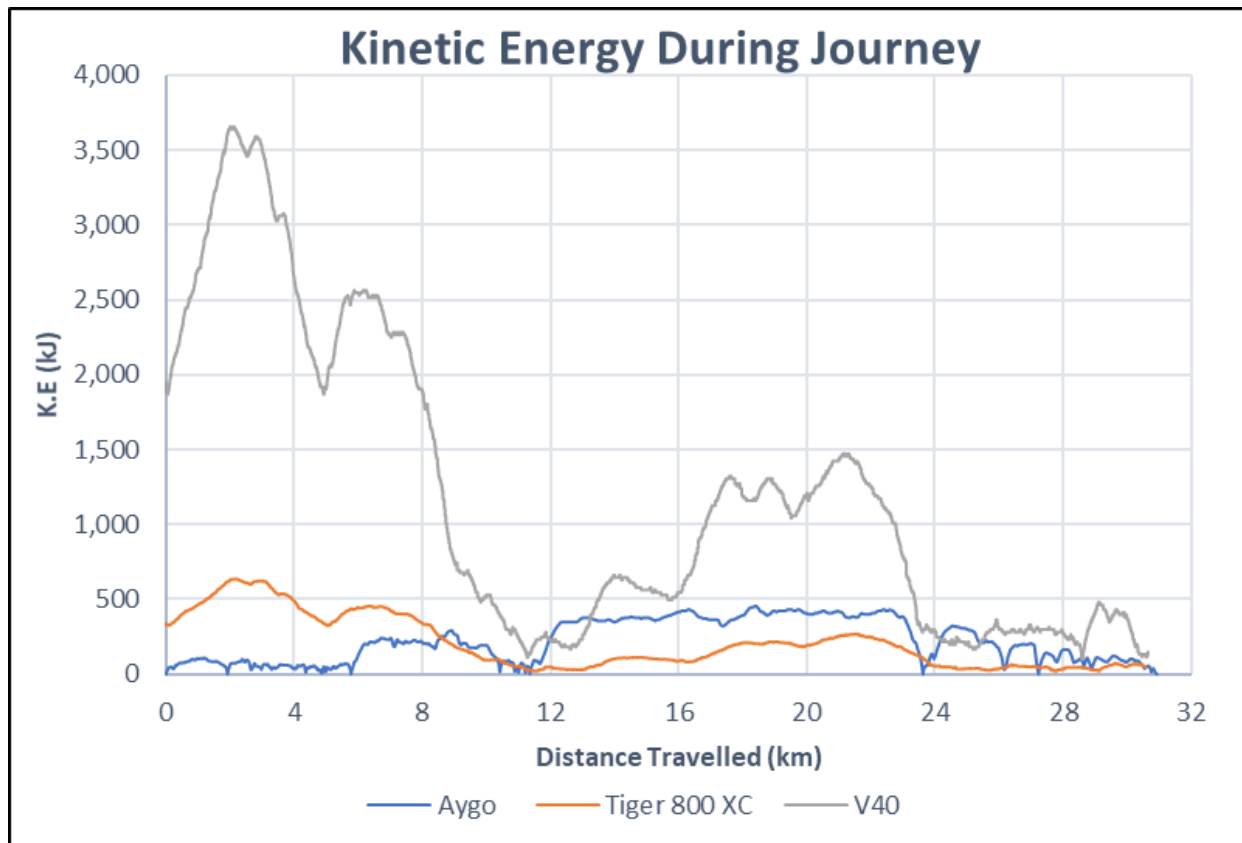
Gravitational Potential energy is the energy stored in an object as the result of its vertical position or height. “The energy is stored as the result of the gravitational attraction of the Earth for the object” (The Physics Classroom, 2016) The P.E depends on two variables, the mass of the component in question and the height which in this case is the total weight of the vehicle and the altitude.



Graph 10 Potential Energy During Journey

As all three vehicles travel the same route and the same distance the altitude will be the same for each vehicle. Therefore the vehicle with the largest mass should have the most potential energy and vice versa, this is proven quite clearly in graph 10.

Furthermore, it is worth noting that to accurately determine the P.E of an object a “zero height position must first be arbitrarily assigned”, in this case the zero height was considered as sea level. Unlike the potential energy of an object, the kinetic energy is the energy an object has due to its motion. Once again there are two variables when calculating the kinetic energy as previously stated in equation 19. The first variable is the vehicles linear velocity which is similar consistent for all three drive cycles meaning the Volvo will be generating the most kinetic energy due to its mass, as proven in graph 11.



Graph 11 Kinetic Energy During Journey

Graph 11 also shows quite how monumental the difference in K.E from the Volvo in comparison with the other two vehicles.

10.6 Fuel Economy

As stated in the brief for this study, all three vehicles deliver the same ‘Real World’ fuel economy of 50mpg. Therefore, in the Volvo is regarded the most efficient of the three vehicles as during the journey it is using the same amount of fuel when it is a substantial amount heavier than the other two vehicles. the Triumph which is much lighter with a difference in mass of 140.46%, is using the same amount of fuel as the Volvo making the Triumph the least efficient followed by the Aygo.

11 Fuelling Studies (Aygo & Triumph 800 XC)

In February 2020, The British Government Announced the plan to put a ban on selling new petrol, diesel or hybrid cars in the UK by 2035, in order to “*clean up air quality & reduce CO₂ emissions*” (Chillingsworth, 2020).

In the mainstream media, all the rage seems to be based around electric vehicles, with companies such as Tesla making leaps and bounds in the automotive industry with their fully electric vehicles. For example the Tesla Model 3 comes with the option of two batteries, the standard 50kWh or the larger capacity 75kWh, a full charge of the larger battery will only set the owner back \$9.75 (*around £8.45*) (Sendy, 2020). Furthermore, with a full charge, the Model 3’s standard driving range is 250 miles (*402 km*), that works out to 3 pence a mile. The average cost of a litre of petrol in the UK as of the 16th March 2020 was 1.203GBP. Therefore an ICE vehicle, assuming a fuel economy of 50mpg, the same as the other vehicles within this paper, travelling 250 miles would cost around £32.17. Therefore, a Tesla owner is saving around 26.27% more money every 250 miles. On the other hand it takes up to 40 minutes for 80% charge whereas filling a vehicle up with fuel takes minutes, so in terms of time it is less efficient.

Therefore, this section of the report is to study other ways of reducing CO₂ emissions by a method of fuel blending and alternative fuels as opposed to jumping on the electric bandwagon.

11.1 Iso-Octane (*Petrol*) & Methanol Fuel Blending

“*Methanol is a clean burning, high octane blending component made from alternative non-petroleum energy sources such as natural gas, coal and biomass*”. (Methanol Institute). Furthermore, Extensive Research and years of experience prove that blending oxygenates with Petrol can improve fuel performance, reduce exhaust emissions and reduce NO_x. This study investigates the effect increasing the Methanol to Iso-octane (*Petrol*) Ratio of an ICE will have on the amount of CO₂ produced during the 60km drive cycle of both the Toyota Aygo and Triumph Tiger 800XC.

Tables 7 & 8 below show the dropdown boxes within the Microsoft Excel spread sheet where the user could select between the two vehicles and the percentage of Iso-octane which will determine the fuel blend ratio.

Vehicle
Triumph Tiger 800 XC
Toyota Aygo
Triumph Tiger 800 XC

Table 7 Vehicle Dropdown Box 2

Fuel One	
Type	Percentage
Iso-Octane	10
	20
	30
	40
	50
	60
	70
	80
	90
	Miles

Table 8 Iso-Octane Percentage for Blend

Even though the option is available to choose between the two vehicles, it is worth mentioning the results are almost identical as they have matching fuel economy and an overall difference in distance travelled of 0.38 miles which is trivial.

Vehicle	Fuel One		Fuel Two		Molecules		
	Type	Percentage	Type	Percentage	Carbon	Hydrogen	Oxygen
Triumph Tiger 800 XC	Iso-Octane	20	Methanol	80	2.40	6.80	0.80

Table 9 Vehicle, Fuel One, Fuel Two, Molecules

When a vehicle is selected and a blend ratio chosen, the Carbon, Hydrogen and Oxygen molecules relative to the ratio of Iso-octane to Methanol will be displayed as shown in table 9. Next, the CO₂, H₂O, N₂ and x values could be calculated, where “x” is the ratio of Nitrogen & Oxygen in the air. For example, table 10 below which has been taken from a previous study carried out by the author in regards to NO_x modelling showing how these values were calculated for a 50/50 blend, the same method was carried out within this study, but altered accordingly dependant on the ratio of the blend.

Iso-Octane & Methanol (50/50 Blend)	
$C_8H_{18} + C_1H_4O_1 + x(O_2 + 3.76N_2)$ $\rightarrow n_1 CO_2 + n_2 H_2O + n_3 N_2$	
$n_1 = 9$	
$2n_2 = 22$ $n_2 = \frac{22}{2}$ $n_2 = 11$	
$2x = 2n_1 + n_2 - \text{Oxygen Molecules}$ $2x = 18 + 11 - 1 = 28$ $x = \frac{28}{2}$ $x = 14$	
$n_3 = 3.76 \times 14$ $n_3 = 52.64$	

Table 10 Iso-Octane & Methanol 50/50 Blend (Hill, 2019)

CO ₂	H ₂ O	N ₂	x	Air Mass	Fuel Mass	Mass of CO ₂
(n1)	(n2)	(n3)		kg	kg	kg/kmol
2.40	3.40	13.91	3.70	507.94	48.40	105.60

Table 11 CO₂, H₂O, N₂, X, Air Mass, Fuel Mass & Mass of CO₂

Table 11 is assuming a 20:80 Iso-Octane to Methanol ratio, it also displays the Air Mass, Fuel Mass & Mass of CO₂ Were calculated using the following three equations;

$$\text{Air Mass} = x \times ((2 \times \text{Molecular Weight of Oxygen}) + \text{Atmospheric Composition Ratio} \times 2 \times \text{Molecular Weight of Nitrogen})$$

Equation 21 Air Mass

$$\begin{aligned} \text{Fuel Mass} = & (\text{Carbon Molecules} \times \text{Molecular Weight of Carbon}) \\ & \times (\text{Hydrogen Molecules} \times \text{Molecular Weight of Hydrogen}) \\ & \times (\text{Oxygen Molecules} \times \text{Molecular Weight of Oxygen}) \end{aligned}$$

Equation 22 Fuel Mass

$$\text{Mass of CO}_2 = \text{CO}_2 \times (\text{Molecular Weight of Carbon} + (2 \times \text{Molecular Weight of Oxygen}))$$

Equation 23 Mass of CO₂

The Atmospheric Composition Ratio and the molecular weights can be found in Appendix 10.1 Next, using the enthalpy of formation for both the Iso-Octane & Methanol and combining them regarding the blend ratio selected which were acquired from McAllister's Fundamentals of Combustion processes and using equation's 25 & 26 & 27 below the LHV Calorific Value of each blend was calculated, the lower heating value is calculated with the product of H₂O in vapour form.

$$h = (\text{CO}_2 \times 393.5) + (\text{H}_2\text{O} \times 241.8)$$

Equation 24 Enthalpy Released from Reaction

$$\text{Net Enthalpy} = h - \text{Enthalpy of Formation}$$

Equation 25 Net Enthalpy

$$\text{LHV Calorific Value} = \frac{\text{Net Enthalpy}}{\text{Fuel Mass}}$$

Equation 26 LHV Calorific Value

Next, in order to calculate the CO₂ Produced across the cycle for each blend, the following steps had to be completed first.

- Mass of Iso-Octane used across the cycle;

$$\text{Mass of Fuel Used} = \text{Density of Fuel} \times \text{Fuel Used}$$

$$\text{Mass of Iso - Octane Used} = 750\text{kg/m}^3 \times 0.0029\text{m}^3$$

Equation 27 Mass of Fuel Used

- Then the energy produced burning Iso-Octane across the cycle was calculated;

$$\text{Energy Produced} = \text{LHV} \times \text{Mass of Fuel Used}$$

$$\text{Energy Produced} = 44.65 \frac{\text{MJ}}{\text{kg}} \times 2.18 \text{ kg}$$

Equation 28 Energy Produced

- Then in order to maintain consistency within the results, the energy produced each ratio of fuel blend was made to match that of just Iso-Octane by itself, 97.46 mJ.
- By dividing the energy produced by the LHV of each blend ratio calculated the mass of the fuel blend used to produce the same amount of energy that Iso-Octane produces.
- To calculate the density of each blend ratio the mass of fuel used was divided by the volume of fuel used in m³.
- Next, the Carbon Dioxide Produced for 1kg of fuel for each blend ratio was calculated using the following equation;

$$\text{Carbon Dioxide for 1kg of Fuel Type} = \frac{\text{Mass of CO}_2}{\text{Fuel Mass}}$$

Equation 29 Carbon Dioxide for 1kg of Fuel Type

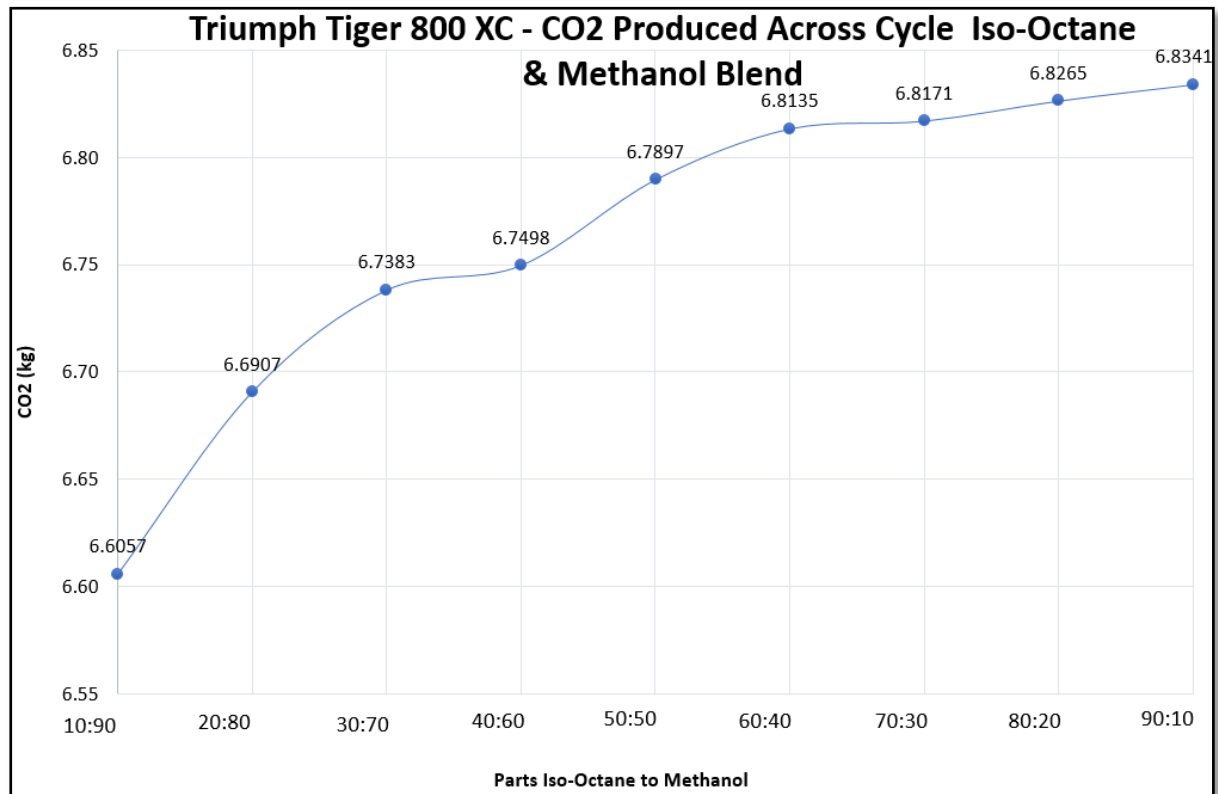
- Finally, the overall CO₂ Produced during commute was calculate;

$$\text{CO}_2 \text{ Produced Across Cycle} = \text{Carbon Dioxide for 1kg of fuel type} \times \text{Mass of Fuel Used}$$

Equation 30 CO2 Produced Across Cycle

Triumph 800 XC	
CO2 Produced Across Cycle	
Ratio	kg
10:90	6.6057
20:80	6.6907
30:70	6.7383
40:60	6.7498
50:50	6.7897
60:40	6.8135
70:30	6.8171
80:20	6.8265
90:10	6.8341

Table 12 Triumph 800 XC CO2 Produced Across Cycle



Graph 12 Triumph Tiger 800 XC - CO₂ Produced Across Cycle Iso-Octane & Methanol Blend

Graph “14” Shows that the larger the Iso-Octane to Methanol Ratio the more CO₂ Emissions are produced. This shows that blending methanol with Iso-Octane will in turn reduce the CO₂ emissions. Furthermore, low contents of Methanol have been added to Petrol since the 1970’s and an important factor is the fact it can be used without requiring any significant changes in the structure of the engine, and “*being part of the various alcohols, ethanol & Methanol are known as the most suitable fuels for SI engines*”. (Iliev, 2018). On the other hand, even though blended fuel ratio increases and the carbon monoxide and hydrocarbon emissions decrease, there is a significant growth in NO_x emissions “*when blended fuel increases up to 30% M30 (E30)*” (Iliev, 2018)

11.2 Alternative Fuels

Fossil Fuel’s are currently the number one energy source world-wide but are finite resources and cause harm to the environment. According to the U.S. Energy Information Administration in 2016 burning fossil fuels was solely responsible for “76% of U.S. greenhouse gas emissions” (EESI, 2017).

This section of the study follows the same methods, carried out in section 6.1 but this time looking at alternative fuelling as opposed to just a fossil fuel blended with Methanol. “*The Second Largest revolution in global automotive manufacturing is currently under way: the race to develop environmentally clean automobiles*” (Topolansky, 1993).

Vehicle	Distance Travelled		Fuel Economy	Fuel Used		
	Miles		mpg	Gallons	Litres	m ³
Toyota Aygo	38.4390		50	0.7688	2.9102	0.0029
Toyota Aygo						
Triumph Tiger 800XC						

Table 13 Vehicle Dropdown Box, Distance Travelled, Fuel Economy & Fuel Used

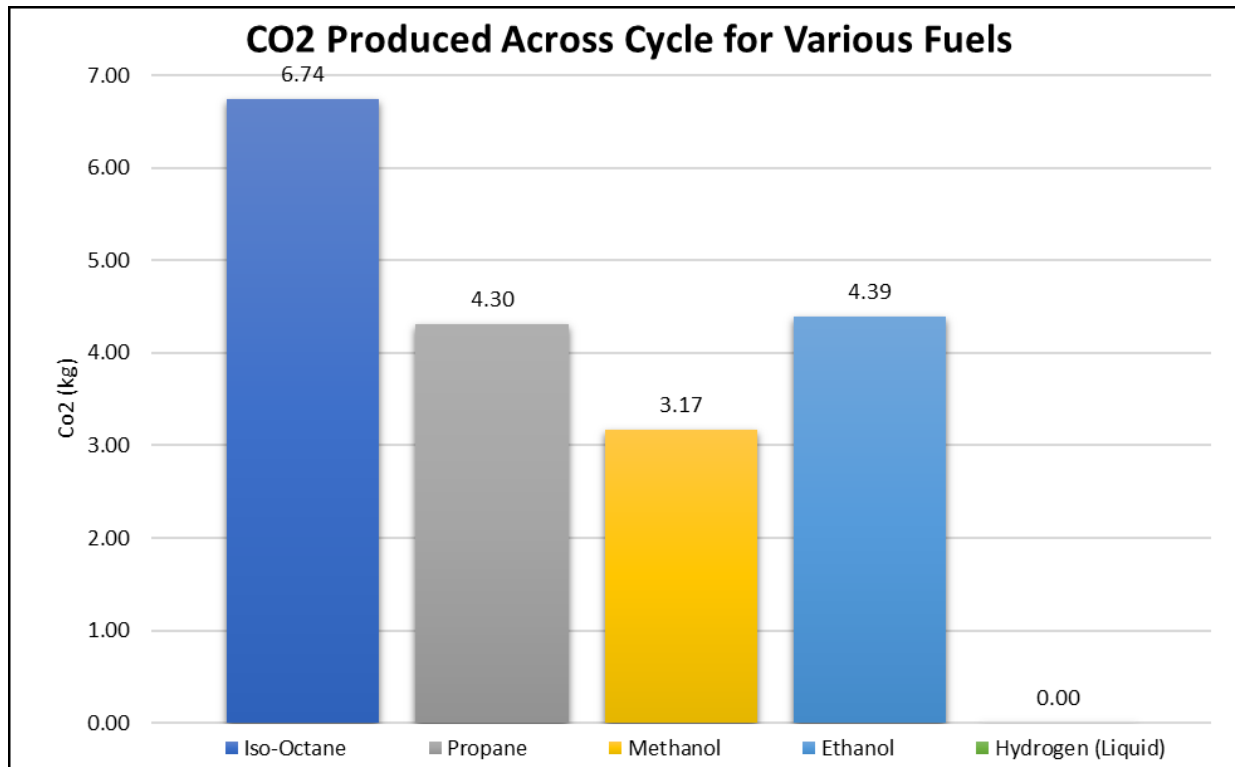
Once again, as in section 6.1 the option between the Toyota Aygo and the Triumph Tiger was available from a dropdown box. Furthermore, Table 14 below shows the results for Iso-Octane and four other alternative fuels, the methods were the same as of that carried out in section 6.1. Although this time the same energy was not used. As the density of each fuel and the lower heating values were known and did not need to be calculated. (S. McAllister).

The Energy produced burning fuel across the cycle could then be calculated assuming that the same amount of fuel was used, and the fuel economy remained the same, as shown in table 14 below.

Fuel Type		LHV	Density of Fuel	Mass of Fuel used	Energy Produced Burning Fuel Across Cycle	Carbon Dioxide Produced for 1kg of Fuel Type	CO ₂ Produced Across Cycle
		MJ/kg	kg/m ³	kg	MJ	kg	kg
Iso-Octane (petrol)	C ₈ H ₁₈	44.65	750.00	2.18	97.46	3.09	6.74
Propane	C ₃ H ₈	46.33	493.00	1.43	66.47	3.00	4.30
Methanol	CH ₄ O	19.92	792.00	2.30	45.90	1.38	3.17
Ethanol	C ₂ H ₆ O	26.80	789.00	2.30	61.54	1.91	4.39
Hydrogen (Liquid)	H ₂	119.96	71.00	0.21	24.79	0.00	0.00

Table 14 Fuel Type, LHV, Density, Mass of Fuel, Energy, & CO₂

Furthermore, Iso-Octane has the highest CO₂ produced which was to be expected, Hydrogen produces no carbon dioxide as there are no carbon molecules in its chemical formula. The second most efficient fuel in terms of CO₂ emissions was Methanol. Furthermore, there are other benefits of using Methanol as an alternative to petrol, it is cheap to produce in comparison to other alternative fuels, it has a lower risk of flammability compared to that of petrol and can be manufactured from a variety of carbon -based feedstocks, such as natural gas and Coal. In the 1990's Methanol was marketed as an alternative fuel for compatible vehicles. "At its peak, nearly 6 million gasoline gallon equivalents of 100% methanol and blend of 85% methanol and 15% gasoline were used annually in alternative fuels in the United States". (U.S Department of Energy, n.d.). On the other hand, it has its disadvantages it has a richer air/fuel ratio than petrol meaning that in a real life scenario it would have a lower fuel economy, also it is highly corrosive and can "eat through fuel lines" if left sitting long enough (Sands, 2015).



Graph 13 CO2 Produced Across Cycle for Various Fuels

Graph 13 shows, that Propane also produces significantly less carbon dioxide compared to that of Iso-octane. Propane, also commonly referred to as LPG, is odourless, non-toxic and is produced as a by-product in the oil refining process. In addition to this, it is highly available, high octane and clean burning and is the third largest motor fuel and most widely used alternative to fossil fuels in the U.S (Campbell-Parnell, n.d.).

Ratio of energy produced by alternative fuels compared to Iso-Octane (<i>Petrol</i>) assuming that the same volume of fuel was used and Distance travelled & Fuel Efficiency all remained the same.	
<i>Propane</i>	1.4662
<i>Methanol</i>	2.1232
<i>Ethanol</i>	1.5836
<i>Hydrogen (Liquid)</i>	3.9319

Table 15 Energy Ratio

Mass of alternative fuel required to replicate the energy produced burning Iso-Octane (<i>Petrol</i>) during cycle.	
	kg
<i>Propane</i>	2.1035
<i>Methanol</i>	4.8936
<i>Ethanol</i>	3.6360
<i>Hydrogen (Liquid)</i>	0.8124

Table 16 Mass of Alternative Fuel Required

Table 15 shows the ratio of energy produced by the alternative fuels compared to Iso-Octane, assuming the same Volume of fuel was used, and that the distance travelled and Fuel Efficiency all remained the same, then the mass of alternative fuel required to replicate the energy produced from Iso-octane during the cycle was calculated, refer to table 16.

Volume of alternative fuel required to replicate the energy produced burning Iso-Octane (<i>Petrol</i>) During Cycle			
	<i>m³</i>	<i>l</i>	<i>Gallons</i>
<i>Propane</i>	0.0043	4.2668	1.1272
<i>Methanol</i>	0.0062	6.1788	1.6323
<i>Ethanol</i>	0.0046	4.6084	1.2174
<i>Hydrogen (Liquid)</i>	0.0114	11.4423	3.0227

Table 17 Volume of Alternative Fuel

Next, the volume of alternative fuel required to replicate the energy produced burning Iso-Octane during the cycle was calculated, table 18. Finally, table 19 shows the distance that could be travelled using the alternative fuels in the same vehicle if it were to produce the same energy produced by Iso-Octane during the cycle, for this the assumption was made to keep the fuel economy as 50mpg, even though this will yield unrealistic results due to different Air:Fuel Ratios', meaning more or less fuel may be used etc. This, then questions the validity of the results so they were not used any further within the study.

Distance that could be travelled from the same energy produced by Iso-Octane (<i>Petrol</i>) during the cycle, assuming the same fuel efficiency of 50mpg			
	<i>Miles</i>	<i>km</i>	
<i>Propane</i>	56.3580	90.6992	
<i>Methanol</i>	81.6130	131.3431	
<i>Ethanol</i>	60.8702	97.9608	
<i>Hydrogen (Liquid)</i>	151.1368	243.2305	

Table 18 Distance That Could be Travelled

12 Kinetic Energy Recovery Systems Study (Volvo V40)

KERS is an automotive system designed to recover a vehicles kinetic energy under braking, the recovered energy is then stored in a reservoir for later use under acceleration. The Volvo S60 is a hybrid vehicle which uncongenially does not rely on batteries to store its electrical energy, instead a flywheel is mounted to the rear axle using regenerative braking to capture otherwise wasted energy. (Burn, 2014)

FLYWHEEL KERS FLYWHEEL MODULE

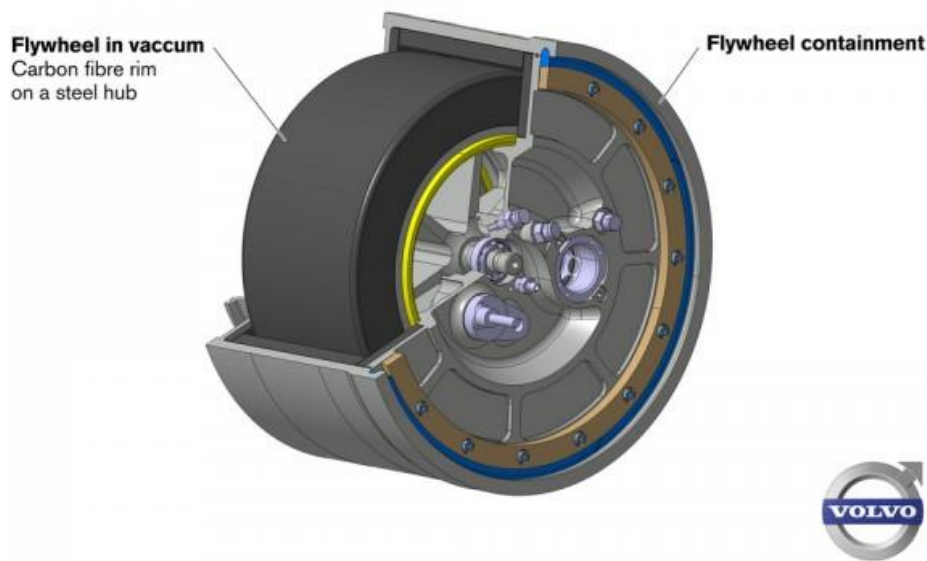


Figure 6 Flywheel KERS (Bill Howard, 2013)

The flywheel can spin rev up to 60,000 RPM and is meant to increase fuel economy by 25% table 20 below shows the Flywheel specifications

KERS Flywheel Specifications		
Mass	6	kg
RPM	60,000	
Angular Velocity	6283.19	Rads
Outer Radius	0.10	m
Inner Radius	0.08	m
Moment of Inertia	0.01	kg.m ²
Kinetic Energy	259.08	kJ
Efficiency	70%	
vehicle 0-60mph	5.50	s
Flywheel Power	32.97	kW

Table 19 KERS Flywheel Specifications

Most of the information was found through research (Bill Howard, 2013). To calculate the flywheel power, moment of inertia and they kinetic energy that can be stored the following three equations were used.

$$J = \frac{1}{2} \times m \times (r_1^2 - r_2^2)$$

Equation 31 Flywheel Moment of Inertia (Boretti, 2010)

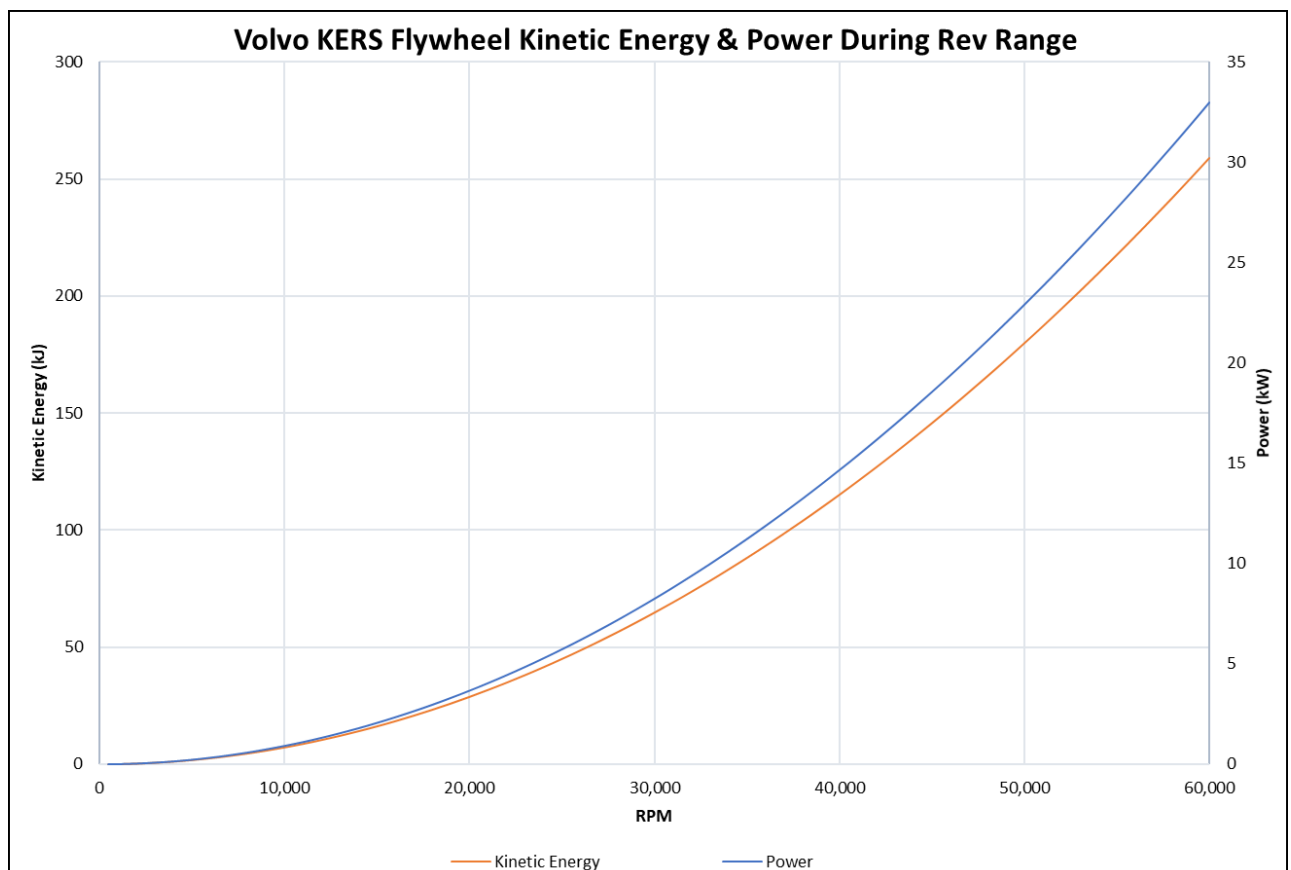
$$E_k = \frac{1}{2} \times J \times \omega^2$$

Equation 32 Kinetic Energy of Flywheel (Moro, 2010)

$$Power = \frac{Joules}{Second}$$

Equation 33 Power

Graph 15 Shows the Kinetic Energy and Power of the KERS flywheel throughout its available rev range, both follow the same trend and seem to follow an exponential pattern.

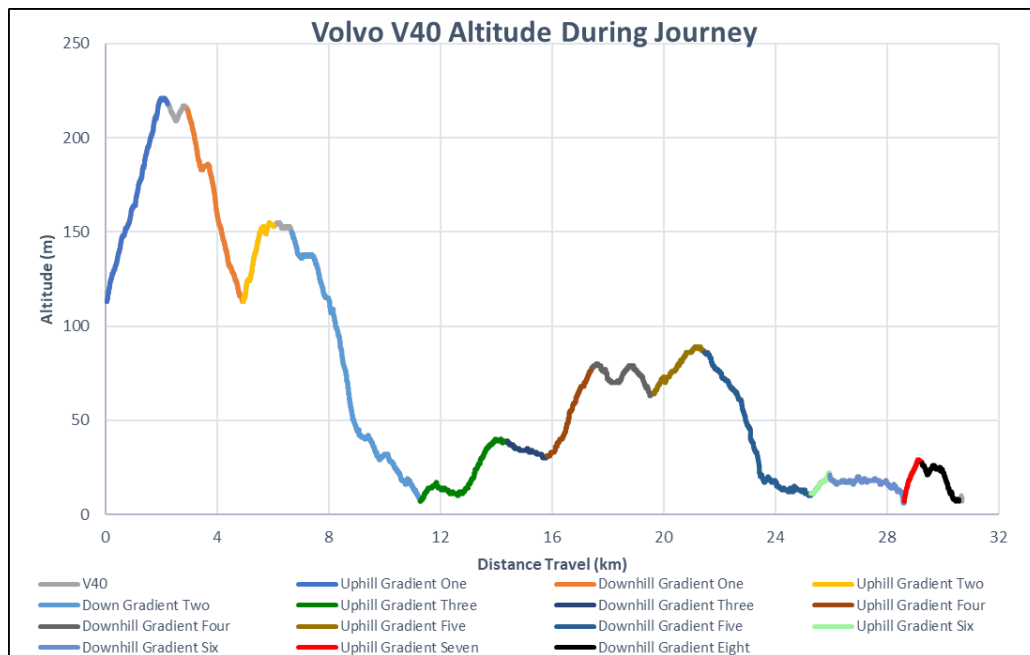


Graph 14 Volvo KERS Flywheel Kinetic Energy & Power During its Rev Range

In order to attempt to apply the KERS technology to the V40, the altitude throughout the drive cycle was analysed and split into 14 sections;

- 7 Uphill Gradients
- 7 Downhill Gradients

As can be seen in graph 16 below.



Graph 15 Volvo V40 Altitude During Journey

As previously stated KERS works by a method of utilising the kinetic energy which would be otherwise wasted during braking. An assumption was made that if the deceleration of the vehicle throughout the cycle was less than -1 then the vehicle was braking. With the use of the filter tool within Excel the data was sorted to only display data points where the Volvo was decelerating at less than or equal to m/s^2 .

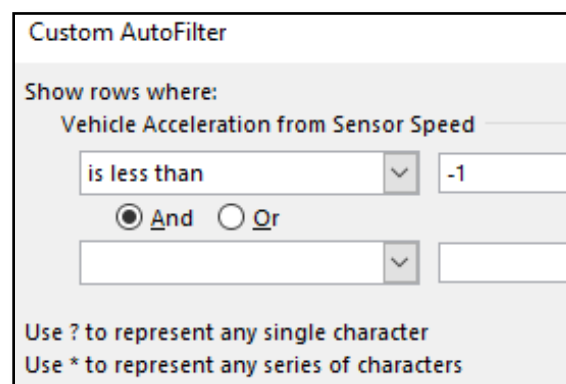


Figure 7 Custom AutoFilter

	Max Kinetic Energy During Braking	Total Kinetic Energy During Braking
	kJ	
Uphill Gradient One	150.2378	1004.6785
Downhill Gradient One	124.8696	1547.4017
Uphill Gradient Two	143.4786	896.9949
Downhill Gradient Two	447.3466	4899.0650
Uphill Gradient Three	146.6688	399.1628
Uphill Gradient Four	632.7554	632.7554
Uphill Gradient Five	558.9379	558.9379
Downhill Gradient Five	447.9388	4905.7450
Uphill Gradient Six	340.1673	2775.4828
Downhill Gradient Six	256.7289	3050.3691
Downhill Gradient Seven	177.8774	1728.0026

Table 20 Max Kinetic Energy During Braking & Total Kinetic Energy During Braking

Next, table 22 was able to be created from the filtered data, showing the maximum kinetic energy being generated by the vehicle during each gradient and the total Kinetic Energy being generated during braking. Finally, if this study was to be repeated further work would consist of calculating how much of this Energy could be utilised within the KERS system.

	Total Time	Time Spent Braking	Amount of Time Spent Braking
	s		Percentage
Uphill Gradient One	184.1270	8.6830	4.72%
Downhill Gradient One	210.2850	16.7130	7.95%
Uphill Gradient Two	100.6710	7.4210	7.37%
Downhill Gradient Two	292.2660	21.3290	7.30%
Uphill Gradient Three	125.8910	3.0510	2.42%
Uphill Gradient Four	54.7920	1.0000	1.83%
Uphill Gradient Five	74.1030	1.0000	1.35%
Downhill Gradient Five	221.0250	18.2880	8.27%
Uphill Gradient Six	86.0990	9.1370	10.61%
Downhill Gradient Six	108.0660	10.4640	9.68%
Downhill Gradient Seven	103.0210	10.0440	9.75%

Table 21 Total Time, Time Spent Braking & Amount of Time Spent Braking,

13 Hydrogen Fuel Cell Powered Vehicle Proposal

In 2003 George Bush, President of the U.S at the time said, “*the first car driven by a child born today could be powered by hydrogen, and pollution free*”. (MIT Technology Review, 2003). That was 17 years ago, and even though the reality of most of the population driving in a hydrogen powered vehicle now seems a bit far-fetched, he wasn’t completely wrong. Hydrogen fuel cell technology is an area of the automotive industry that is rapidly increasing and more and more manufactures such as “Honda,

BMW, Mercedes & Audi have all confirmed that they are working on fuel cell cars, with new models expected to come along in the next couple of years". (Next Greencar , 2020)

A Fuel cell is a device that generates electrical power through a chemical reaction by converting hydrogen into electricity.

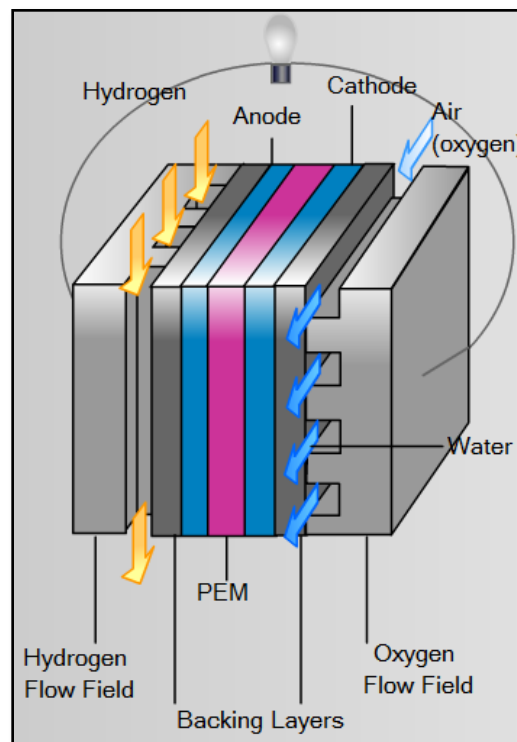


Figure 8 Hydrogen Fuel Cell (Hydrogenics , n.d.)

Pressurized hydrogen gas entering with the fuel cell on the anode side, this gas is then forced through a catalyst by the pressure. When a hydrogen molecule meets the catalyst it splits into two H^+ ions and two electrons. The electrons are conducted through the anode and make way through the external circuit and return to the cathode side of the fuel cell (Hydrogenics , n.d.).

A Huge advantage of a hydrogen fuel cells is its efficiency, an ICE on average uses less than 20% of the chemical energy generated by petrol making it rather inefficient. Whereas, on the contrary a fuel cell utilizes around 60% of the available energy within hydrogen which is monumentally more efficient (Lampton, n.d.). Furthermore, hydrogen produces absolutely no carbon dioxide emissions when an ICE burns fuels derived from the element of carbon producing several by-products, primarily carbon dioxide.

Furthermore, refuelling with Hydrogen takes the same amount of time as refuelling an ICE powered vehicle, as opposed to an electric vehicle, also the range of a fuel cell is generally greater than the average electric car, so there is no “Range anxiety with a fuel Cell.” (AutoTrader, n.d.).

“Hold on? Didn’t Hydrogen cause the 1937 Hindenburg Disaster?” There are numerous theories around what caused the Hindenburg disaster and most of them suggest there was a secondary source of ignition for the “leaky Hydrogen”. Hydrogen, in a lot of cases is safer than the petrol or diesel used to power an ICE, carbon based fuels spread as liquids and when burnt produces hot ash creating heat, but when Hydrogen burns there is no carbon or hot ashes and very little radiant heat is produced “What’s more, when hydrogen leaks, it ascends rapidly into the atmosphere, so it has less time to burn”. (Clark, n.d.).

Currently, Hydrogen fuel cell powered vehicles are not a completely viable option as the UK does not have enough filling stations, meaning they are too expensive to run. However by 2028, it is realistic to believe that the infrastructure will be in place and the technology will be more widely available at a reasonable price, making it a truly sustainable and feasible alternative to fossil fuel powered vehicles.

14 References

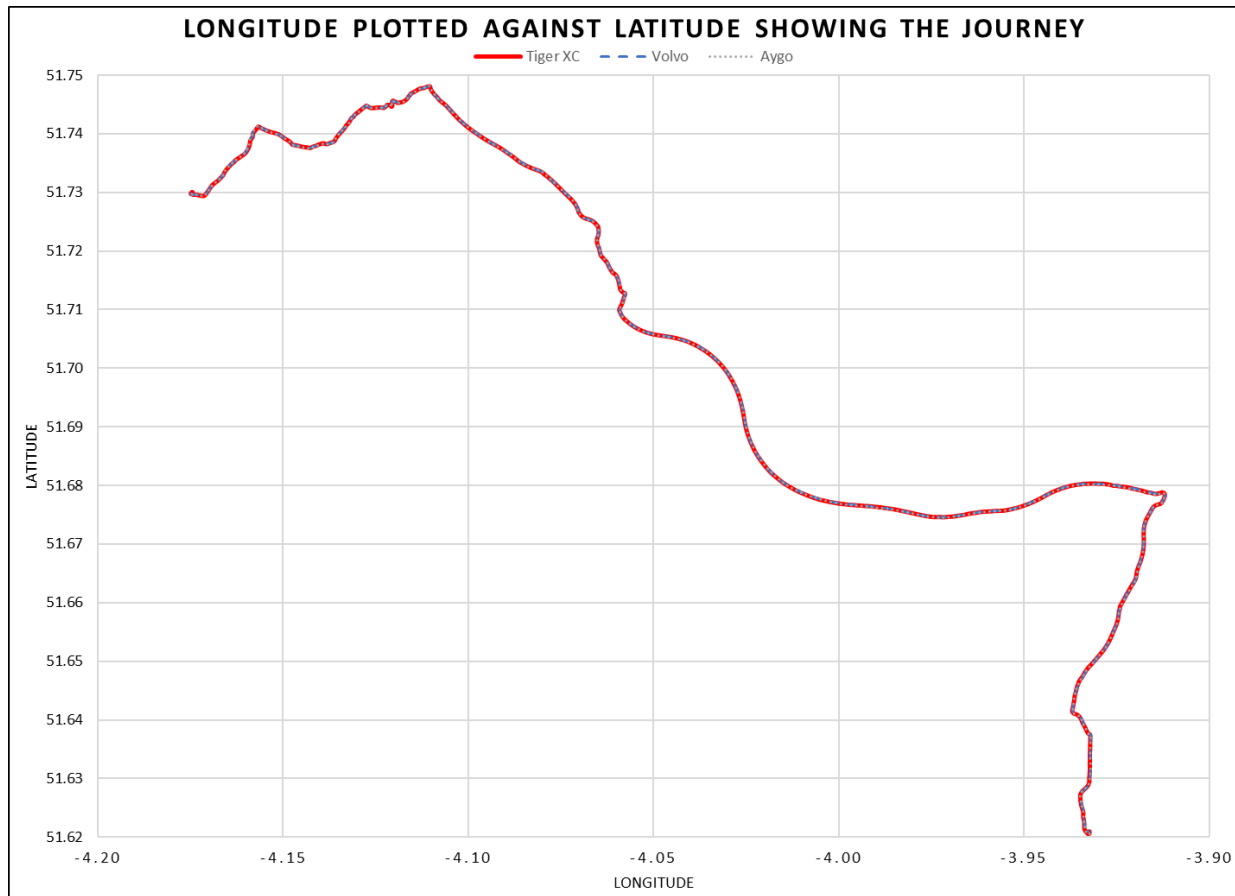
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15 Appendix

15.1 Longitude



Graph 16 Longitude Plotted Against Latitude Showing the Journey (Without Map)

15.2 Alternative Fuels

Atmospheric Composition Ratio
3.76

Molecular Weight		
Air	137.28	kg/kmol
Carbon	12	kg/kmol
Hydrogen	1	kg/kmol
Oxygen	16	kg/kmol
Nitrogen	14	kg/kmol

Fuel Type		Molecules			CO ₂	H ₂ O	N ₂	x	Air Mass	Fuel Mass	Mass of CO ₂
		Carbon	Hydrogen	Oxygen	(n1)	(n2)	(n3)		kg	kg	kg/kmol
Iso-Octane (petrol)	C ₈ H ₁₈	8.00	18.00	0.00	8.00	9.00	47.00	12.50	1716.00	114.00	352.00
Iso-Decane (Diesel)	C ₁₀ H ₂₂	10.00	22.00	0.00	10.00	11.00	58.28	15.50	2127.84	142.00	440.00
Propane	C ₃ H ₈	3.00	8.00	0.00	3.00	4.00	18.80	5.00	686.40	44.00	132.00
Methanol	CH ₄ O	1.00	4.00	1.00	1.00	2.00	5.64	1.50	205.92	32.00	44.00
Ethanol	C ₂ H ₆ O	2.00	6.00	1.00	2.00	3.00	11.28	3.00	411.84	46.00	88.00
Hydrogen (Liquid)	H ₂	0.00	2.00	0.00	0.00	1.00	1.88	0.50	68.64	2.00	0.00

15.3 Iso-Octane (Petrol) & Methanol Fuel Blending

Fuel Type		Molecules			CO ₂	H ₂ O	N ₂	x	Air Mass	Fuel Mass	Mass of CO ₂	ΔH°
		Carbon	Hydrogen	Oxygen	(n1)	(n2)	(n3)		kg	kg	kg/kmol	kJ/mol
Iso-Octane (petrol)	C ₈ H ₁₈	8.00	18.00	0.00	8.00	9.00	47.00	12.50	1716.00	114.00	352.00	259.20
Methanol	CH ₄ O	1.00	4.00	1.00	1.00	2.00	5.64	1.50	205.92	32.00	44.00	201.50

Chemical Blend				Molecules			CO ₂	H ₂ O	N ₂	x	Air Mass	Fuel Mass	Mass of CO ₂	ΔH°	h	Net enthalpy	LHV Valorific Value
Iso-Octane	Methanol	Ratio		Carbon	Hydrogen	Oxygen	(n1)	(n2)	(n3)		kg	kg	kg/kmol	kJ/mol	kJ	kJ	kJ/kg
10:90	1	9	1/9	1.70	5.40	0.90	1.70	2.70	9.78	2.60	356.93	40.20	74.80	207.27	1321.81	1114.54	27.72
20:80	2	8	1/4	2.40	6.80	0.80	2.40	3.40	13.91	3.70	507.94	48.40	105.60	213.04	1766.52	1553.48	32.10
30:70	3	7	3/7	3.10	8.20	0.70	3.10	4.10	18.05	4.80	658.94	56.60	136.40	218.81	2211.23	1992.42	35.20
40:60	4	6	2/3	3.33	8.67	0.67	3.33	4.33	19.43	5.17	709.28	59.33	146.67	220.73	2359.47	2138.73	36.05
50:50	5	5	1	9.00	22.00	1.00	9.00	11.00	52.64	14.00	1921.92	146.00	396.00	460.70	6201.30	5740.60	39.32
60:40	6	4	1 1/2	5.67	13.33	0.33	5.67	6.67	33.21	8.83	1212.64	86.67	249.33	239.97	3841.83	3601.87	41.56
70:30	7	3	2 1/3	5.90	13.80	0.30	5.90	6.90	34.59	9.20	1262.98	89.40	259.60	241.89	3990.07	3748.18	41.93
80:20	8	2	4	6.60	15.20	0.20	6.60	7.60	38.73	10.30	1413.98	97.60	290.40	247.66	4434.78	4187.12	42.90
90:10	9	1	9	7.30	16.60	0.10	7.30	8.30	42.86	11.40	1564.99	105.80	321.20	253.43	4879.49	4626.06	43.72

Toyota Aygo	
CO ₂ Produced Across Cycle	
Ratio	kg
10:90	6.6057
20:80	6.6907
30:70	6.7383
40:60	6.7498
50:50	6.7897
60:40	6.8135
70:30	6.8171
80:20	6.8265
90:10	6.8341

Triumph 800 XC	
CO ₂ Produced Across Cycle	
Ratio	kg
10:90	6.6057
20:80	6.6907
30:70	6.7383
40:60	6.7498
50:50	6.7897
60:40	6.8135
70:30	6.8171
80:20	6.8265
90:10	6.8341

