University of Wales Trinity Saint David

What is The Future for Vehicle Emissions?

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Abstract

The future for the automotive industry is quickly changing, which is aiming to replace the internal combustion engine with a more environmentally friendly alternative by 2035, such as a fully electric vehicle or a hybrid vehicle to lower the emissions by 2050. This report aims to understand more about the internal combustion engine, whether it has a future in the automotive industry, and whether the manufacturers are taking the right approach.

Workshop testing was carried out on two different cars using similar engines of different capacities, a 1.0L EcoBoost engine, and a 1.5L EcoBoost engine. This test was used to gather data about the emissions output from each engine, being run on a rolling road system to simulate as if it were running on a road. The accuracy of this test was improved by adding a calculated resistive force to the rolling road, acting as a rolling resistance similar to that of a road surface.

This testing provided the data to show that these engines can produce low emissions when running at the optimal operating temperature, however, a large amount of Nitrogen Oxide (NOx) was being produced by these engines under load. This gas can potentially be dangerous to our health at a high quantity, so it's beneficial not to run this engine for long periods around pedestrians.

An online survey was also constructed to find the daily contribution of emissions from 51 different people. As expected, all of the participants have access to a vehicle and the majority would drive this vehicle every day. However, there are some participants who would be willing to use public transport if it became cheaper and more reliable, which would benefit the environment with less vehicles being used daily.

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1. Introduction

The automotive legislation today is becoming increasingly stricter on the amount of emissions allowed to be released by a vehicle, this has caused most of the vehicle manufacturers to look for alternative solutions to meet these regulations.

In the past few years, due to the emissions regulations becoming so strict, we are seeing an increasing number of electric vehicles and hybrid vehicles on the road. These electric and hybrid vehicles are quickly becoming the focus points for manufacturers, for them to replace the internal combustion engine looking into the future. With the government planning to eventually stop the sales of internal combustion engines, this will help to reduce the quantity of carbon being released into the atmosphere and therefore lower the effects of global warming. Appendix A explains this in more detail.

There have also been other methods introduced with the intentions to help reduce the emissions being produced by vehicles. One of these methods include motorway speed zones to reduce the emissions, this is by slowing down the vehicles in those areas to reduce the amount of fuel being burnt (Gaffigan, M. 2008). Appendix B explains this in more detail.

In many countries there have been pedestrian-only zones introduced, meaning that any non-electrical vehicles aren't allowed through these areas. This is beneficial for lowering the amount of pollution released into these areas by vehicles, where these areas instead create more space for pedestrians and some of the road can be replaced by bike lanes. Although some vehicles may travel on these roads, such as vehicles owned by locals, zero-emissions delivery vehicles, taxis, and public transit like buses. (Garfield, L. 2018). This is discussed in section 2.6 of the literature review.

1.1. Aims and Objectives

The aims and objectives for this report are a continuation of the previous aims discussed in the seminar paper, where the outcome of each will be discussed in this paper. Since those aims were listed, there has been research and testing completed to gather the required information. The research was completed with the use of relevant and credible sources, such as online sources and literature. The testing was completed with the help and supervision of the university workshop technicians, whilst following all of the health and safety procedures.

1.1.1. Project Aims

- Investigate the real-world problems revolving around the vehicle emissions produced, and the methods implemented in order to reduce this output. Research will Include the impact both environmentally and to our personal health, the amount of harmful gases produced, and the impact these gases have on our personal health.

- Research the euro emissions standards (Euro 5 and 6) to discover the differences between each and discuss the standard for Euro 7 being released in the near future.

- Provide any reasons for the implementation of a permanent speed zone in certain areas, and whether the speed zones make a difference to the air pollution.

- Conduct a series of tests on a vehicle via a rolling road to gather data on the emissions output, then compare it to a similar vehicle with a different engine capacity to develop an understanding of the benefits or disadvantages with engine downsizing.
- To conduct an online survey to gather data from different drivers about their daily contribution of emissions, this will provide a general view of the journey frequencies and durations

2. Literature Review

A popular problem with emissions is the fact there are so many variables to affect the output of a vehicle's emissions, before a vehicle can be sold it must be tested in accordance with the New European Driving Cycle (NEDC) discussed further in section 2.1.4. A governing body will assess these tests in order to confirm that the vehicle follows all regulations and guidelines to be suitable for road driving, because before any vehicle is allowed on public roads it first needs to comply with all of the guidelines given by the Euro Emissions Standards.

Usually a clear sign that a vehicle isn't filtering the harmful gases efficiently would be smoke coming from the exhaust. There can be white smoke, which is usually harmless, often caused by condensation in colder conditions. whereas blue or black smoke could indicate an issue, such as blue smoke indicating there may be oil combusting with the air and fuel mixture and the black smoke may be indicating an overly rich fuel and air mixture, therefore it's not efficiently combusting the mixture and the unburnt fuel will escape through the exhaust pipe. Figure 1 below shows the smoke you may see from an exhaust pipe.

Figure 1 – Harmless Exhaust Smoke (Smith, L. 2017)

These Euro Emissions Standards will vary on the year of production for the given vehicle, in which these standards get stricter each step by lowering the maximum values allowed from the engine as the standards increase. For example, Euro 6 standards have a stricter emissions limit than the Euro 5 standards, whereas Euro 7 standards, to be released in the near future, will have a stricter emissions limit than the Euro 6 standards.

Each increase in the Euro Emissions Standards, will decrease the maximum values for emissions that can be produced by an engine. These constantly lowering values required for the emissions standards have started causing many difficulties within the manufacturing process of a vehicle, this is due to the restrictions becoming increasingly difficult to follow, therefore causing some manufacturers to start resorting to a number of different production methods in order to follow these restrictions.

"Of the total global CO2 emissions, the transportation sector contributes to about 14%. In order to control the emissions of the automotive sector, in all major countries (USA, Europe, China, Japan) of the world, tough emissions targets were being set to reduce the vehicle traffic's contribution of CO2" (Hannappel, R. 2017). Appendix A explains this in further detail.

2.1. Euro Emissions Regulations

What are these regulations? “The regulations, which are designed to become more stringent over time, define acceptable limits for exhaust emissions of new light duty vehicles sold in EU and EEA (European Economic Area) member states.” (RAC.2020)

Each updated set of Euro standards will introduce a stricter limit on the maximum values for each vehicle emissions output, as discussed briefly in Section 2. These regulations will provide a maximum value for each vehicle type and class, this will include Petrol vehicles, Diesel vehicles and light trucks etc. The limits for each produced emission will differ between the vehicle classes, for example, a diesel car will produce more Particulate matter (PM) than the petrol equivalent so this will be more lenient (RAC. 2020). However, a petrol car will produce more Carbon Monoxide (CO) than the diesel equivalent so this will be more lenient. Figure 2 below shows the smoke produced from a diesel vehicle that isn’t filtering the gases efficiently, this can be due to a fault or blockage in the filtering system, such as a particulate filter blockage. Figure 2 below shows the black smoke released from unburnt fuel.

Figure 2 – Harmful Exhaust Smoke (RAC. 2018)

“*The aim of Euro emissions standards is to reduce the levels of harmful exhaust emissions, chiefly:*

Nitrogen oxides (NOx)

Carbon monoxide (CO)

Hydrocarbons (HC)

*Particulate matter (PM)****”***

(RAC. 2020)

Although the Nitrogen oxides (NOx) have been reduced in previous years, the EU has announced that the levels haven’t reduced as much as expected. This is apparently due to the ‘real-world’ driving conditions being higher than when the vehicle is tested (RAC. 2020), meaning the results through testing don’t always produce the same values that the customer would achieve whilst driving the vehicle on the road. Because of this, there had to be an introduction of a more realistic testing method. Therefore, a new testing device was developed to attach onto the rear of the vehicle, which this device is able to measure the emissions produced whilst driving the vehicle on a road.

Figure 3 below shows the device fitted to the rear of a vehicle when the emissions produced are being tested through a road test.

Figure 3 – Road Emissions Tester (Buyacar. 2019)

This machine helps to prevent or minimise any software changes from the manufacturers to reduce emissions under test conditions, they manage this by adjusting the vehicle mapping if it detects certain changes. For example, if the bonnet is opened whilst the engine is running then it would assume that it's being tested. Then from this data, it would use the Electronic Control Unit (ECU) to adjust the engine timings to produce the lowest possible emissions values to pass the test.

The adjustments made by the ECU include advancing or retarding the ignition timing to provide a more efficient combustion of the air and fuel mixture, shortening or extending the valve timing to open/close the valves earlier or remain open for longer periods, and adjusting the air to fuel ratio entering the cylinder to produce lower levels of harmful emissions.

A few manufacturers have been caught using this method, such as Volkswagen. Two different vehicles from Volkswagen were tested for emissions on a road test, a Jetta and a Passat. During a road test of both vehicles, the testers were shocked to find that the values were around 5 times higher than what is should be producing, climbing up to around 30-35 times under certain conditions (Gardiner, B. 2019). Appendix D explains this in more detail.

2.1.1. Euro 5 Regulations (January 2011 – September 2015)

The Euro 5 regulations came with a new limit to reduce the harmful particulates in diesel vehicles resulting in the introduction of the particulate filters (DPFs) for diesel vehicles, with the other emission limits being lowered alongside this. The instalment of a particulate filter on diesel vehicles is capable of capturing 99% of the overall particulates being produced, resulting in the particulates released from the vehicle being equivalent to one grain of sand per kilometre the vehicle drives (RAC. 2020).

The reasoning behind this focus on reducing the diesel particulates comes from research and testing which has found that these particulates can cause respiratory problems, especially individuals with respiratory conditions such as asthma. (Dieselnet. 2012)

The Euro 5 regulations brought the limit of particulates down by 80% from the previous Euro 4 regulations, dropping this limit from 0.025g/km in the Euro 4 regulations, down to just 0.005g/km. This is shown in Appendix E.

2.1.2. Euro 6 Regulations (September 2015 to Present)

The Euro 6 regulations had found that Nitrogen Oxide (NOx) gases can cause respiratory difficulties, similarly to the diesel particulates that were reduced in the Euro 5 regulations.

Because of this factor, a method of reducing the NOx had to be implemented. This was achievable by introducing Selective Catalytic Reduction (SCR) or an Exhaust Gas Recirculation system (EGR), altogether helping to reduce the NOx gases from a limit of 0.18g/km down to 0.08g/km.

The euro emissions regulations have come a long way to lower the vehicle emissions to the levels being produced by current vehicles on the road. Below shows data taken in 2017, representing the difference in the current emissions compared against where they were when the European emissions regulations came into effect in 1992 (Frost & Sullivan. 2016):

"These standards are having a positive effect, with the SMMT (Society of Motor Manufacturers and Traders), claiming: "It would take 50 new cars today to produce the same amount of pollutant emissions as one vehicle built in the 1970s

In 2017, the SMMT quoted the following figures in support:

Carbon monoxide (CO): petrol down 63%, diesel down 82% since 1993

Hydrocarbons (HC): petrol down 50% since 2001

Nitrogen oxide (NOx): down 84% since 2001

Particulate matter (PM): diesel down 96% since 1993" (RAC. 2020)

2.1.3. Euro 7 Regulations (Soon to be Implemented)

The Euro 7 regulations will develop stricter emissions standards than Euro 6 regulations for all vehicle classes including petrol and diesel cars, vans, lorries and buses. This will be part of the 'European Green Deal' to make the EU's economy more sustainable and cut pollution, hoping to not produce any net emissions of greenhouse gases by 2050.

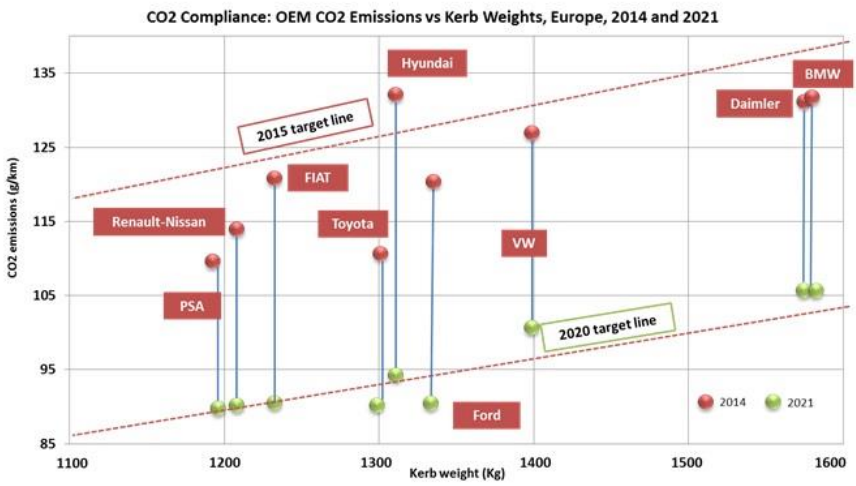
"To ensure vehicles on EU roads are clean over their lifetime, the proposed rules will consider new vehicle technologies and ensure emissions are measured in real-time". (Commission, EU. 2020).

The aims for Euro 7 regulations include lowering the limit of Carbon Dioxide (CO2), dropping from the Euro 6 values of 130gm/km down to 95gm/km. however, the emissions limits are based on the vehicle mass, using a limit value curve as shown below in figure 4.

Where some manufacturers are believed to meet these targets such as Renault, Nissan and Toyota, it may cause other manufacturers such as BMW to produce more ultra-low emission vehicles. But they may also need to downsize their engines and possibly move to a hybrid system or a fully electric system in order meet these targets.

The Euro 7 CO2 target will have a one year 'phase-in' period, where 95% of the manufacturers will need to be compliant with the regulations by 2020, then by 2021 every manufacturer will need to be compliant.

Figure 4 – Vehicle Limit Graph (Frost & Sullivan. 2016)



For any manufacturers that are unable to meet the 2020/2021 targets will be charged an excess premium of €95 per every gram of CO2 over the limit, raising the sale price of vehicles from the manufacturers struggling with these limits who will have to pay this premium. According to (Frost & Sullivan. 2016) the German OEMs are expected to pay over 1.5 to 2 billion euros as a fine due to existing technology roadmaps and the relative distance to their 2020 targets.

"All 3 German OEMs analysed by Frost & Sullivan will not be compliant in 2022 and, on average, will exceed their target by 3 to 5 gm/km in 2020/2021, while all Asian OEMs will comply with their targets by 2020 and average 2 to 3 gm/km of CO2 below their respective targets". (Frost & Sullivan. 2016)

2.1.4. New European Drive Cycle (NEDC)

When a vehicle is being tested for its' emissions, it will complete a drive cycle where it will experience periods of constant acceleration, deceleration and speed (Barlow, Latham, McCrae, Boulter. T, S, I, P. 2009). These changes are meant to simulate a vehicle driving on a road, therefore achieving a more realistic output of emissions compared to just using a steady speed. Figure 5 below compares three different drive cycles, with distances, times and speeds.

Figure 5 – European Drive Cycles Table (Dieselnet. 2020)

Characteristics	Unit	ECE 15	EUDC	NEDC†
Distance	km	0.9941	6.9549	10.9314
Total time	s	195	400	1180
Idle (standing) time	s	57	39	267
Average speed (incl. stops)	km/h	18.35	62.59	33.35
Average driving speed (excl. stops)	km/h	25.93	69.36	43.10
Maximum speed	km/h	50	120	120
Average acceleration[1]	m/s^2	0.599	0.354	0.506
Maximum acceleration[1]	m/s^2	1.042	0.833	1.042

† Four repetitions of ECE 15 followed by one EUDC
[1] Calculated using central difference method

The drive cycle frequently used is the New European Drive Cycle (NEDC). Figure 5 shows that the NEDC drive cycle is much longer than the EUDC cycle, but it's completed at a lower speed and is left to idle for a much longer period of time. This drive cycle became effective in

year 2000, and eliminated the idling time allowed in the previous Urban Cycle (ECE) and Extra Urban Drive Cycle (EUDC), instead the emission sampling starts at the same time the engine starts.

Figure 6 – Example Graph of NEDC Cycles (Barlow, Latham, McCrae, Boulter. T, S, I, P. 2009)

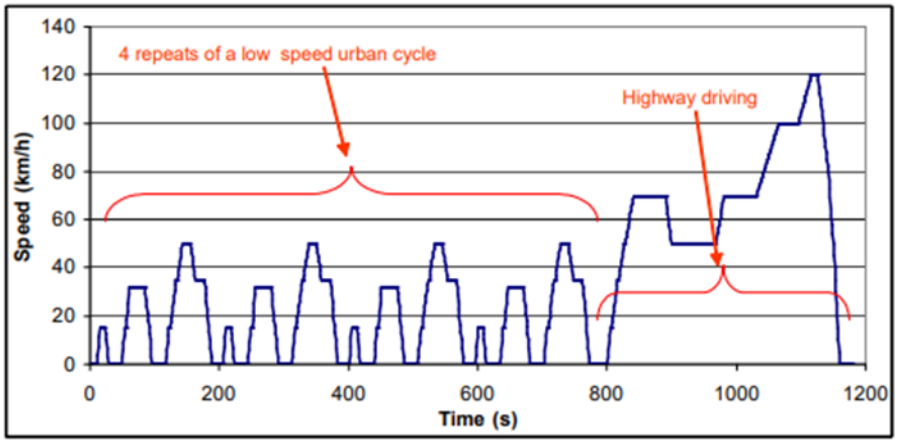


Figure 6 above shows an example of an NEDC drive cycle, indicating the different speed sections. There will be a section at a lower speed to simulate the vehicle driving around a city, followed by a higher speed section to simulate the vehicle driving on a motorway.

2.2. Methods to Lower Vehicle Emissions

Such manufacturing methods can include engine downsizing to help reduce the emissions or some manufacturers will try to adjust the emission values during the certain tests as discovered in the past. This is achieved by allowing the vehicle to detect any test conditions, such as when the engine is running with the bonnet open, then the ECU would notice that the bonnet is open and switch to a different engine map to lower the emissions due to the possibility of it undergoing an emissions test, which will then be reverted back to the old engine map with increased emissions after the test had taken place.

Manufacturers such as Volkswagen and BMW have been discovered using this method in the past, which has resorted in extra tests coming into place to avoid this happening again in the future. A new test being implemented would include a live road test where the vehicle is driven in realistic conditions on a road.

There can also be the introduction of currently developed technology such as and EGR system (Exhaust Gas Recirculation), this is where the exhaust gases are recirculated through the engine to reduce the amount of NOx produced. However, this can cause some of the other exhaust gases to increase by a small amount, but still beneficial when introduced to the system compared to the higher amounts of NOx. Another method of reducing the emissions will include the addition of an additive into either the fuel or exhaust system, containing urea which when added to the exhaust gases it helps to convert some of the harmful gases in the system into less harmful gases. This additive can be inserted into the fuel tank when refilling to mix with the fuel.

Another method to lower emissions can be weight reduction, this reduces the stress on the engine or possibly result on a smaller capacity engine. majority of manufacturers are trying to lighten their powertrains, and this is because a 100kg weight reduction can reduce the CO2 emissions by around 8.5grams per 100km (Frost & Sullivan. 2016). This has resulted in most manufacturers taking the route of engine downsizing and electrifying their powertrain in order to reduce the overall weight of the vehicle.

2.2.1. Catalytic Converters

The catalytic converter is a part of the exhaust system, this assists in breaking down harmful compounds passing through the exhaust. It uses catalyst substances to clean up harmful gases from the engine according to (RAC. 2018), but because it works more efficiently when it's hot they're usually placed close to the engine so it can warm up quicker.

"Inside its metal casing there are usually two ceramic blocks made up of thousands of micro cellular channels – which resemble a honeycomb. The surfaces of these ceramic blocks are coated with precious metals such as platinum, palladium and rhodium. Because they're located close to the engine, they heat up and cause the chemical reaction that breaks down the toxic gases and converts them into carbon dioxide and water vapour before being emitted into the atmosphere". (RAC. 2018)

A catalytic converter would often last around 10 years or between 70,000 to 100,000 miles, although if the car is only used for short journeys then this can cause problems due to it not reaching the optimum operating temperature. This means that any built-up carbon deposits inside won't be burnt off, eventually clogging up the catalytic converter and resulting in it either needing a deep cleaning or the driver receiving an expensive bill to replace it.

Below in Figure 7, shows what the material looks like inside of a catalytic converter.

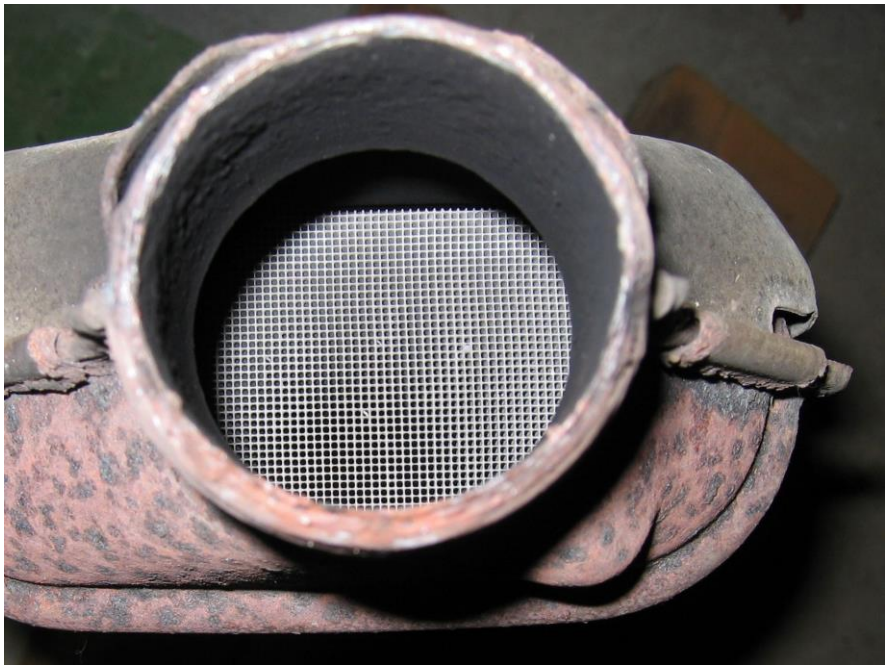


Figure 7 – Catalytic Converter Internal (Jerew, B. 2019)

Appendix F shows a diagram of a catalytic converter in more detail.

2.2.2. Exhaust Gas Recirculation (EGR)

The exhaust gas recirculation system does exactly what the name suggests, after the air/fuel mixture is burnt and released from the cylinder into the exhaust system, a portion of this gas is sent back into the intake and mixes with the air. This causes a lower heat release and peak cylinder temperature, therefore reducing the formation of NOx.

This gas being recirculated may also pass through an EGR cooler before entering back into the intake, on a diesel engine this recirculated gas could reach up to around 50% under some operating conditions. When applied, the EGR can increase the particulates.

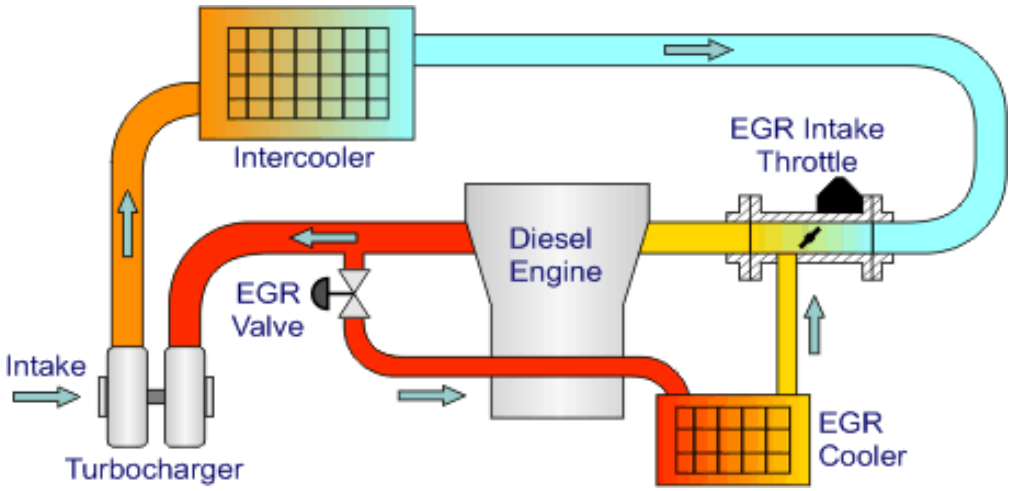


Figure 8 – EGR Diesel System (Jääskeläinen, Khair. H, M. 2019)

Appendix G shows a graph of the effects with an EGR system working.

2.2.3. Selective Catalytic Reduction (SCR)

This is also a method of converting the NOx gases into less harmful gases, namely Nitrogen, water and small amounts of Carbon Dioxide. This is possible by injecting a liquid into the exhaust system to mix with the exhaust gases, often used is automotive-grade urea, capable of reducing the levels of NOx up to 90%.

2.2.4. Diesel Particulate Filters (DPFs)

These filters are able to capture and store the exhaust soot produced by diesel vehicles, however because they don't have a large capacity, the collected soot needs to be emptied or burned off as explained by (RAC. 2018). For these filters to work efficiently, it needs to become hot enough to burn off the soot being collected, so a driver only covering short distances in a diesel vehicle will likely experience a blockage in this filter, resulting in smoke from the exhaust pipe as this soot is no longer being filtered efficiently. Figure 9 below shows the internals of a Diesel Particulate Filter (DPF).

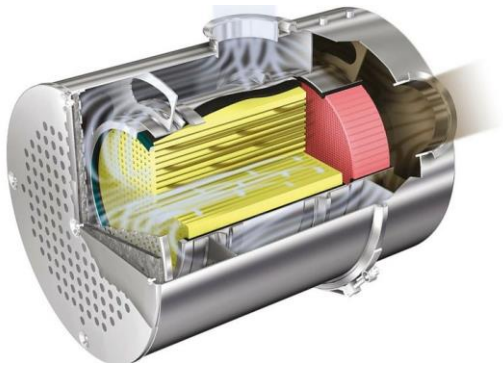


Figure 9 – Diesel Particulate Filter (DPF) (RAC. 2018)

2.3. Motorway Speed Zones and Speed Cameras

The motorway speed zones come with a lot of mixed feelings from motorists. For example, Port Talbot 50mph speed zone was put into place on July 24th 2019, with the aims of being a temporary method of reducing the amount of emissions being released from cars passing on the M4 and busy built up areas such as Port Talbot, Newport, the A470, the A483 and the A494. However, these 50mph speed zones were instead made permanent by the welsh government to tackle the high amounts of emissions they were previously struggling to improve.

A welsh government spokesman had confirmed that the Nitrogen Dioxide levels being produced by the vehicles was over the legal limits so it needed to be reduced quickly, and these speed zones was found to be the quickest method of reducing these Nitrogen Dioxide levels to within the legal limits.

Figure 10 – Speed Cameras. Dron, W (2018)

A Transport Minister, Ken Skates, stated that he hopes motorists would agree slowing down to reduce emissions is more important than saving a small amount of time driving along the road (Skates, 2019). This is due to the high amounts of air pollution reportedly having an effect on the life span of those living locally to the area.

However, many motorists believe that the speed zone has a very little effect on the air pollution around Port Talbot, or even no affect at all. This is due to the lower speeds implemented instead causing more congestion in this area, therefore increasing the amount of time spend in the area and polluting the area for a longer period.

Appendix B explains that Dutch researchers have found reducing the speed of a vehicle to 50mph would lower the transport-related CO2 emissions by 30%. (Squatriglia, C. 2010).

It also mentions that lowering the speed of a vehicle can boost fuel economy by around 10% in most cases, this is because a vehicle travelling faster will have a higher wind resistance, therefore requiring more fuel. (Gaffigan, M. 2008)

However, whilst these speed zones could potentially help to lower the emissions, they increase the journey time for a driver passing through the speed zone

2.3.1 What Was the Impact from These Being Introduced?

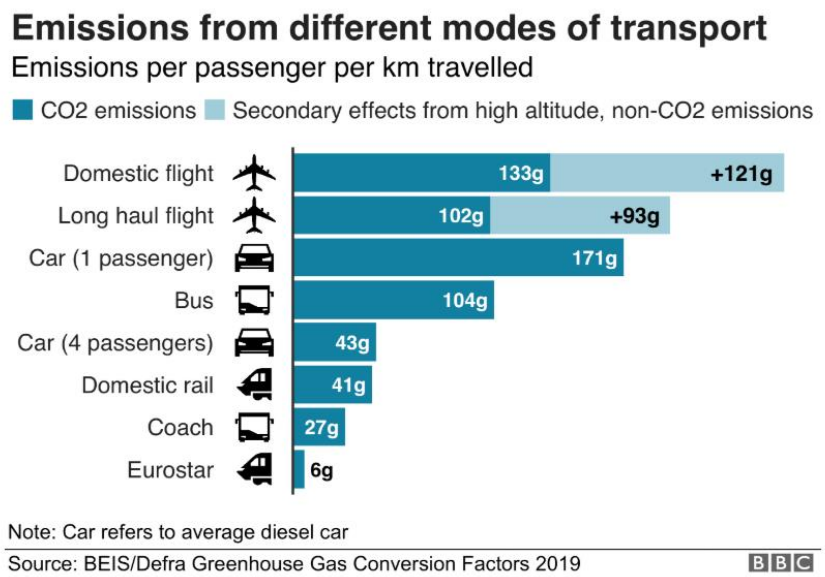
Since these average speed cameras were installed there has been a reduction in collisions, especially high severity, therefore improving the safety of the motorists on these roads. According to (Owen, Ursachi, Allsop. R, G, R. 2016) Between 2000 and June 2015, data was collected from 25 average speed cameras covering a total of 294km of road.

This data was collected by the RAC Foundation and the data explains that fatal and serious collisions had fallen by 25-46%, whilst personal injury collisions had fallen by 9-22%. As the installation cost for these cameras continue to drop, there will likely be an increase in the number of average speed camera sites. This is shown in Appendix H.

2.4. The Banning of Sales for Petrol and Diesel Cars

The reasoning behind banning the sale of petrol and diesel cars by 2040 comes from the ambitions that the UK can achieve a virtually zero carbon output in the near future, meaning that the UK wants to lower the amount of carbon it produces to reduce the impact of global warming.

Figure 11 – Transport Emissions Graph (News, BBC. 2019)



"Experts said the original target of 2040 would be too late if the UK wanted to achieve its target of emitting virtually zero carbon by 2050." (News, BBC. 2020)

The reasoning behind introducing this sale ban in 2040 is to provide a 10-year gap where any vehicles bought before this time will reach the end of its' life around 2050, therefore encouraging the motorists to trade in their vehicles for something that is carbon neutral, such as electric or hydrogen powered vehicles.

However, if properly maintained, a vehicle life span can range up to between 10 and 15 years (around 150,000 to 200,000 miles) according to (Harbid, T. 2019), therefore forcing the original deadline of 2040 to be brought forward another 5 years to accommodate this.

"The ban is being introduced in 2035 - five years earlier than previously planned." (News, BBC. 2020)

Bringing the deadline forward to 2035 will aim to have almost all previously bought vehicles off the roads and replaced with carbon neutral vehicles by the 2050 target. Therefore, by 2050 the majority of vehicles on the road should be releasing little or no carbon into the atmosphere. This will be highly beneficial to the air quality around built up areas, reducing the air pollution in cities and highly polluted countries such as China (UNHCR. 2017).

However, because hybrid vehicles (Engine and Electrical) can still produce carbon from their engines, these have also become included in the list of banned vehicles for this deadline. Therefore from 2035 onwards, there will also be no further sales of hybrid vehicles.

"The ban is also being expanded to hybrid cars and plug-in hybrids, which had not been included under the original proposals. As a result, people will be able to buy only electric or hydrogen cars and vans." (News, BBC. 2020)

2.4.1. What Impact will These Changes Have?

Removing the carbon being produced by vehicles on the road will have large benefits to the environment and the air quality of cities and highly polluted countries. The volume of greenhouse gases released into the atmosphere from vehicles will reduce, lowering the impact of global warming. *"About a third of CO2 emissions in the UK come from transport."* (News, BBC. 2020)

The earth's temperature is increasing rapidly and the continuation of this by just a few degrees can have severe consequences, resulting in more extreme weather such as flash floods and heat waves. So therefore, removing a large contributor of these greenhouse gases will help to slow the temperature increase, helping to prevent further damage to our planet.

2.5. Pedestrian-only Zones

These car-free zones will prevent any car from travelling through it, this can help to improve the air quality in cities and to provide safe circulation for pedestrians, allowing them to occupy the entire space safely. "*A pedestrian zone is simply an area where vehicles are restricted and reserved for pedestrians who are free to occupy the entire space"*. (Sisman, E. 2013)

Also mentioned is that this can cause the neighbours to become unhappy if there's no proper parking management around these zones, causing 'overspill parking'. This can be from motorists parking in nearby streets or areas not designed specifically for parking, such as alleyways.

Unfortunately, this can often involve some parking violations or creating difficulties for others, where motorists would double park, or they would park on a pedestrian path making it especially difficult for wheelchair users. If vehicles are parked in a manner that leaves insufficient space for other vehicles to pass, this will also cause problems for the emergency services or delivery services if their vehicles are not being able to pass.

2.5.1. What Benefits will These Zones Have?

The implementation of these zones can reduce the chances of road accidents, this is because there will be no cars near the pedestrians and therefore increases the safety for these pedestrians.

Children are known for walking onto the road in front of vehicles, so these zones are especially beneficial for the safety of children.

These zones can also allow for more landscaping, making the area more appealing to encourage more locals to visit. This will bring in more revenue to the area if there are shops and attractions, this is because there will be more people in the area spending money.

"The pedestrian system should enhance the public realm of the city. The pedestrian system should be designed not only to serve a transportation function, but also to provide public spaces that enhance community, interaction, economic vitality, and the image of the city. Good design should enhance the look and feel of the pedestrian environment. The pedestrian environment includes open spaces such as plazas, courtyards, and squares, as well as the building facades that give shape to the space of the street (Figure 7). Amenities such as street furniture, banners, art, plantings and special paving, along with historical elements and cultural references, should promote a sense of place." (Sisman, E. 2013)

2.6. Engine Downsizing

Automotive manufacturers are joining the movement of downsizing their engines, these range from cheaper vehicles by Ford and Volkswagen, to more expensive vehicles by Porsche and Ferrari. The method behind engine downsizing is to use a smaller capacity engine and introduce a forced induction system to it such as turbocharging or supercharging, this improved the power output of the smaller engine and increased the fuel economy.

However, these smaller turbocharged engines would provide less torque at lower speeds and have poor transient response (Lake, Keenan. T, M. 2010). This affects the speed in which the vehicle can pull away from stationary, especially when compared to a larger capacity and naturally aspirated engine of a similar peak power and torque.

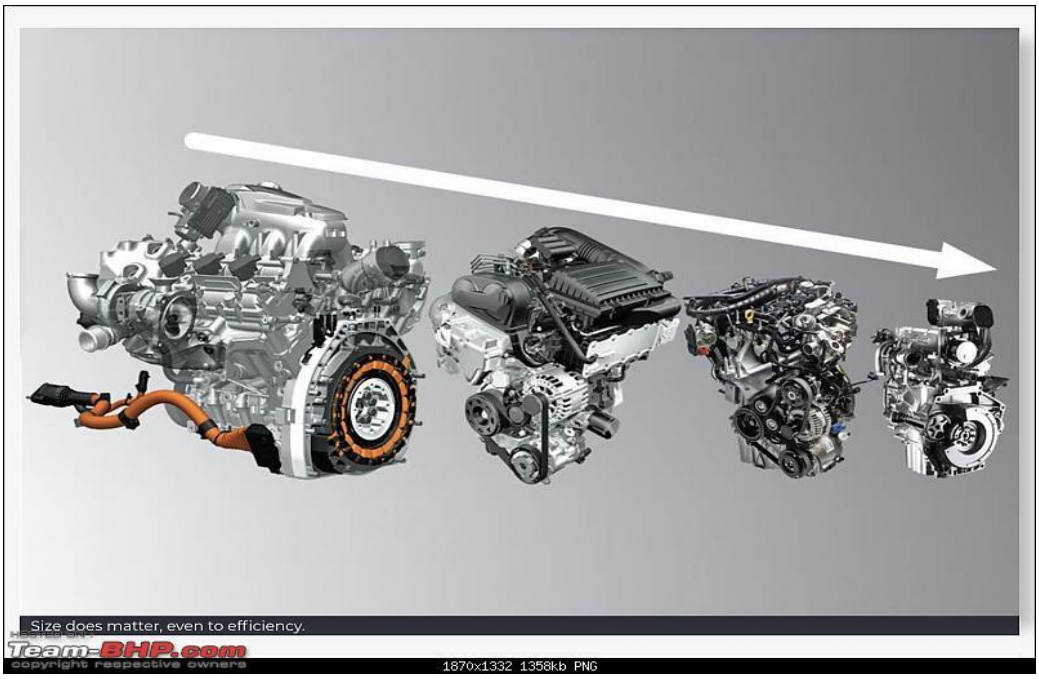


Figure 12 – Engine Downsizing (Kotwal, S. 2018)

Where a large benefit of these downsized engines is the reduced fuel consumption, these engines were also meant to reduce the emissions produced compared to an engine of similar power. However, recent tests on these downsized engines are slowly introducing higher values for the emissions than those specified, sometimes being higher than the compared engines.

Engine downsizing is achievable through the use of forced induction and higher compression. However, this increase in compression can cause the engine parts to fail easier, which is a big downside to these engines with the parts being fairly expensive. (Finley, S. 2017)

A reason for the increase in damaged parts comes from the use of low speed pre-ignition, this is where combustion can occur before the spark plug ignition time due to the increase in compression.

2.6.1. Engine Upsizing

From having the downsized engines around for a while now, they are slowly increasing in problems and this is making some manufacturers now change direction to upsize their engines, also commonly known as “rightsizing” (AS Direct. 2018). This term comes from the decision to use appropriately sized engines based on the vehicle, where a lightweight car would use a smaller engine such as a 1.0L to maybe a 1.4L as it requires less power, and a heavier car would use a larger engine such as a 2.0L to provide the essential power needed for that vehicle.

Figure 13 – Mazda SkyActive Engine (Mazda. 2020)

Mazda have become known for taking this direction instead of downsizing, instead deciding to work on the engines currently fitted to their vehicles, such as the Mazda 6 with the 2.0L SKYACTIV-G engine capable of using only 5.5 litres of fuel per 100km. Audi have also begun to follow this direction and improved the 2.0L engine in the A4 to improve the fuel economy, which despite the power of 190hp it can achieve 4.8 litres per 100km.

“Cars will have to perform largely as well in real-world driving as they do in the lab, and without some significant changes, that may well rule out the downsized engines we've seen dominating in the industry in recent years. Instead, we're likely to see more manufacturers "rightsizing" like Mazda, and others taking the hybrid path, improving performance while being able to harvest and deploy energy to the benefit of efficiency.” (Ingram, A. 2017)

With the downsized engines experiencing more problems over time, there may be more manufacturers making the change towards improving their larger engines instead. This will result in the development of new technology to lower the emissions, or the trials of existing technology introduced to the system to try and achieve this goal.

3. Alternative Fuels

While a large area of interest is based on fully electric cars in the future for 'zero-carbon' vehicles by 2035, there are also manufacturers putting research into using alternative fuels to achieve lower emission outputs. A big contender for this is the use of Hydrogen as an alternative fuel to replace petrol, this is due to it being a natural gas and its ability to produce no harmful by-products, this is discussed in further detail below in section 3.1.

3.1. Hydrogen

There is a list of advantages that comes with using hydrogen as an alternative fuel source in cars, after all it is a renewable energy source and in a massive supply on the earth, it produces safe by-products when used as fuel, and it can produce a lot of energy per pound of fuel used. However, there is a drawback to using it because of the difficulties in storing the hydrogen, this means that the storage tanks won't be capable of holding much of it and the gas will slowly escape. Therefore, the miles covered per refill of a hydrogen vehicle may be slightly lower than the distance covered by an engine, although the sale price of hydrogen is extremely low compared to petrol or diesel, which in the long run will save the driver money.

"Hydrogen is the most basic of all Earth elements. The hydrogen atom is made up of a single proton and a single electron. As such, it is very abundant, but it doesn't really exist as a separate form of matter. Instead it is usually combined with other elements. To separate hydrogen gas from its companion substances takes a lot of work but it produces a powerful, nearly clean source of energy. As a gas, it can be used in fuel cells to power engines." (Rinkesh. 2020)

Figure 14 – Hydrogen Powered Car (Parkinson, G. 2018)

3.1.1. Benefits of Using Hydrogen

The use of hydrogen as a replacement fuel source will be far more beneficial to the environment because of the harmless gases produced when burnt. This means that these vehicles will be safe to use within close proximity of pedestrians, possibly allowing these vehicles to be used through a town.

Hydrogen is a renewable gas and most gases aren't as infinite as hydrogen, meaning there is such a low possibility of running out like most other sources of energy, as explained by (Rinkesh. 2020).

It's also a highly efficient energy source, where it can produce a lot of energy per pound of fuel when burnt. This means that the distance a hydrogen vehicle can travel can be very high for the fuel being used before it needs to be refuelled.

3.1.2. Problems with Hydrogen

For someone to retrieve hydrogen, it may require the use of a costly method such as electrolysis or steam reforming (Rinkesh. 2020). This is thanks to the methods used for extracting the hydrogen from other elements, such as water (H2O).

Unfortunately, storing hydrogen is more difficult than storing petrol or diesel. This is due to the very low density compared to other fuels, meaning the hydrogen needs to be compressed to a liquid state and stored at a lower temperature.

Hydrogen doesn't really produce an odour. This means that a leak is almost impossible to detect without the use of sensors that can detect the presence of this gas, therefore increasing the price of this system.

4. Methodology

In order to collect a sufficient amount of data to better the understanding of these emissions, it was beneficial to use a combination of research and different data sources. The sources used to collect data included in-house testing with use of equipment in a workshop, and an online survey based upon the daily impact of emissions for different drivers to develop an average value.

To ensure that the recorded data we gathered would have the closest accuracy to the car being driven on a road, there was a force applied to the wheels to add a rolling resistance, these resistances are calculated in section 4.1.

For gathering the data on the behaviour of different drivers, an online survey was constructed with questions involving their daily journeys. The aims of this survey was to develop an understanding of what percentage of people are driving cars daily compared to those who use public transport, would some of those drivers change to public transport if different circumstances were applied, how they feel about speed zones on motorways, what interests a driver when buying a car, and then finished off with a comparisons of two different cars. The results of this online survey are discussed in section 4.2.

4.1. Emissions Testing

Due to the factor of not owning the required vehicles, they firstly needed to be acquired before the testing can be done. This was achieved thanks to the help of other students who owned the vehicles and were happy to let us use them.

When the vehicles were loaded onto the rolling road for testing, there needed to be an applied force (N) to the wheels that simulates the rolling resistance of a road. To calculate this force for the wheels, the use of an equation was needed as shown below in equation 1 and equation 2.

The equation to calculate the rolling resistance is as follows:

Rolling Resistance (N) = Rolling coefficient x Vehicle mass (Kg) x gravity (m/s²)

Using this formula, the rolling resistances for both vehicles can be calculated, as shown below:

Calculated the rolling resistance of the Ford Kuga1.5L EcoBoost, using:

Vehicle mass = 1500kg / 1.5 tonne

Rolling coefficient of asphalt = 0.03

Value of gravity = 9.81 m/s²

Rolling Resistance = Rolling coefficient x Vehicle mass x gravity

$$Rr = 0.03 \text{ x } 1500 \text{ x } 9.81$$

Rolling Resistance Equation 1

(Engineering Toolbox. 2008)

Rolling Resistance = 440N

Calculated the rolling resistance of the Ford Fiesta 1.0L EcoBoost, using:

The vehicle mass = 1100kg / 1.1 tonne

Rolling coefficient of asphalt = 0.03

Value of gravity = 9.81 m/s²

Rolling Resistance = Rolling coefficient x Vehicle mass x gravity

$$Rr = 0.03 \text{ x } 1100 \text{ x } 9.81$$

Rolling Resistance Equation 2

(Engineering Toolbox. 2008)

Rolling Resistance = 324N

4.2. Online Survey – Vehicle Emissions

When creating an online survey there are different factors to consider, such as the length of the survey, and keeping the questions relevant. Google Forms was used to construct the survey as this was free and very easy to use, providing graphs for each answer and it allows the creator to filter the results.

When the survey was complete it was then shared around, this meant that there could be a larger number of participants, and it would also increase the diversity in the answers.

According to (SurveyMonkey. 2020), there are many beneficial factors to improve a survey. These include:

- Focus on asking closed-ended questions, this requires less effort.
- Keep the survey questions neutral, this reduces the audience influence to an answer.
- Keep a balanced set of answers, this allows for honest feedback.
- Don't confuse the respondents, this makes the survey easier to follow.
- Try not to make questions similar, repetitive questions may get annoyed.
- Allow some optional questions, this reduces the time to complete the survey.
- Do a test run before sharing it, this helps to remove mistakes and make improvements.

5. Results/Data

The results gathered from the emissions testing has helped to develop an understand of the differences between similar engines of a different capacity, although there are a lot of similarities between each engine at higher speeds, as explained throughout section 5.

The emission data collected for each vehicle is shown and discussed below in sections 5.1.1 and 5.1.2.

The online survey answers are shown and discussed below in section 5.2.

5.1. Workshop Emissions Testing

To collect the emissions data from both of the two chosen vehicles, the Ford Kouga 1.5L EcoBoost and the Ford Fiesta 1.0L EcoBoost, the use of a sufficient extraction system was required because the engines were running inside of a closed room in order to reduce the contamination of the results from fresh air coming in.

5.1.1. Ford Kouga 1.5L EcoBoost

Figure 15: Ford Kouga 1.5L EcoBoost (Watkins, D. 2020)

Installing this vehicle was very easy thanks to the adjustable wheelbase fitted into the rolling road system used, so despite the long wheelbase it was still very easy to fit comfortably on the rolling road. However, we came across a difficulty with this vehicle because of the use of a dual exhaust pipe, this meant that we were limited with only having a device capable of measuring one exhaust pipe.

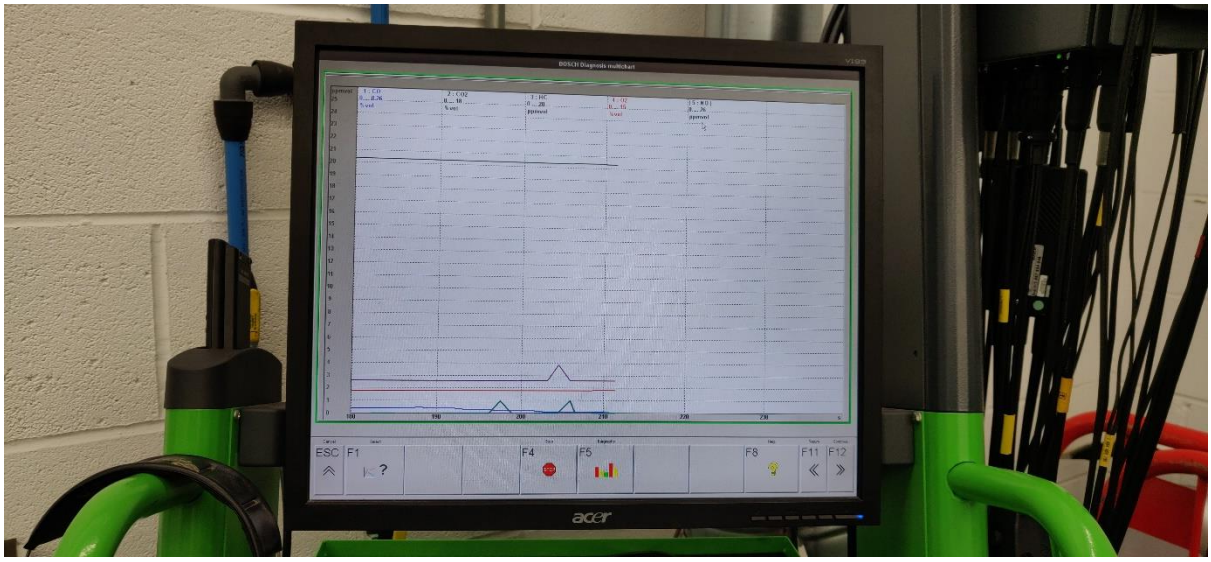


Figure 16: Warm Engine Emissions at Idle (Watkins, D. 2020)

Due to the lack of time when testing this vehicle, we didn't have enough time to allow the engine to cool down for a cold start, so instead the idle data was taken at the end. The Nitrogen Oxide (NOx) values represented by the black line in figure 16, clearly shows that a large quantity of NOx gas is being measured compared to the other gases, even at idle. At a high quantity this can be a very harmful gas to a persons' respiratory system

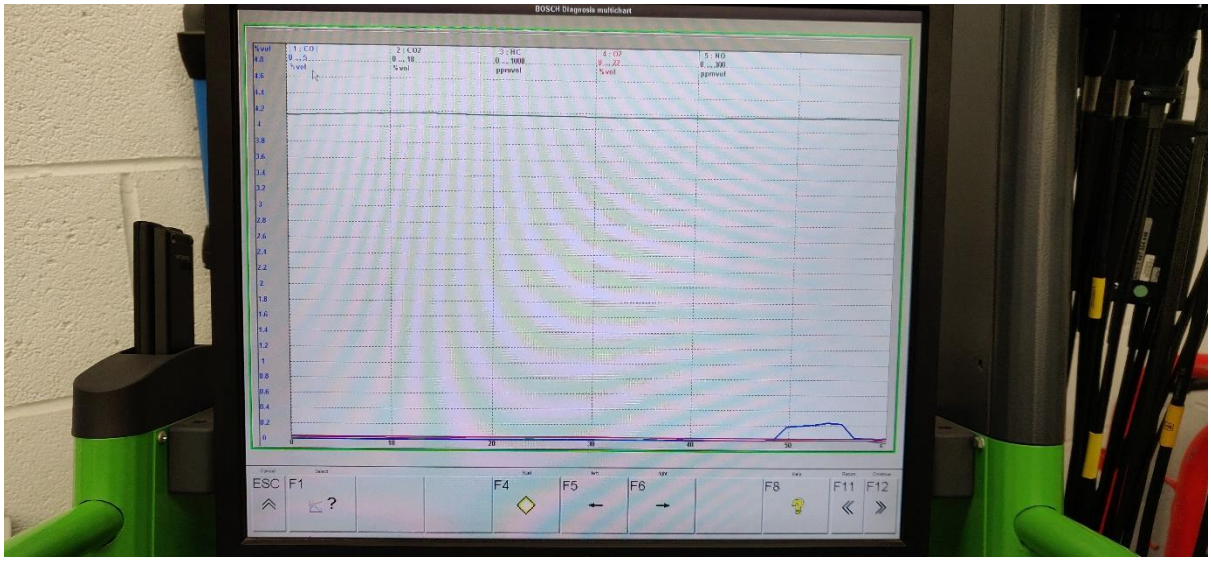


Figure 17: Steady Speed CO %/vol (Watkins, D. 2020)

The recorded Carbon Monoxide (CO) value, represented by the blue line on figure 17, was consistently below 0.2 %/vol. This is because of an efficient combustion process, and when the engine reaches optimal running temperature it can adjust the air to fuel ratio further towards a lean mixture (less fuel).

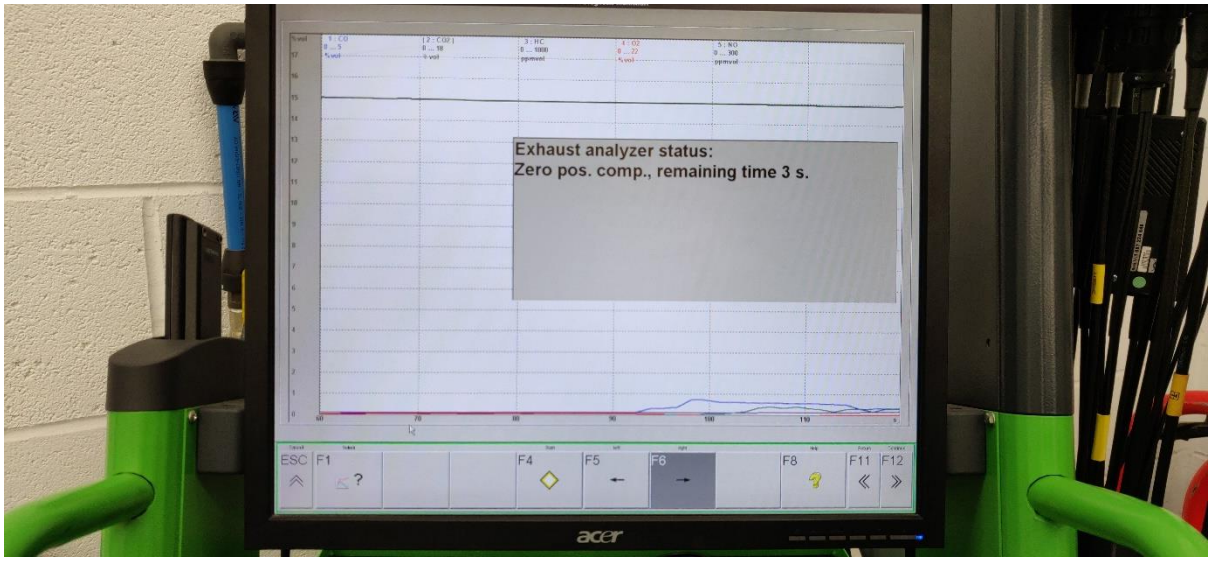


Figure 18: Steady Speed CO2 %/vol (Watkins, D. 2020)

The recorded Carbon Dioxide (CO2) value, represented by the green line on figure 18, also appears consistently below the 1 %/vol when the engine up to temperature. As shown in figure 18 there are spikes in data from the Carbon Monoxide (CO) values, represented by the blue line, and the Carbon Dioxide (CO2) data represented by the green line, which are due to the driver of the vehicle lifting off the power.

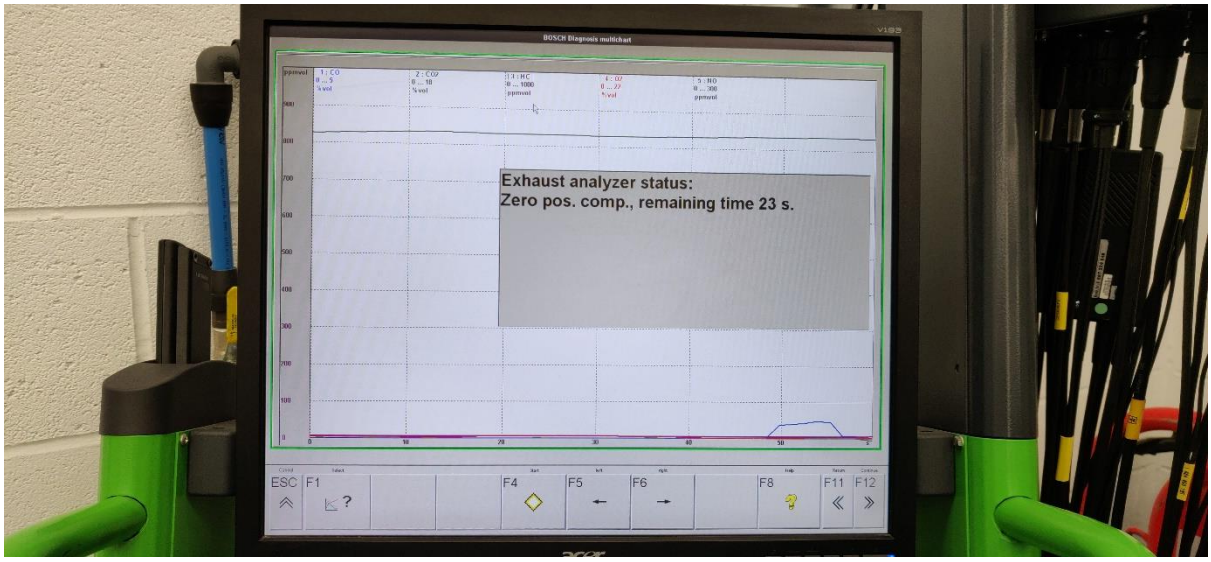


Figure 19: Steady Speed HC ppm/vol (Watkins, D. 2020)

The recorded Hydrocarbon (HC) value, represented by the purple line on figure 19, will be very low as the engine is at a steady speed. This is due to the combustion process being more efficient at a steady speed, this is because the valve timing and spark ignition timing will adjust to burn the air and fuel mixture efficiently as possible, and without sudden speed changes this efficiency can be easier to maintain.

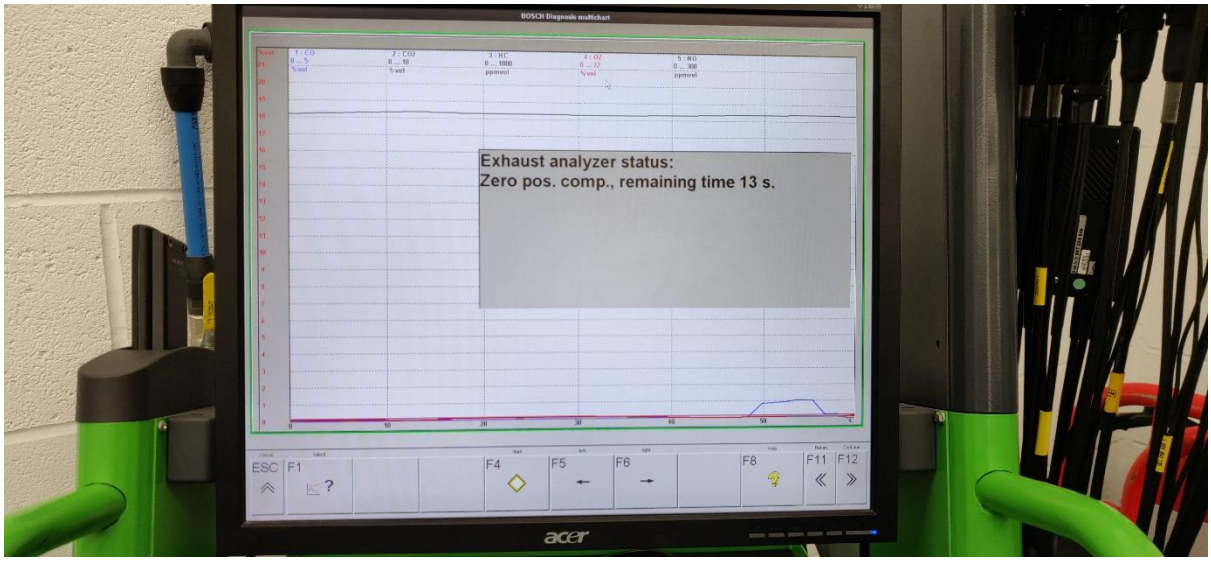


Figure 20: Steady Speed O2 %/vol (Watkins, D. 2020)

The recorded Oxygen (O2) value, represented by the red line on figure 20, will remain very low due to the oxygen in the cylinder being ignited with the fuel. The measured oxygen can be due to a lean mixture where a very tiny amount of air may remain unburnt. But with an EGR system this may be sent back into the inlet and mix with the fuel, therefore reducing this value further.

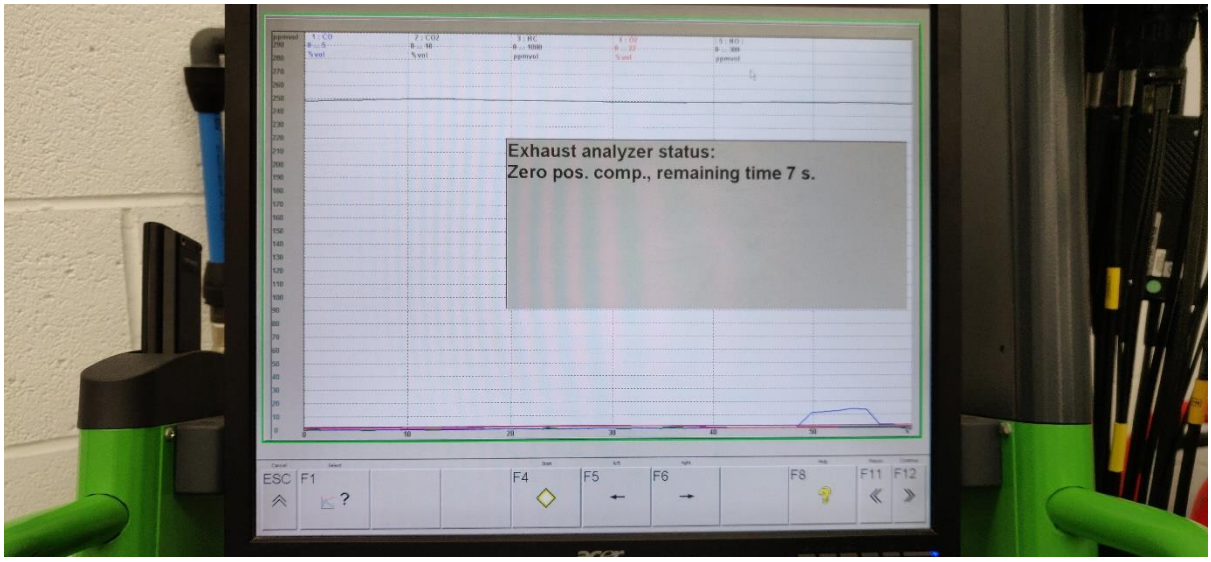


Figure 21: Steady Speed NOx ppm/vol (Watkins, D. 2020)

The recorded Nitrogen Oxide (NOx) value, represented by the black line on figure 21, clearly shows that a large quantity of NOx gas is being measured. Unfortunately, at a high quantity this can be a very harmful gas to a persons' respiratory system, so this can potentially be dangerous to pedestrians who were to spend time around the vehicle with the engine running.

5.1.2. Ford Fiesta 1.0L EcoBoost

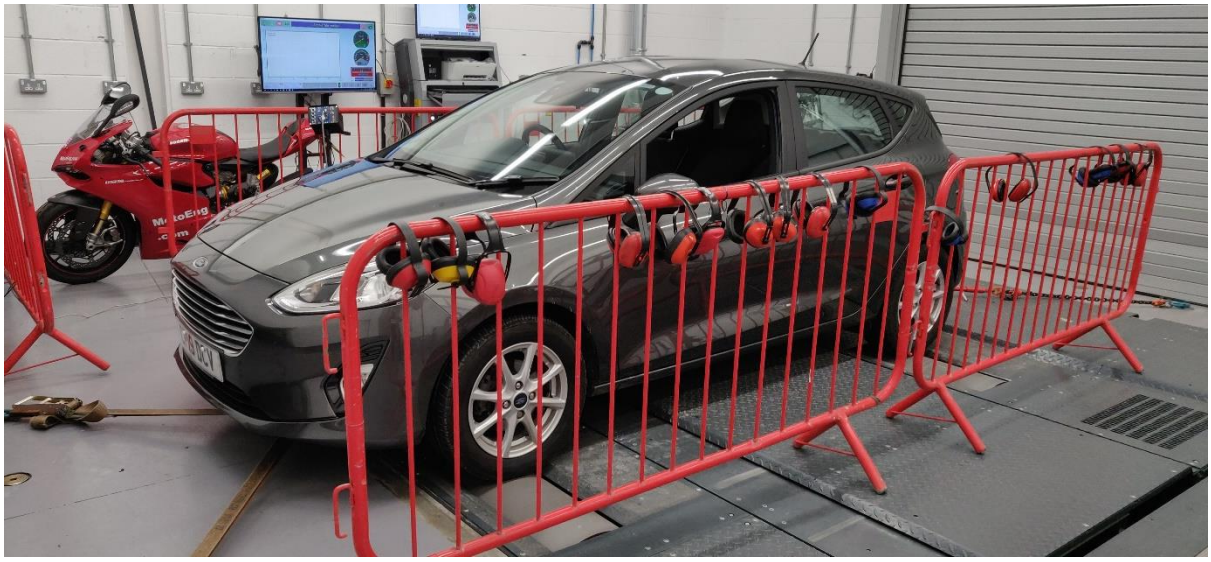


Figure 22: Ford Fiesta 1.0L EcoBoost (Watkins, D. 2020)

fitting this vehicle onto the rolling road system was very easy, only minimal adjustments were needed to match the vehicle wheelbase. Also, the emissions were easy to measure due to the use of only a single exhaust pipe.

Figure 23: Cold Engine Emissions at Idle (Watkins, D. 2020)

The initial spikes of the values shown in figure 23 were caused by the vehicle cold cranking, and these values are shown to decrease as the engine warmed up at idle. However, the recorded Nitrogen Oxide (NOx) value, represented by the black line, are very high at around 240-250ppm, this amount can be dangerous if around pedestrians for prolonged periods of time.

Figure 24: Steady Speed CO %/vol (Watkins, D. 2020)

With this vehicle at a steady speed the recorded Carbon Monoxide (CO) value, represented by the blue line in figure 24, appears to remain below the 0.2 %/vol as shown. As explained in section 5.1.1, this is because of an efficient combustion process, and when the engine reaches optimal running temperature it can adjust the air to fuel ratio further towards a lean mixture (less fuel).

Figure 25: Steady Speed CO2 %/vol (Watkins, D. 2020)

The recorded Carbon Dioxide (CO2) value, represented by the green line in figure 25, appear to also remain very low similarly to section 5.1.1. This is due to the combustion process being very efficient at the optimal operating temperature.

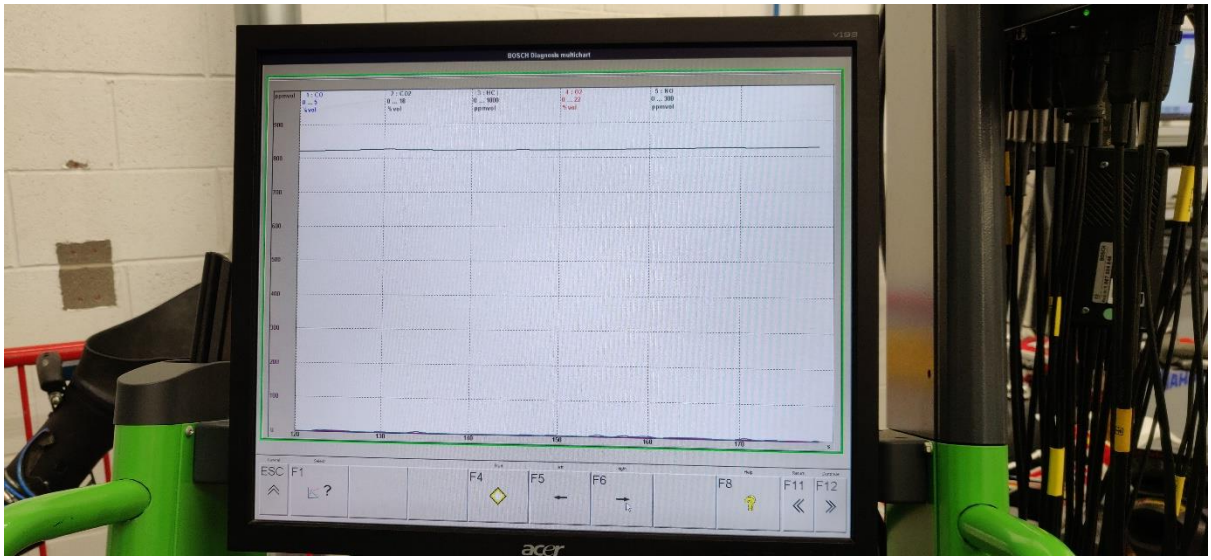


Figure 26: Steady Speed HC ppm/vol (Watkins, D. 2020)

The recorded Hydrocarbon (HC) value, represented by the purple line in figure 26, also remains at a very low value due to the efficient combustion process at a steady speed.

Figure 27: Steady Speed O2 %/vol (Watkins, D. 2020)

The recorded Oxygen (O2) value, represented by the red line in figure 27, remains at a very low value similarly due to an efficient combustion process with an air to fuel ratio burning almost all of the mixture in the cylinder.

Figure 28: Steady Speed NOx ppm/vol (Watkins, D. 2020)

The recorded Nitrogen Oxide (NOx) value, represented by the black line in figure 28, still remains at a very high quantity similarly to the value in figure 23 and the vehicle tested in section 5.1.1. As previously discussed, these can be dangerous levels of NOx gases if around pedestrians for prolonged periods of time.

5.1.3. Testing Equipment

Whenever any type of testing needs to be completed, these days it would most likely include the use of a machine, which would provide an accuracy percentage. During the testing procedure, some of these machines can experience a spike in the data similarly to the one shown below in Figure 29, and this can be for many reasons.

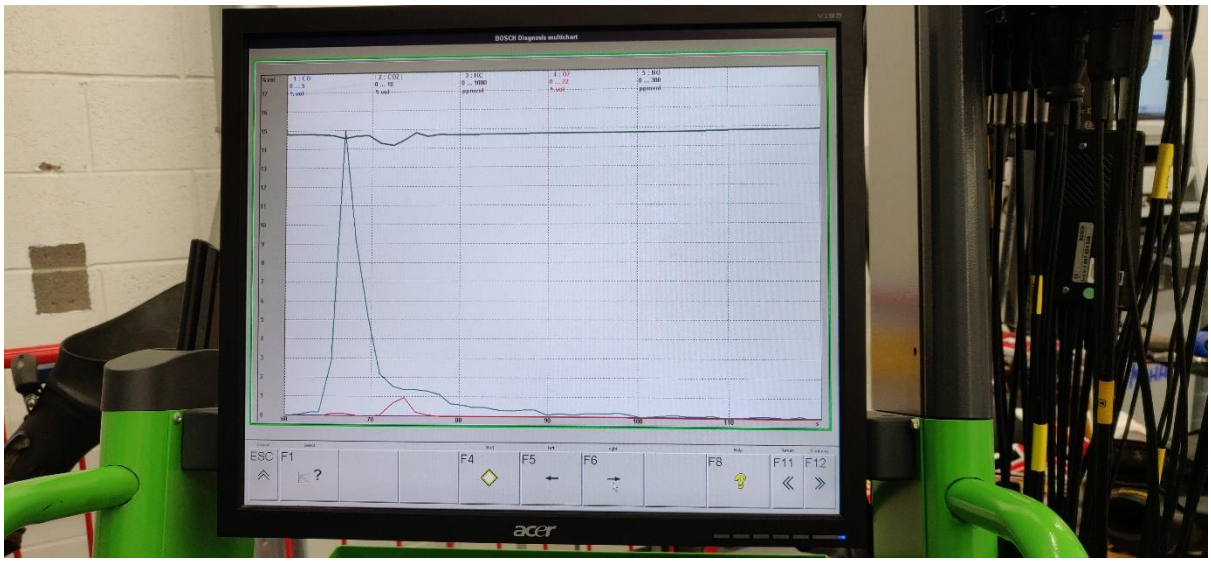


Figure 29: Emissions Testing Spikes (Watkins, D. 2020)

A lot of testing equipment would vary in accuracy depending on the test being carried out, or even the connection in the wires. Some tests may present a spike in the recorded data if a wire is knocked or if there is an interference in the connection, such as dust or dirt on a sensor.

5.2. Emissions Survey

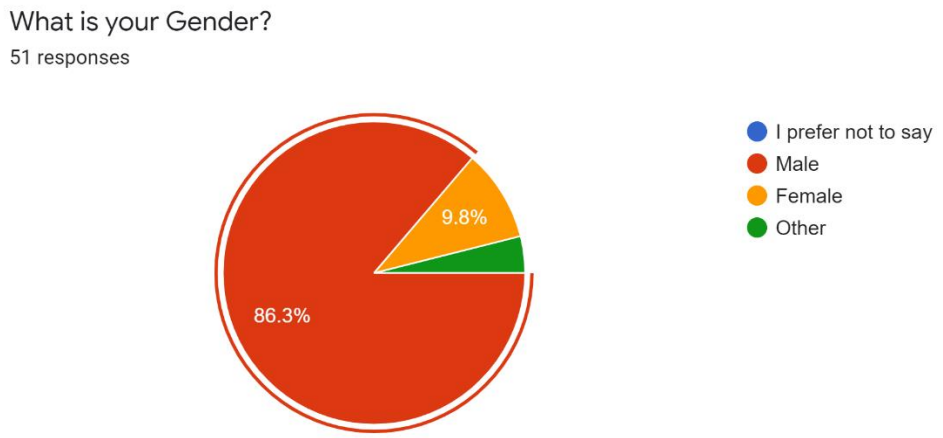


Figure 30: Survey Question 1 (Watkins, D. 2020)

According to the survey, figure 30 shows that 86% of the participants appear to be male. This may influence the survey answers to represent a male preference, who often prefer a car with a larger engine for example.

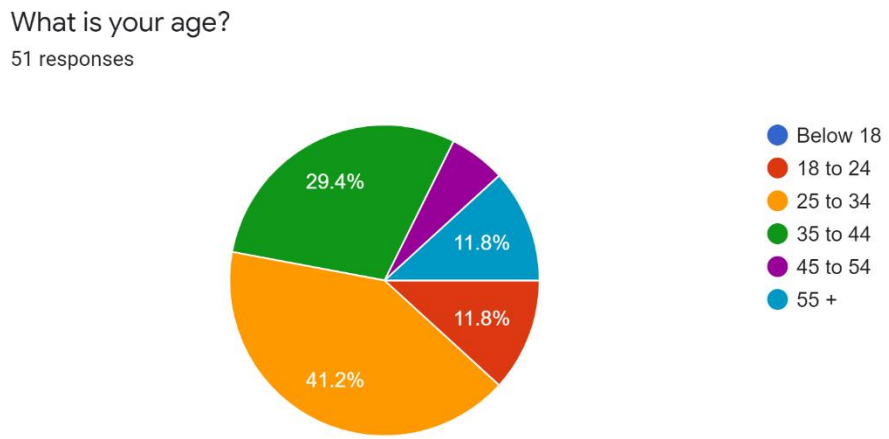


Figure 31: Survey Question 2 (Watkins, D. 2020)

As the above chart in figure 31 shows, 41% of the participants were in the age bracket of 25 to 34 years of age. This age bracket can influence the results due to these participants likely having a family and working daily which requires a form of personal transport.

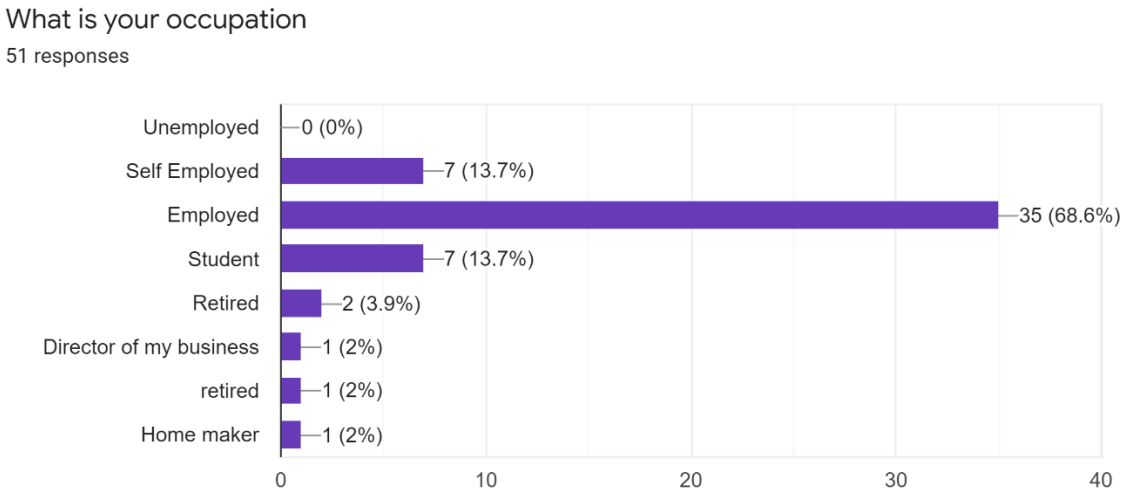


Figure 32: Survey Question 3 (Watkins, D. 2020)

Following the previous result in figure 31, these results in figure 32 clearly match my previous statement that the majority of participants will be employed.

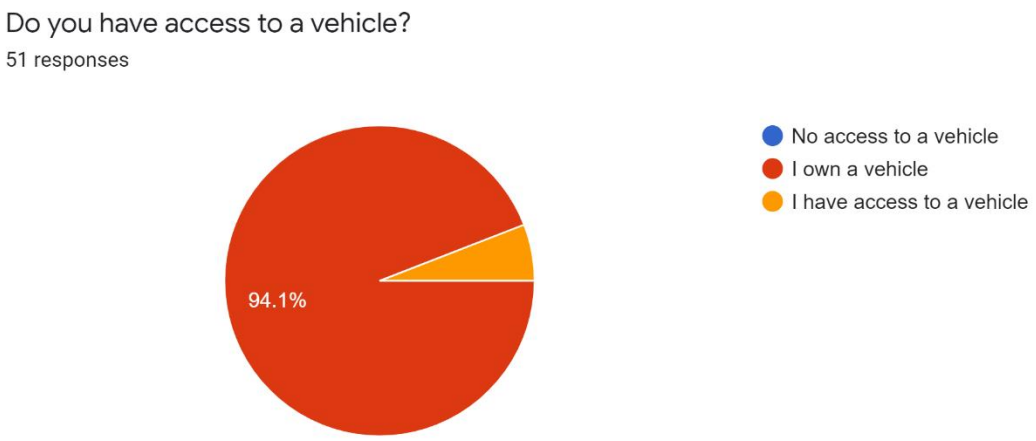


Figure 33: Survey Question 4 (Watkins, D. 2020)

Also confirming the previous results in figures 31 and 32, this chart in figure 33 clearly shows that the participants are either using a personal vehicle or have some level of access to one, possibly via a family member or supplied from an employer.

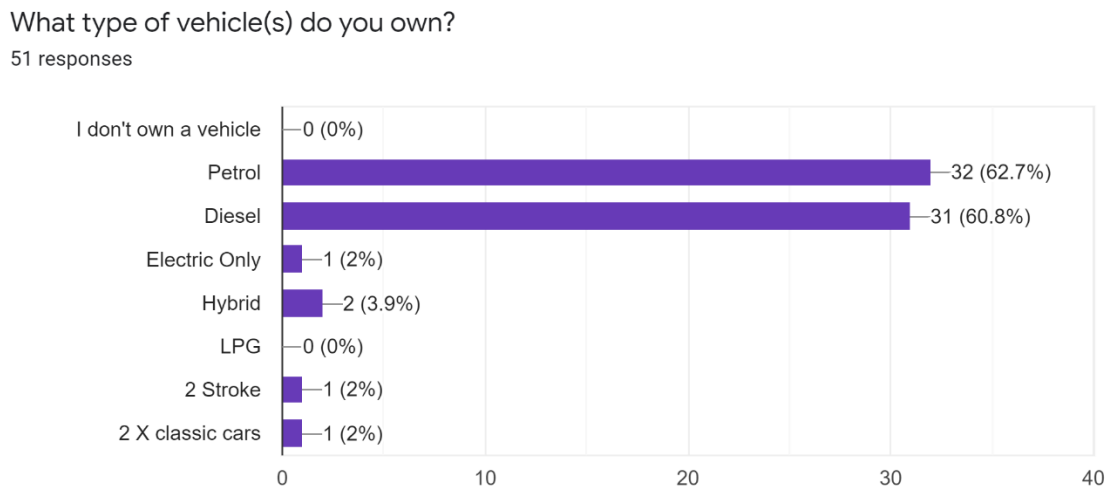


Figure 34: Survey Question 5 (Watkins, D. 2020)

The above graph, shown in figure 34, shows that the majority of participants own either a petrol or diesel vehicle, with only a small amount owning either an electric or hybrid vehicle. This means that almost all of the participants will be driving a vehicle which produces the emissions tested in section 5.1.

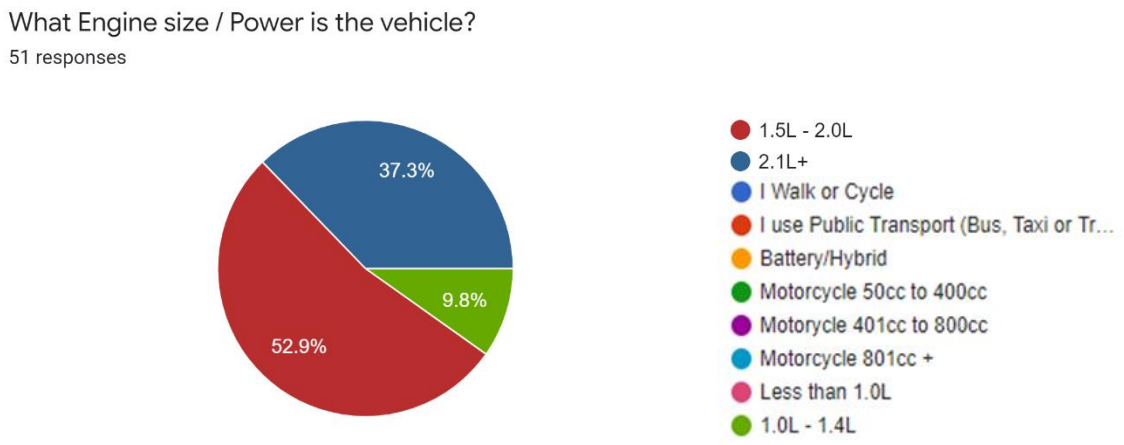


Figure 35: Survey Question 6 (Watkins, D. 2020)

In relation to figure 31, the above chart in figure 35 shows that over half of the participants are driving a vehicle with a larger engine capacity. This can be due to the age bracket as discussed in figure 31, where they are employed and use the vehicle for transport.

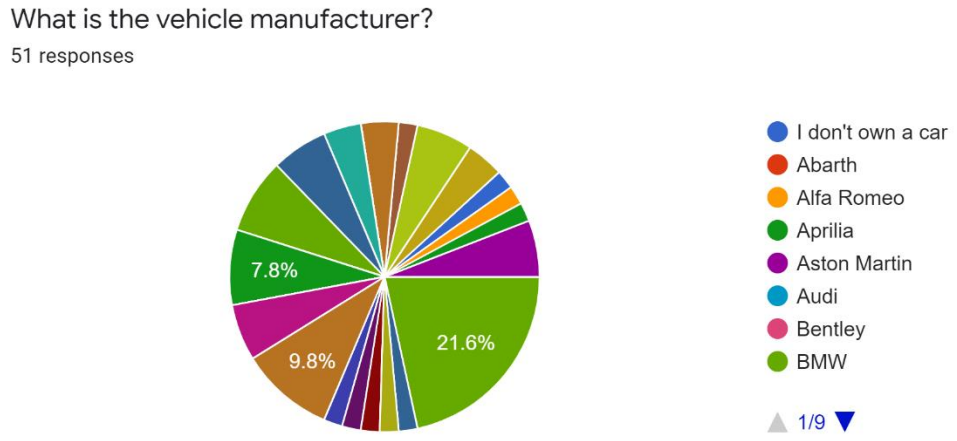


Figure 36: Survey Question 7 (Watkins, D. 2020)

The chart shown above in figure 36, shows that the highest value of participants (21%) drive a BMW, which this matches the previous answers in figure 35 because a lot of BMW cars driven on the road are within this engine capacity bracket.

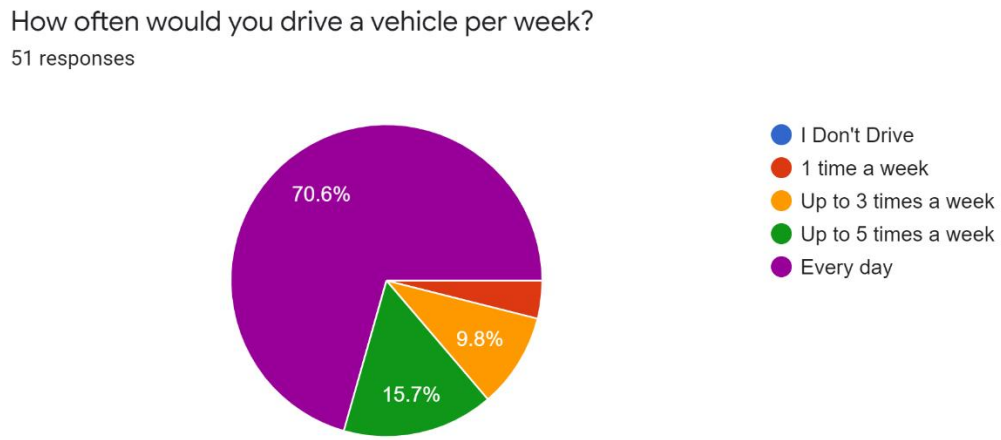


Figure 37: Survey Question 8 (Watkins, D. 2020)

The chart shown above in figure 37, shows that 70% of the participants will drive their vehicles on the road every day, with a combined 25% of the participants driving their vehicles a few days a week.

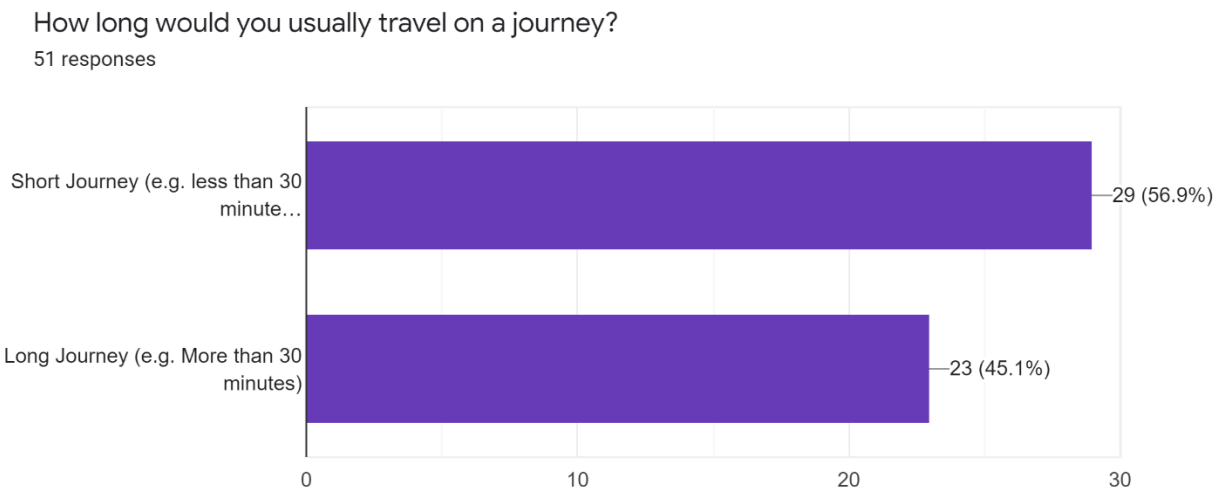


Figure 38: Survey Question 9 (Watkins, D. 2020)

The above graph shown in figure 38, indicates that over half of the participants often drive on short journeys. Which over time, frequent short journeys can cause a problem for diesel vehicles, especially with the particulate filters as discussed in section 2.2.4. this would then increase the amount of harmful exhaust gases being released from the exhaust pipe.

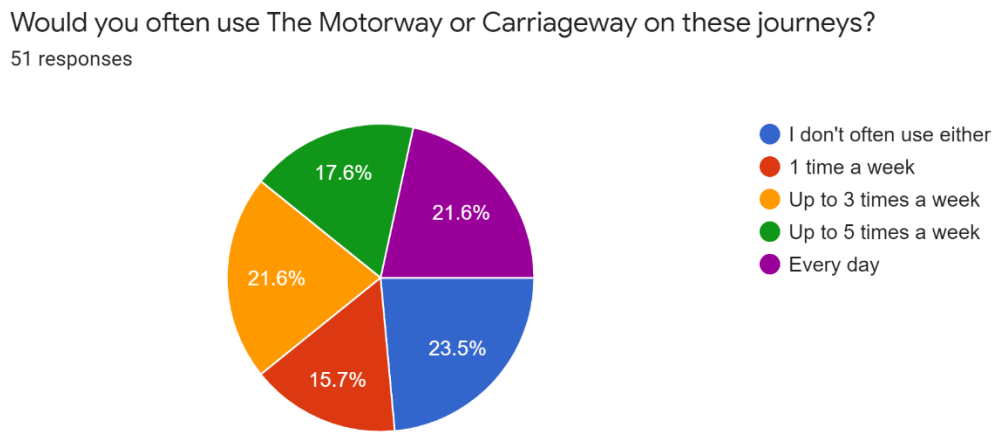


Figure 39: Survey Question 10 (Watkins, D. 2020)

The above chart shown in figure 39, shows that 23% of the participants don't drive on the motorway on their journeys, whereas the rest of the participants would use the motorway on their journeys. This means that those using the motorway will likely pass through speed cameras and possibly an average speed zone, as discussed in section 2.3.

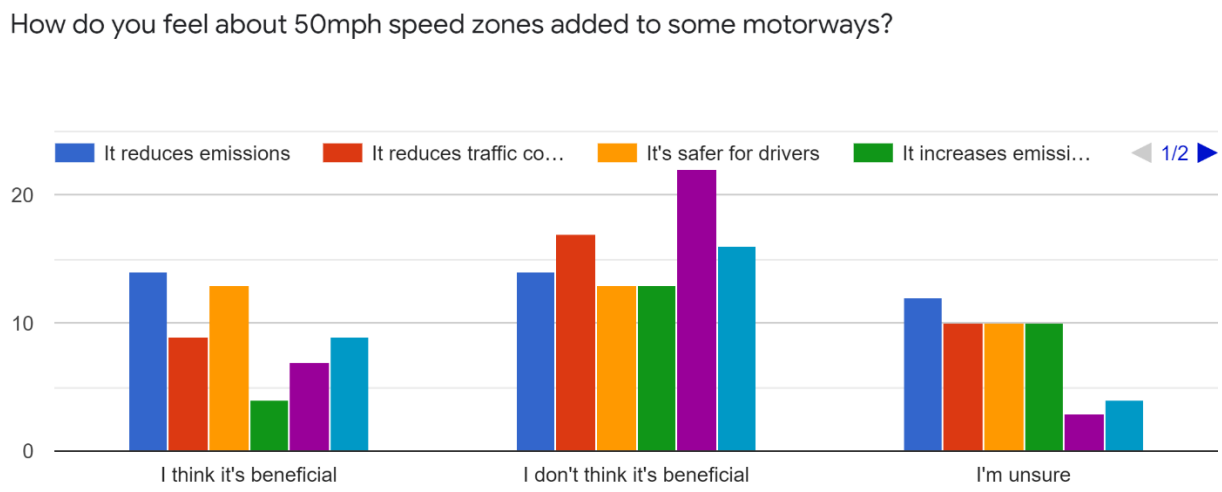


Figure 40: Survey Question 11 (Watkins, D. 2020)

The above graph shown in figure 40 compares the opinions of the participants regarding speed zones on a motorway, as clearly shown, there are more participants who said that they don't think the speed zones are beneficial because these zones cause congestion.

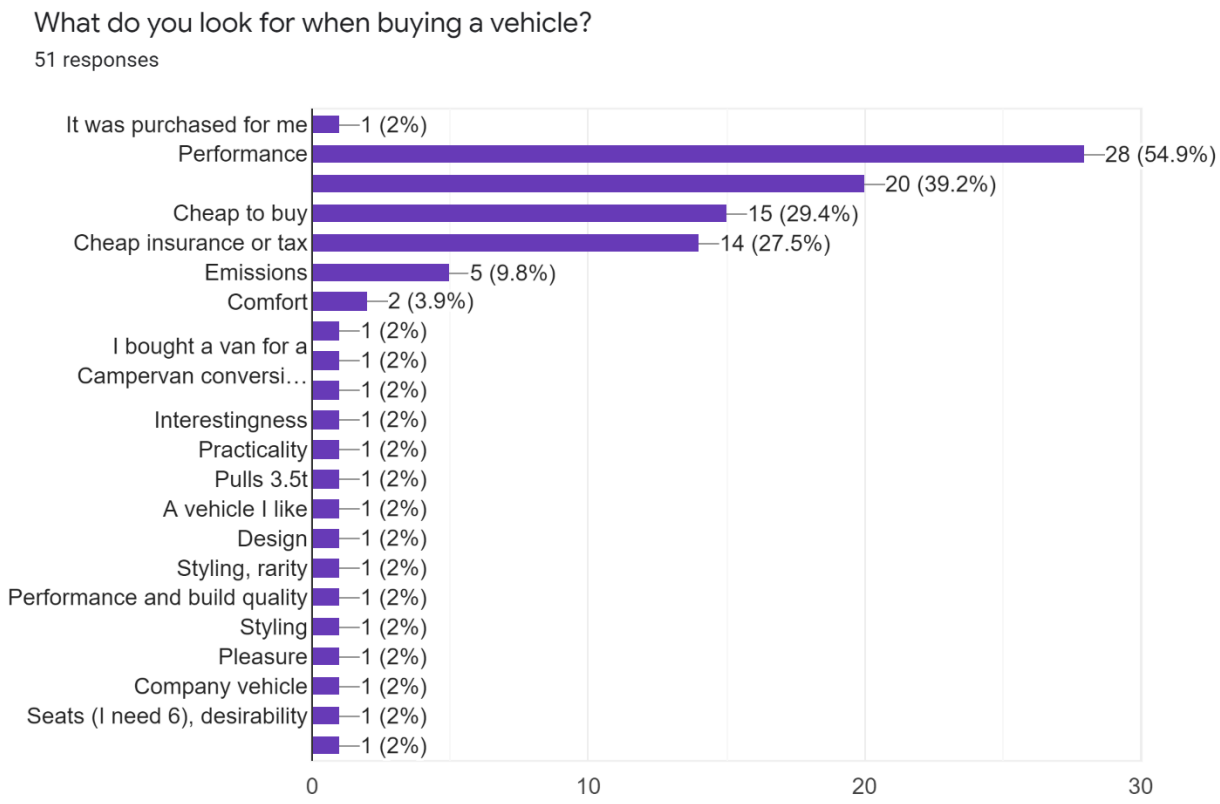


Figure 41: Survey Question 12 (Watkins, D. 2020)

The graph above in figure 41, shows the different preferences from motorists when buying a car, with the majority of participants saying they would look for a car with good performance over the other factors, followed closely by the price of running the vehicle.

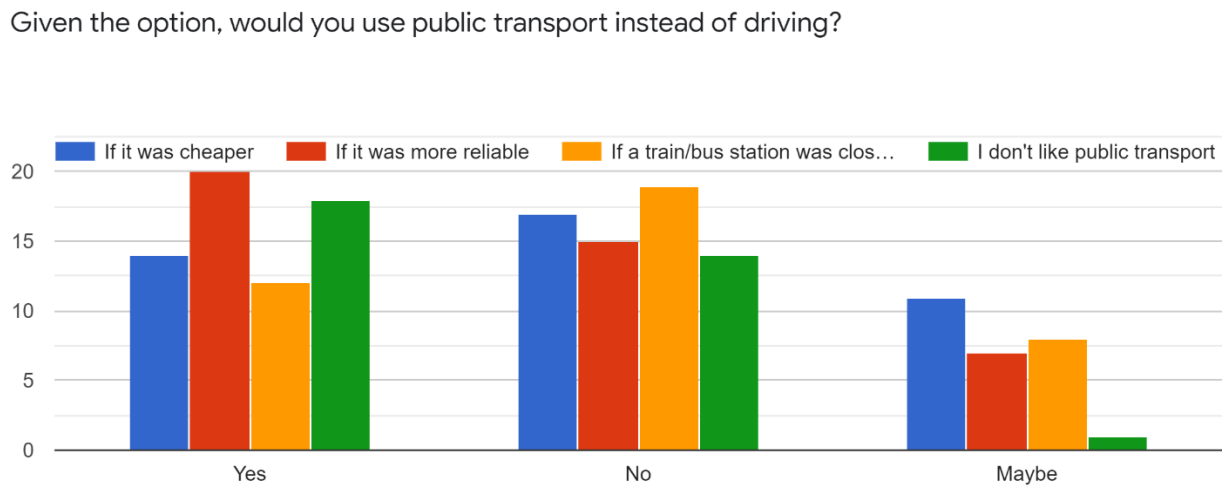


Figure 42: Survey Question 13 (Watkins, D. 2020)

The above graph in figure 42 asked the participants if they would like to use public transport instead of personal vehicles to lower emissions, and surprisingly there are more that would use public transport if it was cheaper and more reliable. This is beneficial for lowering the total carbon produced by vehicles on the road.

5.2.1. Survey Vehicle Comparison

The vehicle comparison section of this survey was aimed to test the participants, comparing two vehicles with different engine capacities to see what they thought would be best in each category. The vehicles are shown in Appendix K.

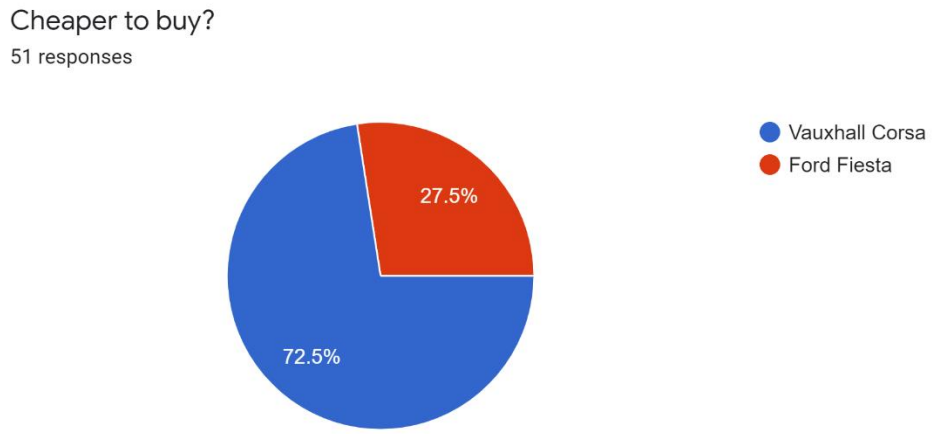


Figure 43: Survey Question 14 (Watkins, D. 2020)

The above chart in figure 43 shows that 72% of the participants thought the Vauxhall Corsa, with the larger engine, would be cheaper to buy. The majority of participants were correct as shown in Appendix K. £157/m compared to £298/m.

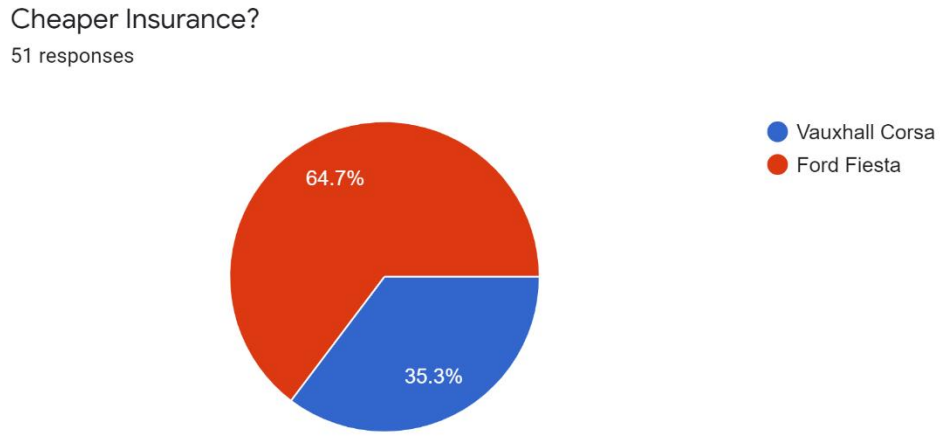


Figure 44: Survey Question 15 (Watkins, D. 2020)

The above chart in figure 44 shows that 64% of the participants thought the Ford Fiesta would be cheaper on insurance, however they were incorrect, as shown in Appendix K. insurance group 10E compared to insurance group 12E.

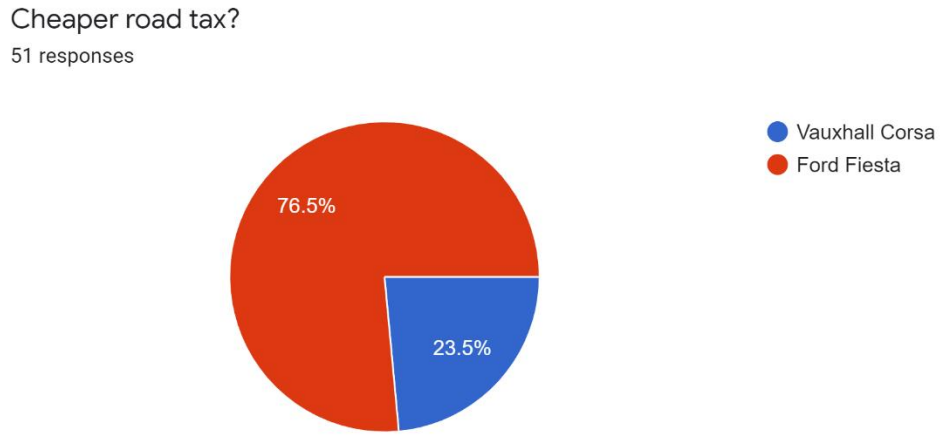


Figure 45: Survey Question 16 (Watkins, D. 2020)

The above chart in figure 45 shows that 76% of the participants thought the Ford Fiesta would have cheaper road tax, however they were incorrect, as shown in Appendix K. £125 annually compared to £150 annually.

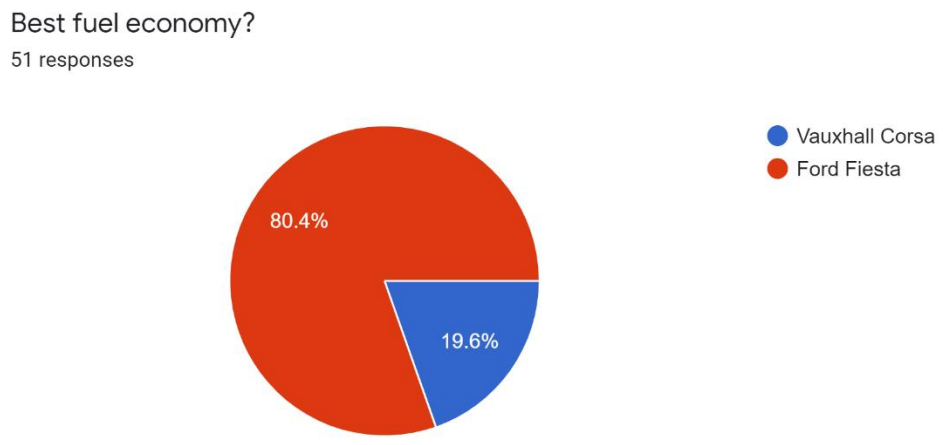


Figure 46: Survey Question 17 (Watkins, D. 2020)

The above chart in figure 46 shows that 80% of the participants thought the Ford Fiesta would have better fuel economy, however they were incorrect, as shown in Appendix K. 68.9mpg compared to 58.8mpg.

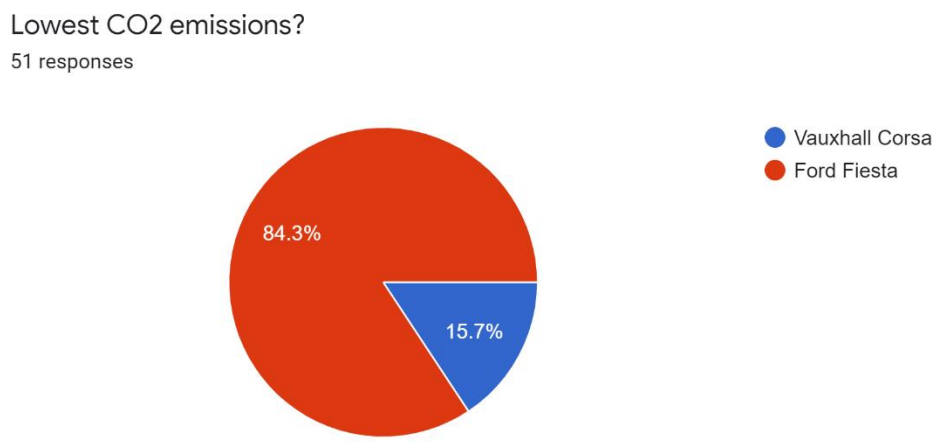


Figure 47: Survey Question 18 (Watkins, D. 2020)

The above chart in figure 47 shows that 84% of the participants thought the Ford Fiesta would produce the lowest levels of CO2, however they were incorrect, as shown in Appendix K. 93g/km compared to 108g/km.

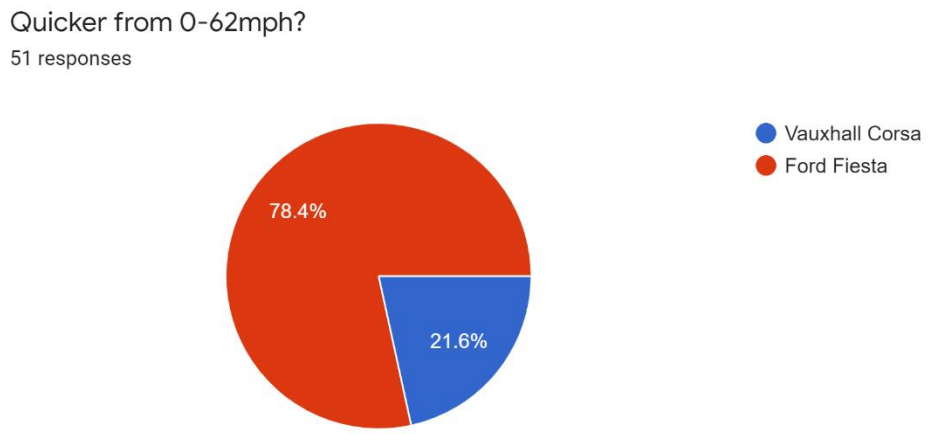


Figure 48: Survey Question 19 (Watkins, D. 2020)

The above chart in figure 48 shows that 78% of the participants thought the Ford Fiesta would have a quicker time of 0-60mph, the majority of participants are correct, as shown in Appendix K. 10.4s compared to 13.2.

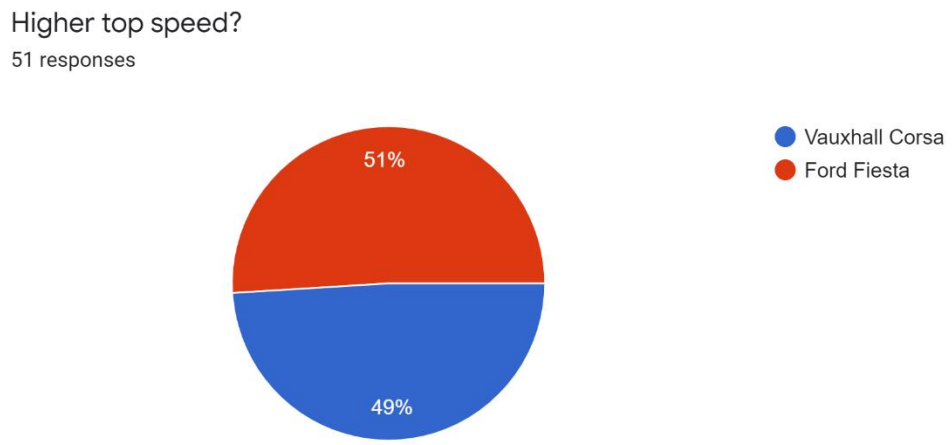


Figure 49: Survey Question 20 (Watkins, D. 2020)

The above chart in figure 49 shows that 51% of the participants thought the Ford Fiesta would have a higher top speed, the majority of participants were again correct, as shown in Appendix K. 121mph compared to 108mph.

6. Conclusion

From completing the emissions testing on the downsized engines, it has become clear to myself that there aren't only good sides to these engines, they also have disadvantages. However, just because of a few bad points of the tested downsized engines, this doesn't mean that they are bad engines and should be ruled out.

Vehicle manufacturers in recent years have invested a lot of money into the development of downsized engines, this is because of the improved fuel efficiency compared to an engine of similar power outputs, as discussed in section 2.6. And from the addition of a forced induction system, these smaller engines are capable of producing similar power figure to a larger engine, therefore reducing the power difference from downsizing the engine.

Although many automotive manufacturers have been downsizing their engines in recent years, we are slowly seeing an increase in these manufacturers abandoning this, to instead make modifications to their engines of a larger capacity. This is recently proving to have some benefits for those trying this method. Therefore, more manufacturers may soon also follow this.

The results produced from the online survey were connecting together well, in my opinion. The outcomes for each separate answer were closely related to the expected answer supplied from the previous charts, meaning that there was a correlation. For example, the majority of participants were of the age bracket between 25 to 34 years of age, meaning they were likely in employment, which was later confirmed to be correct. Then because these participants were employed, they would likely have the use of a vehicle, which was then confirmed to be correct.

7. Evaluation

Throughout this report, there has been many issues discussed and possible solutions. However, there could have been improvements to some areas. During the emissions testing section of the report, many issues were presented in collecting the required data. As shown in figures 15-29, the machine used had unfortunately run into a few problems, including the absence of printing paper and the tester needing to reset after being used for a duration of time. These issues resulted in a time restriction for us to collect the data, and the only method of retrieving the data from the machine was via photographs of the screen, which unfortunately left the images more difficult to see. Also, with the appearance of the Covid-19 virus, my work had become affected with a lack of access to the university facilities.

8. Recommended Further Work

Research further into the development of larger capacity engines, such as the Mazda SkyActiv engine. This is a very interesting project and I would be interested to see if this technology would have a future in the automotive industry, instead of electric vehicles replacing the internal combustion engine by 2035.

Emissions testing on other downsized engines would be beneficial for the future, this will allow a further understanding of other engine emissions, to see if there are similar characteristics to those engines as found in the EcoBoost engines tested in section 5.1 of this report.

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10. Appendices

10.1. Appendix A

"One cause of global warming of the earth's atmosphere is the emission of human made gases (methane, CO2, nitrous oxygen, etc.) into the environment. Of the total global CO2 emissions, the transportation sector contributes to about 14%. In order to control the emissions of the automotive sector, in all major countries (USA, Europe, China, Japan) of the world, tough emissions targets were being set to reduce the vehicle traffic's contribution of CO2. These are derived from the global climate conference' target to limit the maximum temperature increase of the earth of 2 degrees Celsius until 2100.

In order to achieve these stringent targets, the automotive industry will face a major change in its drivetrain. It will move from combustion to electrical engines. The technical realization of these engines will most likely be battery and fuel cell driven propulsion systems. In order to achieve that transition a major effort is required in 4 industrial areas, i.e. growing electrical charging infrastructure, lowering battery cost, increasing the battery-electric vehicle ranges and developing new environmentally friendly hydrogen production methods". (Hannappel, R. 2017). Retrieved from: https://aip.scitation.org/doi/pdf/10.1063/1.4996530

10.2. Appendix B

"Everyone knows easing up on the accelerator can improve your fuel economy and reduce your emissions. But what kind of impact would it have on the environment if everyone had to slow down? A potentially big one, as it turns out.

Dutch researchers say lowering the speed limit to 80 km/h (50 mph) would cut transportation-related CO2 emissions by 30 percent. Less drastic cuts in maximum speed would yield reductions of 8 to 21 percent, according to the study by CE Delft. How?

Beyond significantly reducing the amount of fuel vehicles burn, a strictly enforced 50 mph speed limit would increase the time required to cover a given distance. That would lead many people facing long commutes to ditch cars in favour of other modes of transport, like rail". (Squatriglia, C. 2010). Retrieved from: https://www.wired.com/2010/06/50-mph-speed-limit-curb-emissions/

10.3. Appendix C

"For a vehicle traveling at high speed, reducing its speed increases fuel economy. In general, at speeds over approximately 35 to 45 mph, if a vehicle reduces its speed by 5 mph, its fuel economy can increase by about 5 to 10 percent, because air resistance, or drag, increases exponentially as a vehicle goes faster. 4 Conversely, air resistance diminishes more rapidly as a vehicle slows down, thus increasing its fuel economy". (Gaffigan, M. 2008). Retrieved from: https://www.gao.gov/new.items/d09153r.pdf

10.4. Appendix D

"John German had not been looking to make a splash when he commissioned an examination of pollution from diesel cars back in 2013. The exam compared what came out of their exhaust pipes, during the lab tests that were required by law, with emissions on the road under real driving conditions. German and his colleagues at the International Council on Clean Transportation (ICCT) in the US just wanted to tie up the last loose ends in a big report and thought the research would give them something positive to say about diesel. They might even be able to offer tips to Europe from the US's experience in getting the dirty fuel to run a little cleaner.

But that was not how it turned out. They chose a Volkswagen Jetta as their first test subject, and a VW Passat next. Regulators in California agreed to do the routine certification test for them, and the council hired researchers from West Virginia University to then drive the same cars through cities, along highways and into the mountains, using equipment that tests emissions straight from the cars' exhausts.

It was clear right away that something was off. At first, German wondered if the cars might be malfunctioning, and he asked if a dashboard light had come on. That didn't really make sense, though – the cars had just passed the California regulators' test. His partners thought there might be a problem with their equipment, and they recalibrated it again and again. But the results didn't change. Nitrogen oxide (NOx) pollution from the Jetta's tailpipe was 15 times the allowed limit, shooting up to 35 times under some conditions; the Passat varied between five and 20 times the limit. German had been around the auto industry all his life, so he had a pretty good idea what was going on. This had to be a "defeat device" – a deliberate effort to evade the rules". (Gardiner, B. 2019) Retrieved from: https://www.theguardian.com/environment/2019/mar/22/dirty-lies-how-the-car-industry-hid-the-truth-about-diesel-emissions

10.5. Appendix E

RAC Euro 4 emissions regulations & Euro 5 emissions regulations.

RAC Breakdown Cover Insurance Route Planner Shop Buyin

Euro 5

Implementation date (new approvals): 1 September 2009

Implementation date (all new registrations): 1 January 2011

The big news for Euro 5 was the introduction of particulate filters (DPFs) for diesel vehicles, along with lower limits across the board. For type approvals from September 2011 and new cars from January 2013, diesel vehicles were subject to a new limit on particulate numbers. DPFs capture 99% of all particulate matter and are fitted to every new diesel car. Cars meeting Euro 5 standards emit the equivalent of one grain of sand per kilometre driven.

Euro 5 emissions standards (petrol)

CO: 1.0g/km
THC: 0.10g/km
NMHC: 0.068g/km
NOx: 0.06g/km
PM: 0.005g/km (direct injection only)

Euro 5 emissions standards (diesel)

CO: 0.50g/km
HC + NOx: 0.23g/km
NOx: 0.18g/km
PM: 0.005g/km
PN [#/km]: 6.0x10 ^11/km

Euro 4 (EC2005)

Implementation date (new approvals): 1 January 2005

Implementation date (all new registrations): 1 January 2006

Euro 4 emissions standards (petrol)

CO: 1.0g/km
THC: 0.10g/km
NOx: 0.08g/km

Euro 4 emissions standards (diesel)

CO: 0.50g/km
HC + NOx: 0.30g/km
NOx: 0.25g/km
PM: 0.025g/km

Figure 50: Euro 4 & Euro 5 Regulations (RAC. 2018)

10.6. Appendix F

Diagram to show the internals of a Catalytic Converter

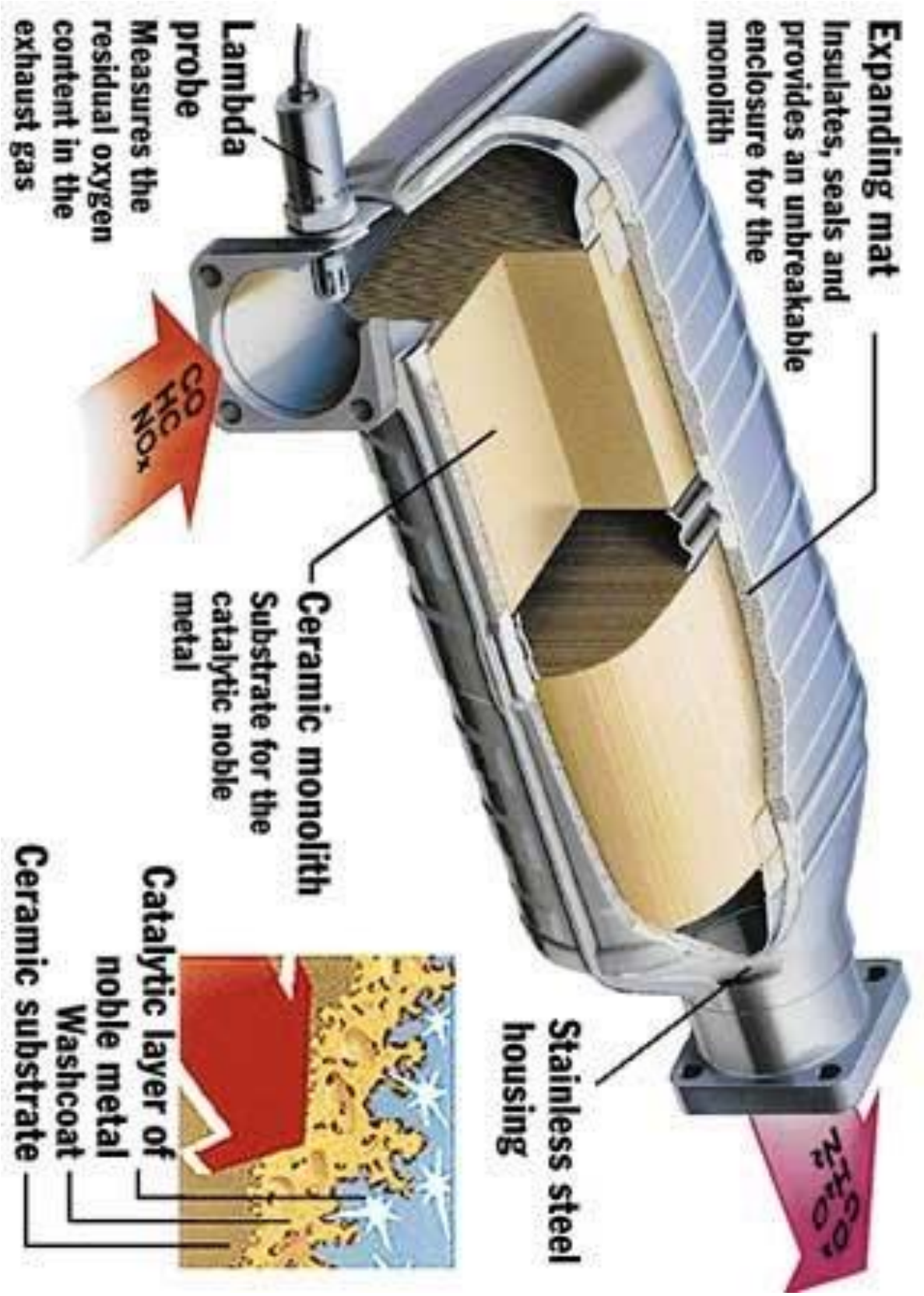

Figure 51: Catalytic Converter (Schoolworkhelper. 2019)

10.7. Appendix G

Diagram to show the effects of an EGR system

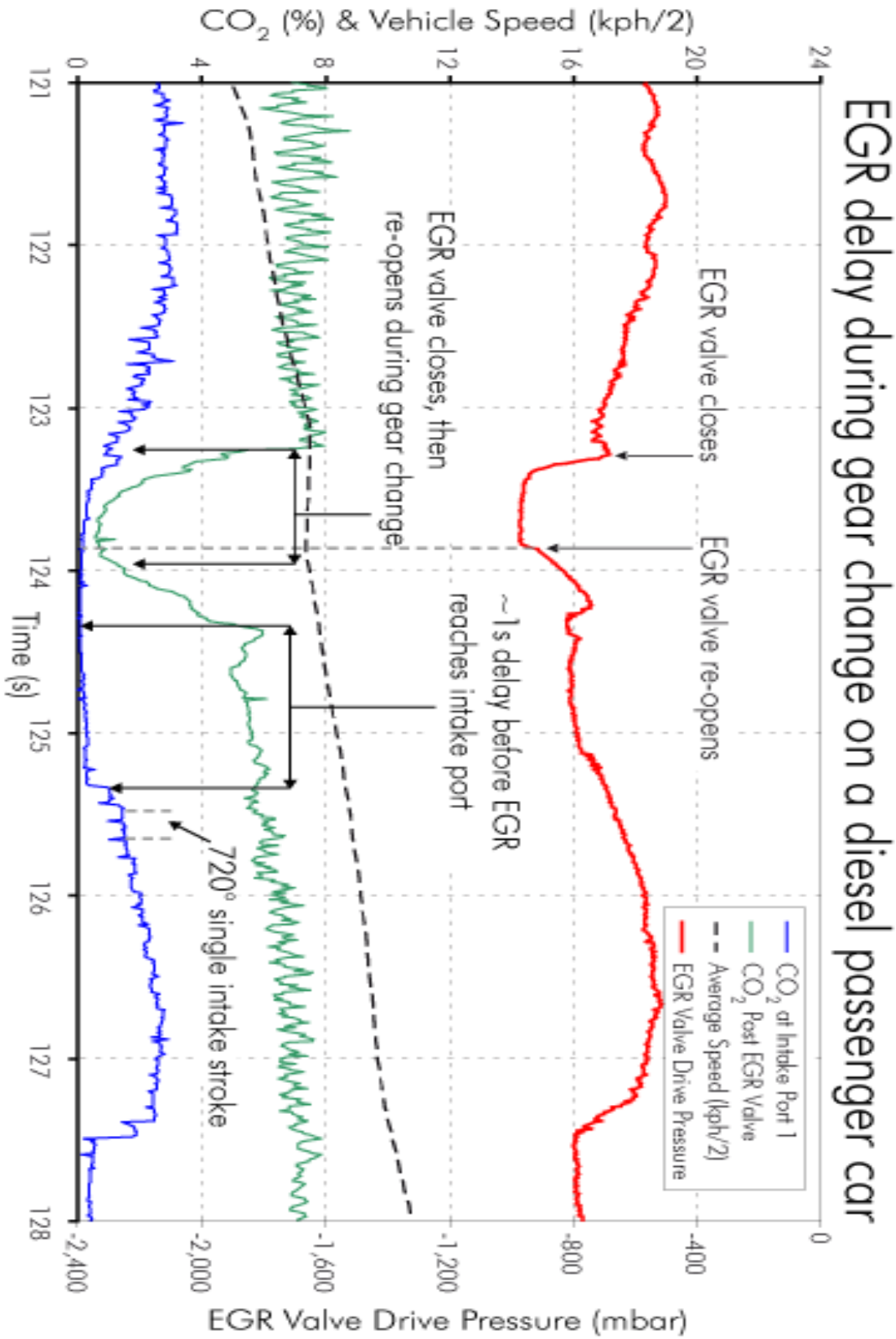

Figure 52: EGR System Working (Cambustion. 2020)

10.8. Appendix H

The image below shows the RAC Foundation data collected from the average speed camera sites

Information relating to **51** permanent average speed camera sites, installed **between 2000 and June 2015**, was collected as part of this study.

25 average speed camera were **analysed in detail** with **294 km of road** covered by these sites.

On average, the permanent average speed camera sites analysed saw **reductions** in injury collisions, **especially** those of a **higher severity**.

Fatal and serious collisions fell, by **25-46%** while **personal injury** collisions fell, by **9-22%**.

Permanent average speed camera sites are estimated to have cost up to **£1.5m per mile** in **2000** but **today** cost an **average of £100,000 per mile**.

The number of average speed camera sites are likely to **increase** as **installation costs** continue to **decrease**.

Installation costs are **declining** due to the **falling cost of technology** and **increased competition** in the market.

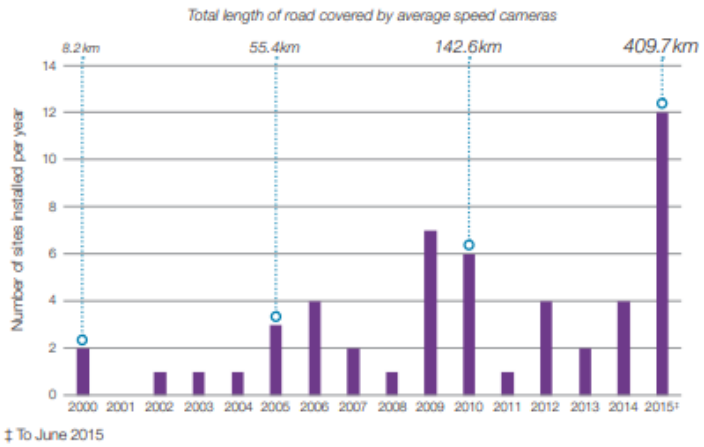

Figure 53: RAC Speed Camera Data (Owen, Ursachi, Allsop. R, G, R. 2016)

10.9. Appendix I

The image below shows the specifications of a 1.5L Ford Kuga, used in section 5.1.

Performance

Power	147 bhp
Top Speed	121 mph
0-60 mph	9.4 secs
Torque	240 Nm, 177 ft-lb
CO_2 Emissions	143 g/km
Euro Emissions Standard	6
Miles Per Tank	594 miles

Costs

Used price range	£9,470 - £13,285
› See 2,976 used Ford Kuga (12-20)s for sale, starting at £6,475	
Fuel consumption (i) Pre-2017 test standard Explanation	45 mpg
Insurance group	21
Annual road tax	£165
Monthly company car tax cost (Basic Rate)	£130 - £130
Monthly company car tax cost (Higher Rate)	£260 - £260

Dimensions

Fuel Capacity	60 litres
Weight	1504kg
Length	4549mm
Width	2077mm
Height	1689mm
Wheelbase	2690mm
Turning Circle	11m

Equipment list & trim options

Figure 54: Ford Kuga 1.5L EcoBoost Vehicle Weight (Parkers. 2020)

10.10. Appendix J

The image below shows the specifications of a 1.0L Ford Fiesta, used in section 5.1.

2017 Ford Fiesta 1.0 EcoBoost Trend specifications Langu

2017 Ford Fiesta 1.0 EcoBoost Trend data

bodywork			
Body type	4/5 seater hatchback		
Number of doors	5		
Designer			
dimensions & weights			
	mm	inches	
Wheelbase	2493	98.1	
Track/tread (front)			
Track/tread (rear)			
Length	4040	159.1	
Width	1735	68.3	
Height	1476	58.1	
Ground clearance			
length:wheelbase ratio	1.62		
Kerb weight	1163 kg	2564 lb	
Weight distribution			
fuel tank capacity	42 litres	9.2 UK Gal	11.1 US Gal
aerodynamics			
Drag coefficient	0.3		
Frontal area	2.15 m^2		
CdA	0.65		
engine			

Figure 55: Ford Fiesta 1.0L EcoBoost Vehicle Weight (Carfolio. 2020)

10.11. Appendix K

The below images show the two vehicles compared in section 5.2.1

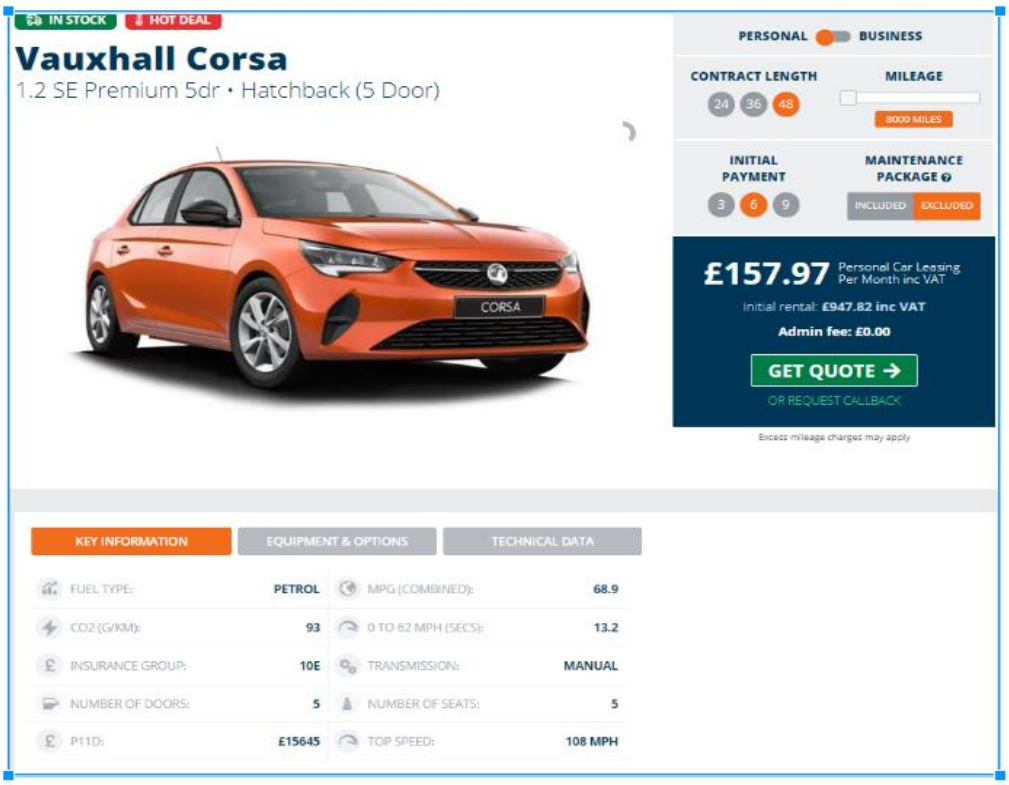

Figure 56: Vauxhall Corsa 1.2L Specifications (Riverleasing. 2020)

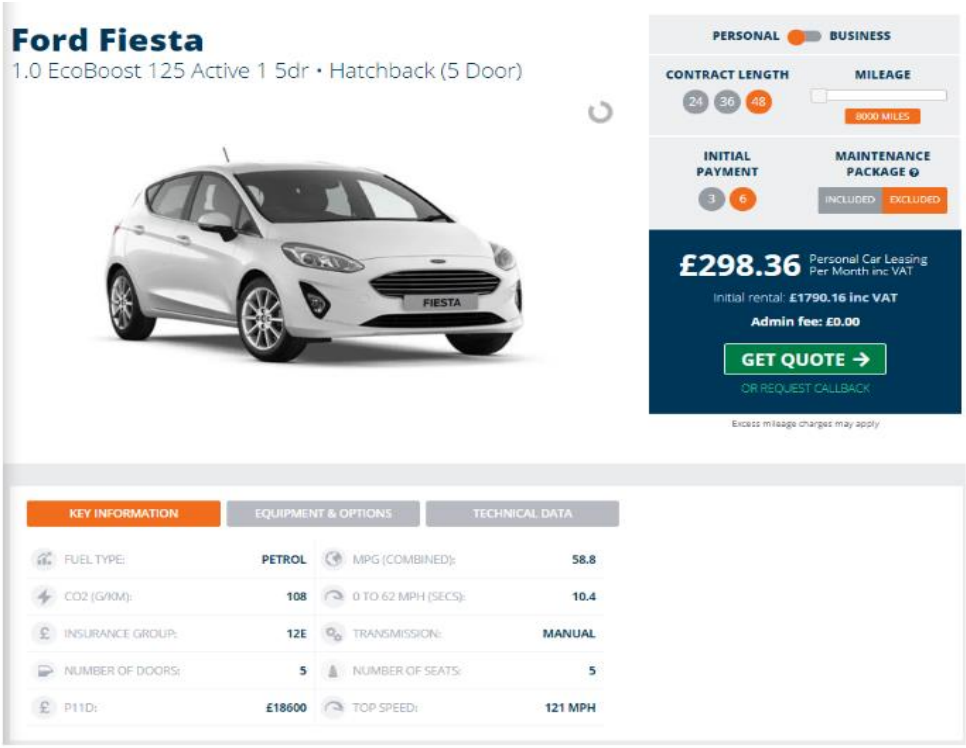

Figure 57: Ford Fiesta 1.0L EcoBoost Specifications (Riverleasing. 2020)