The Cotswold Motoring Museum and Toy Collection

Bourton on the Water, Gloucestershire

Will Plastic Dinosaurs Soon Become Extinct?

The Impact of the Internal Combustion Engine over the last 130 years and its future in the 21st century

Purpose of this Document

This document has been produced in support of a current museum display. It provides much more detail than can reasonably be reproduced in the museum space available and is intended for those who wish to understand the origin of figures quoted in the displays and who may wish to pursue some of the topics in greater depth.

Thank you for downloading the document, we hope you enjoy the read and please feel free to let us know your impressions.

Museum Staff and Volunteers

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Cover image: The Old Mill, Bourton-on-the-Water, today home to the Cotswold Motoring Museum and Toy Collection.

The IMPACT of the Internal Combustion Engine

The Big Question

The title of this paper "Will Plastic Dinosaurs Soon Become Extinct?" harks back to a popular 20th century newspaper headline concerning our dependence on oil. Namely:

"Has ***Peak Oil*** - the point when more oil has been extracted and burnt than is still to be discovered and able to be economically recovered - been reached?"

Quite apart from the world of motoring and transport in general, society depends upon oil for power generation, medical, chemical, textile and many other industries. Although we may not have thought to ask specific questions about plastic dinosaurs, plastic production uses oil – consider the extent to which society today depends on plastic in all its forms - hence the reference to the plastic dinosaur.

In the 21st century it is becoming increasingly clear, based on a global mass of sound science, that our major concern should be about what will happen to our planet if we continue to burn oil. The question we should be asking is:

"What is the environmental impact of motoring and how can it be minimised?"

1. Setting the Scene

There is some dispute about who actually ***invented*** the internal combustion engine. In 1884 a French engineer, Edouard Delamare-Deboutteville, built and drove a vehicle with a single-cylinder, four-stroke engine that ran on petrol and although the design was registered, the vehicle never went into production.

In 1885, Gottlieb Daimler produced a prototype of the modern petrol engine. It was used to power a two-wheeled vehicle, the "Reitwagen" (Riding Carriage) and, a year later, the world's first four-wheeled motor vehicle.

For the first petrol-fuelled car to go into production, and which became available for sale to the public, we must thank Karl Benz who received the first patent (DRP No. 37435) on 29 January 1886.

For the last 130 years, the internal combustion engine has been used to power land, sea and air transport as well as portable plant and machinery. The IMPACT of the Internal Combustion Engine could be summarised as:

a disruptive technology which, over the past 130 years, has brought a multitude of benefits to humanity …
…. plus, several associated problems

Cars powered by the internal combustion engine had an immense influence on the history of the 20th century and, along with other inventions, from the printing press, electric light and textile mills to personal computing and the internet, can fully justify the description of a 'disruptive technology'. ***Just what are these 'benefits' and associated 'problems'?***

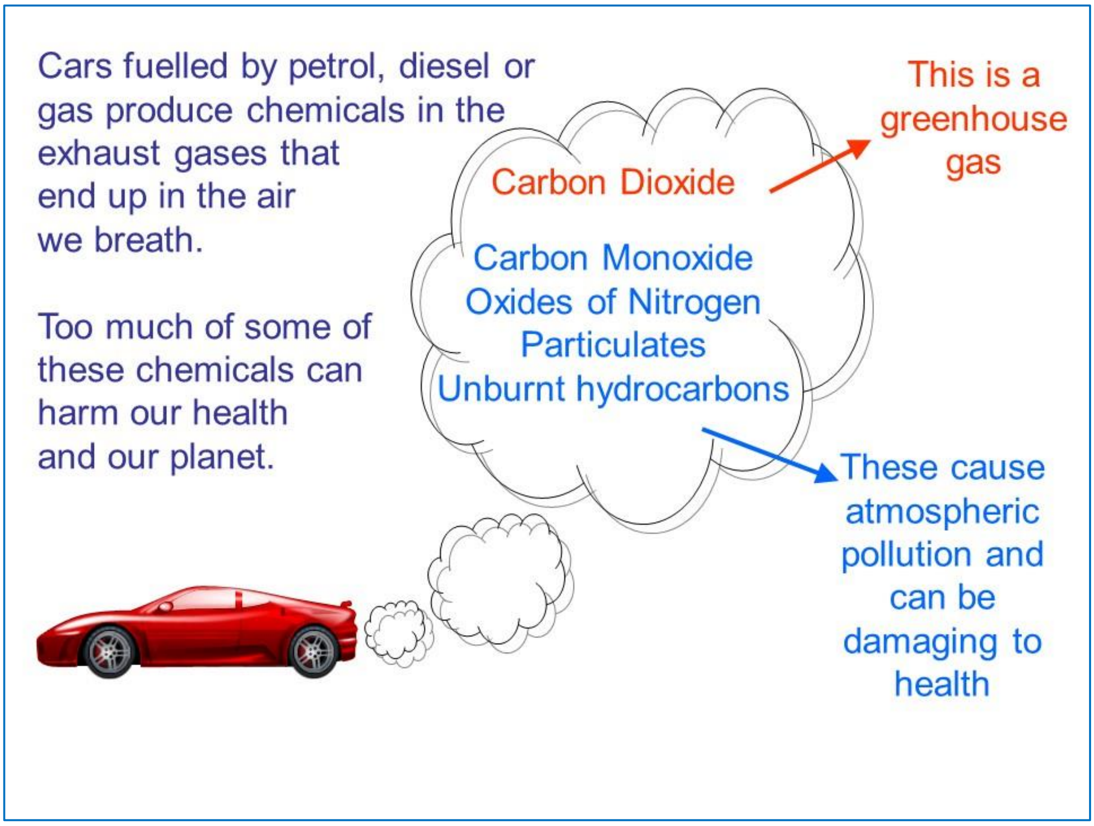
Pros:

- Improved social mobility
- Educational advancement
- Industrial advancement – especially in terms of manufacturing processes
- Enhanced national and international prosperity
- Enhanced employment opportunities
- Enhanced leisure opportunities
- Improved health and well-being[1]
- Environmental benefits[2]

Cons:

- Environmental concerns, including (but not limited to):
  - Air pollution, particularly in urban areas, and consequent detriment to human health
  - Contribution to global warming and acidification of the oceans

The "Cons" list may be shorter, but the IMPACT may be greater and be with us for centuries.



[1] Fresh produce to shops across the country within hours of being gathered or off-loaded at the ports provides choice and health benefits unavailable at the dawn of the motoring age, the car providing the final link to home in the chain.

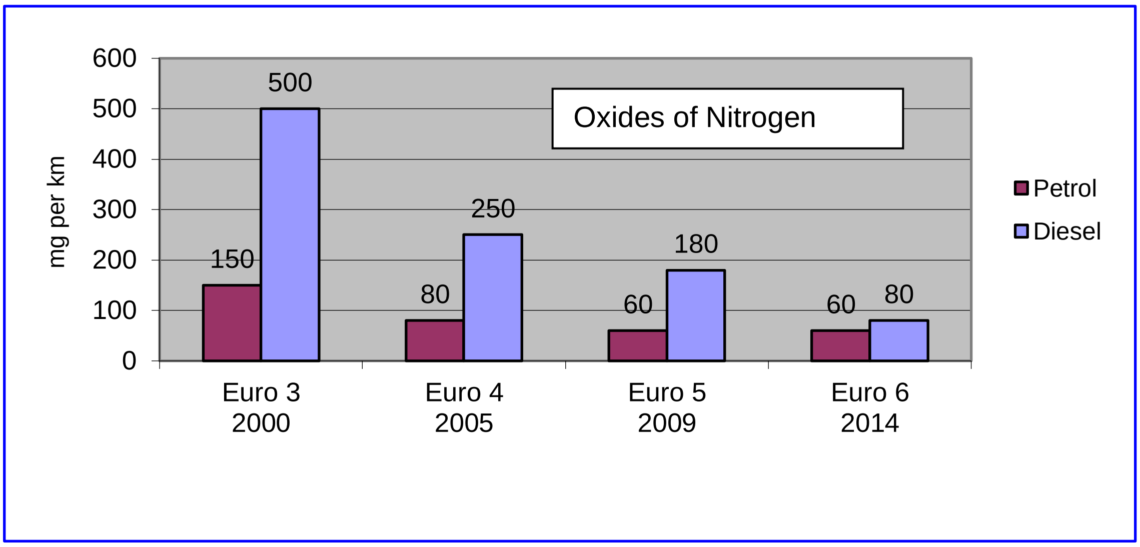
[2] In 1894, the Times of London estimated that every street in the city would be buried under 9ft of horse manure by 1950 and in 1900, in London alone, 50,000 horses provided the motive power for public transport. They produced 1000 tonnes of dung per day. Then along came the car!

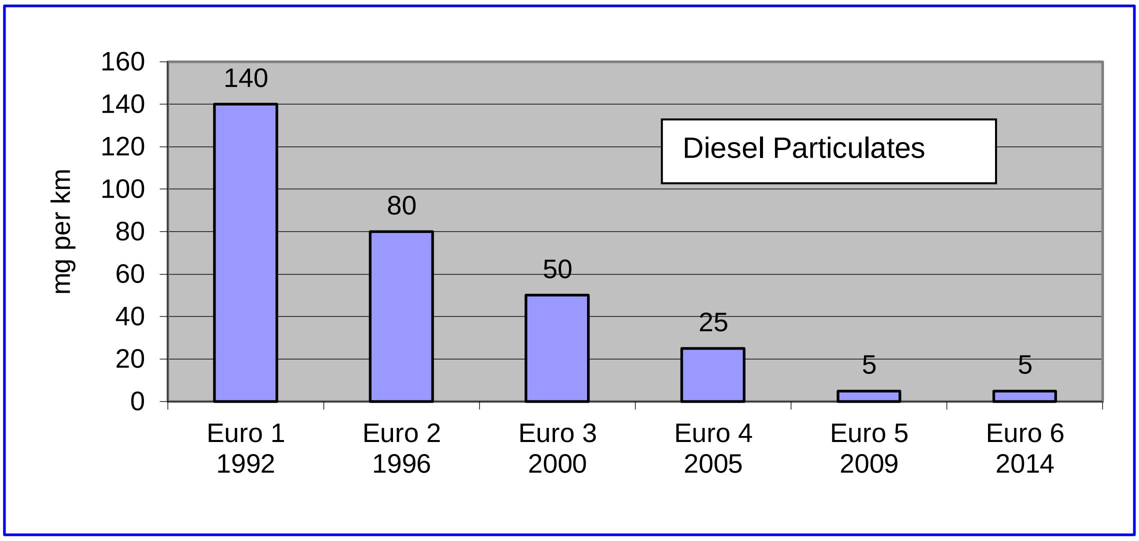
2. Air Pollution and Health

Air pollution has been linked to respiratory and cardiovascular disease, diabetes and cancer. It may also harm foetuses and cause cognitive problems in children and adults. In 2014, the World Health Organisation estimated that air pollution was a factor in ***7 million*** premature deaths worldwide each year. The corresponding figure for the UK is ***40,000*** each year of which nearly half are due to nitrogen dioxide[3]. A recent report from King's College London claims that, in 2015, there were ***9,500*** premature deaths per year, in London, due to air pollution: specifically, particulate matter and nitrogen dioxide. For comparison, the number of fatalities through road traffic accidents in Great Britain during 2017 was 1793 (131 in London).

What steps are being taken to reduce harmful emissions from road transport?

Since 2000, European legislation, for both diesel and petrol cars offered for sale within the EU, has sought to legislate ever lower levels of harmful gases and fuel-derived particulates.





[3] Death certificates do not bear the words "Air Pollution" as a cause of death. It is the mixture of particulate and gaseous vehicle emissions from which expert bodies, such as the UK Committee of the Medical Effects of Air Pollutants, assess the shortening effect on lifespan to be equivalent to tens of thousands of deaths per year.

(Particulates produced by wear from tyres, brakes and the road are excluded from these figures). Two examples of the Euro 5 and 6 levels, along with earlier limits, expressed as milligrams (mg) per kilometre driven, are shown in the graphs above.

So surely, cars are getting cleaner, things are getting better?

Well, there are several reasons why we should be wary of graphs such as those above.

Firstly, a demonstration of compliance with the legally required standards shown in the graphs must be reproduceable from manufacturer to manufacturer and laboratory to laboratory across the globe. Consequently, the legislation defines a driving cycle against which emissions are measured and this driving cycle, known as the New European Drive Cycle (NEDC), ensures consistency across all laboratory testing.

It is however, widely recognised that this testing cycle is not representative of real-world driving. Consumer groups and others have shown that under real-world driving conditions, some new diesel-powered vehicles, compliant with Euro 6 under NEDC testing, can emit up to 20 to 25 times the Euro 6 limits of nitrogen dioxide.

Consequently, new diesel-powered cars are now required to comply with Real Driving Emissions (RDE) testing, which is being introduced in two phases: RDE1 and RDE2.The graphic on the following page adds some figures and dates to this new testing regime.

There are further reasons why the earlier graphs, which suggest we should be seeing a significant improvement in air quality, should be treated with caution. Since 1994, when compliance with the Euro 1 standard became mandatory:

- the number of vehicles on the UK roads has increased from around 25 million (of which 21 million were cars) to 38.7 million as at the end of June 2019. Of these 31.8 million were private cars.

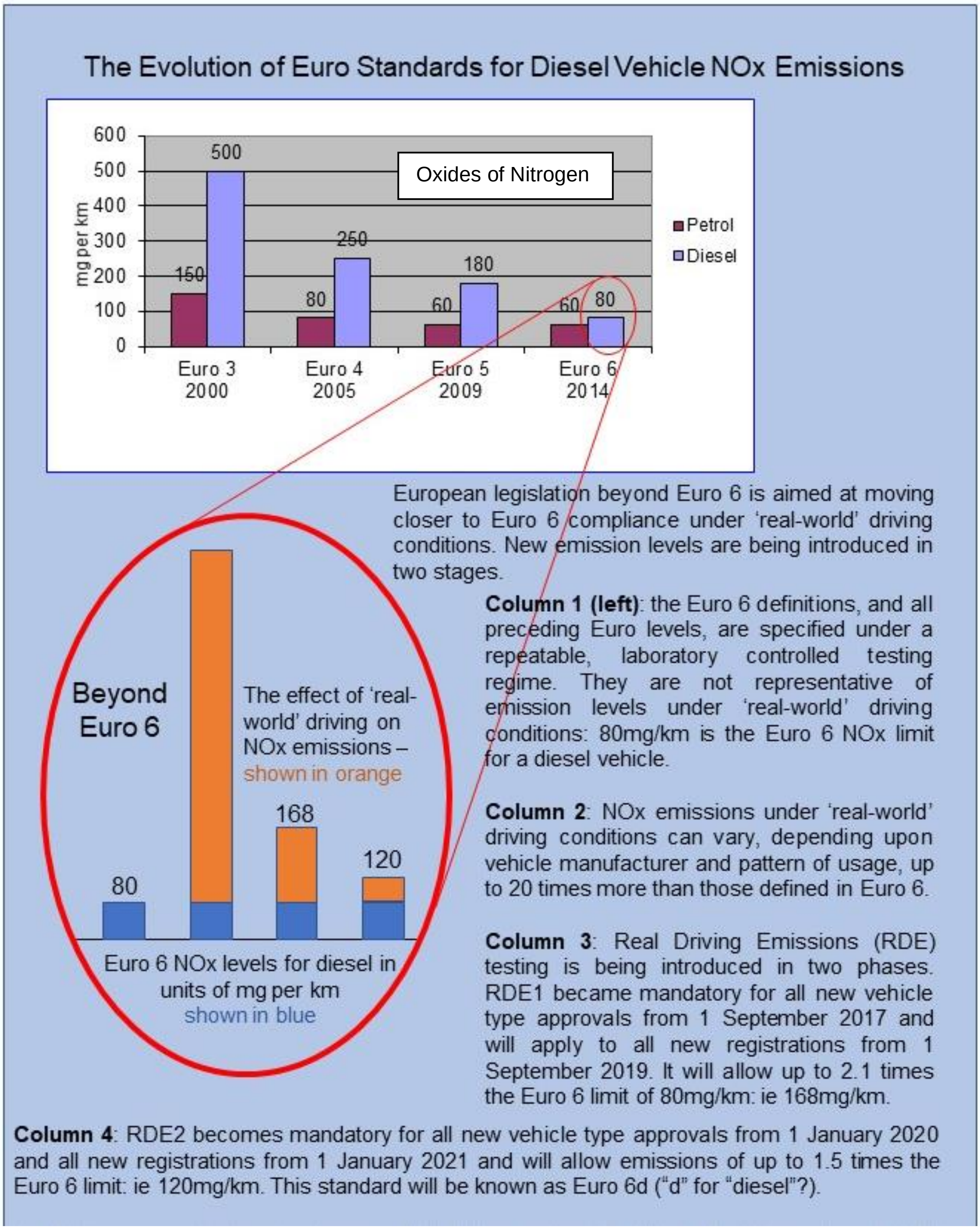
- The fastest growing category of vehicle is the van (Light Commercial Vehicle – LCV), growing in number by 29% over the decade 2002 to 2012, compared with just 11% for the number of cars. Delivering our internet shopping means that the average LCV typically covers 60% more miles per year than the average car. (As from September 2016, all new LCVs also must comply with Euro 6).

- the proportion of diesel cars, of ***all*** ages on UK roads, has increased from 7.4% in 1994 to 40.1% in 2017 (with a slight fall to 39% in 2018).

So, in summary:

- particulate matter and nitrogen dioxide in car exhaust emissions adversely affect human health
- both are emitted in greater quantities from diesel engines than petrol
- the legislated emissions levels are far exceeded in real-world driving conditions
- the number of vehicles on the road has increased year on year since WW2
- the mix of vehicles has changed (more diesel, more LCV)

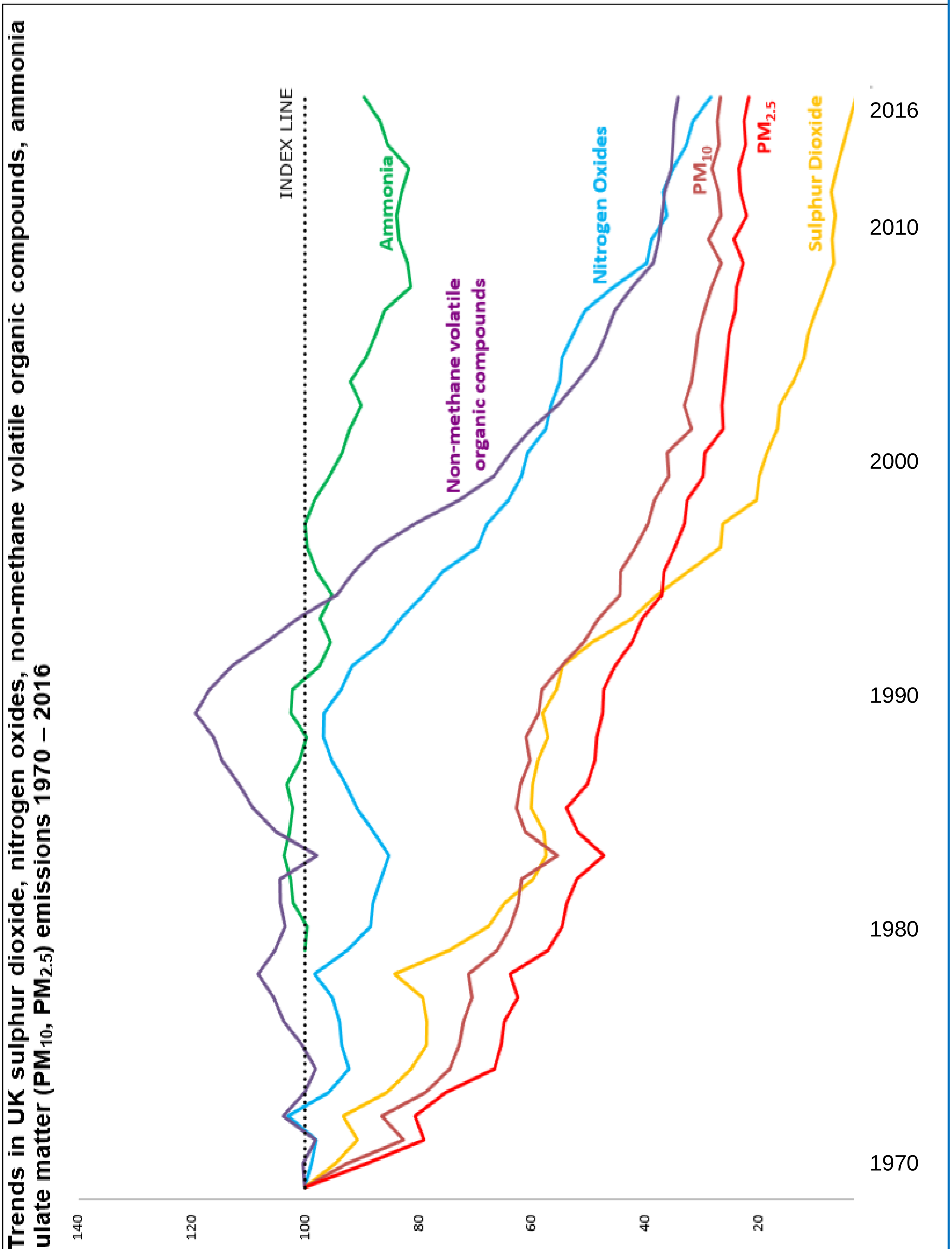
all hindering efforts to improve air quality in our urban areas.



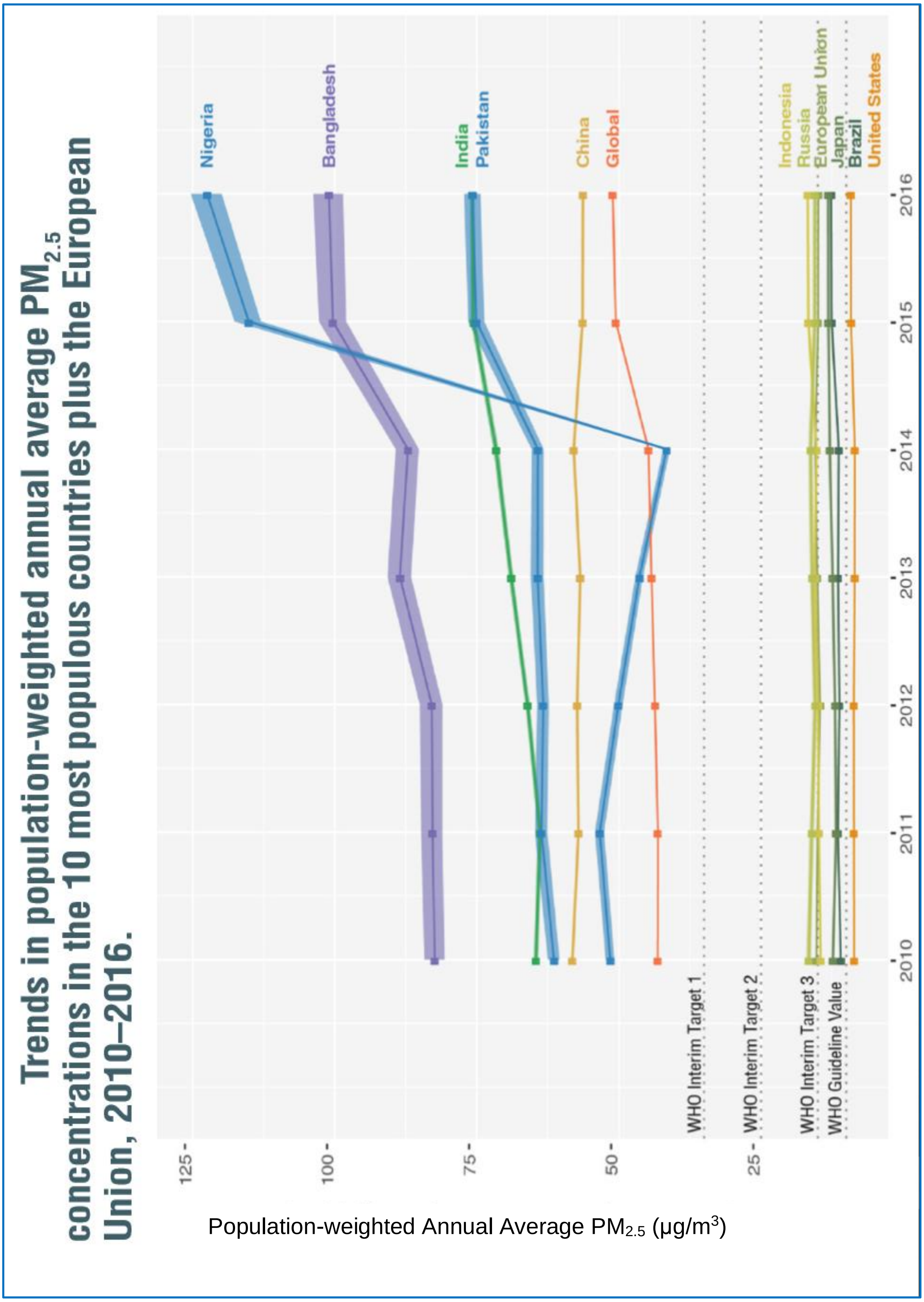
But, across the UK, EU, US, Australia and New Zealand, ***air pollution levels are falling***. For example, figures for particulate matter (soot) less than 2.5microns (ie 2½ thousandths of a millimetre), denoted as $PM_{2.5}$ in the figures below, have fallen steadily since 1970. DEFRA (Department for Environment, Food and Rural Affairs) figures for the UK are shown in the following chart.

They have not however, fallen fast enough to meet World Health Organisation guidelines and, globally, the figures are dwarfed by the increases from developing countries such as Nigeria, Bangladesh, India and China[4].

[4] See both New Scientist, 6 May 2017 and the sources of their data, "DEFRA STATISTICAL RELEASE: 15 FEBRUARY 2018 EMISSIONS OF AIR POLLUTANTS IN THE UK, 1970 TO 2016" and "The State of Global Air 2018" from which the following two graphs are reproduced.



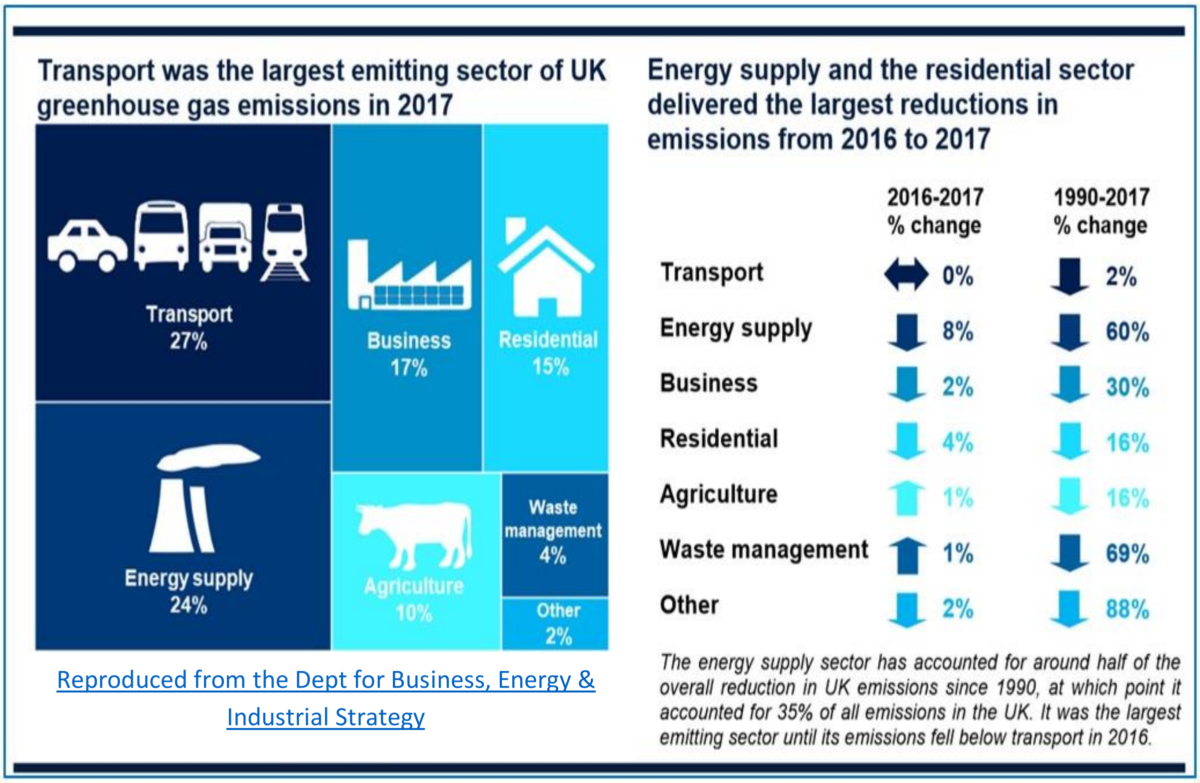
Figures relative to 100 in 1970
(1980 for ammonia)
DEFRA National Statistics Release: Emissions of air pollutants in the UK 1970 to 2016


Trends in population-weighted annual average $PM_{2.5}$ concentrations in the 10 most populous countries plus the European Union, 2010–2016.
Nigeria
Bangladesh
India
Pakistan
China
Global
Indonesia
Russia
European Union
Japan
Brazil
United States
WHO Interim Target 1
WHO Interim Target 2
WHO Interim Target 3
WHO Guideline Value
125
100
75
50
25
2010
2011
2012
2013
2014
2015
2016
Population-weighted Annual Average $PM_{2.5}$ (µg/m^3)

3. Air Pollution and Global Warming

Carbon dioxide (CO_2), methane, nitrous oxide and other so-called greenhouse gases in the Earth's atmosphere have increased steadily since the time of the industrial revolution. Many graphs can be found that show pre-industrial levels of CO_2 averaging around 200 parts per million (ppm) while today, that level exceeds 400ppm: a level not seen for over 400,000 years[5]. Initially, the main contributors to the increase came from the new 19th century industrial economies of Europe, subsequently the US and are now dominated by China, India and newer, developing economies whilst the EU and US emissions are in decline.

Globally and closer to home across the 28 (27?) nations of the EU, power generation, with its heavy dependence on coal, has been the largest single source of CO_2 emissions: larger than the transport sector. In the UK, however, in 2016, for the first time, greenhouse gas emissions from transport exceeded those from energy supply and this trend continued into 2017. It is due to the reduction in the use of coal for power generation whilst the transport figures remain largely constant since 1990. The main contributors to the transport figures are petrol and diesel vehicles.



Reproduced from the Dept for Business, Energy & Industrial Strategy

Historically, CO_2 emissions from road vehicles were not covered by EU legislation. With the increasing evidence that rising CO_2 levels are having a role in global warming, this changed in 2007. As a first step, EU legislation required the CO_2 emissions to be achieved by 65% of new cars registered in the EU from 2012, from each manufacturer, not to exceed 130 grams per kilometre (g/km). A sliding scale of limits applied from 2012 to 2015 at which time 100% had to meet the 130 g/km value.

[5] Air bubbles trapped in ancient ice; in case you were wondering.

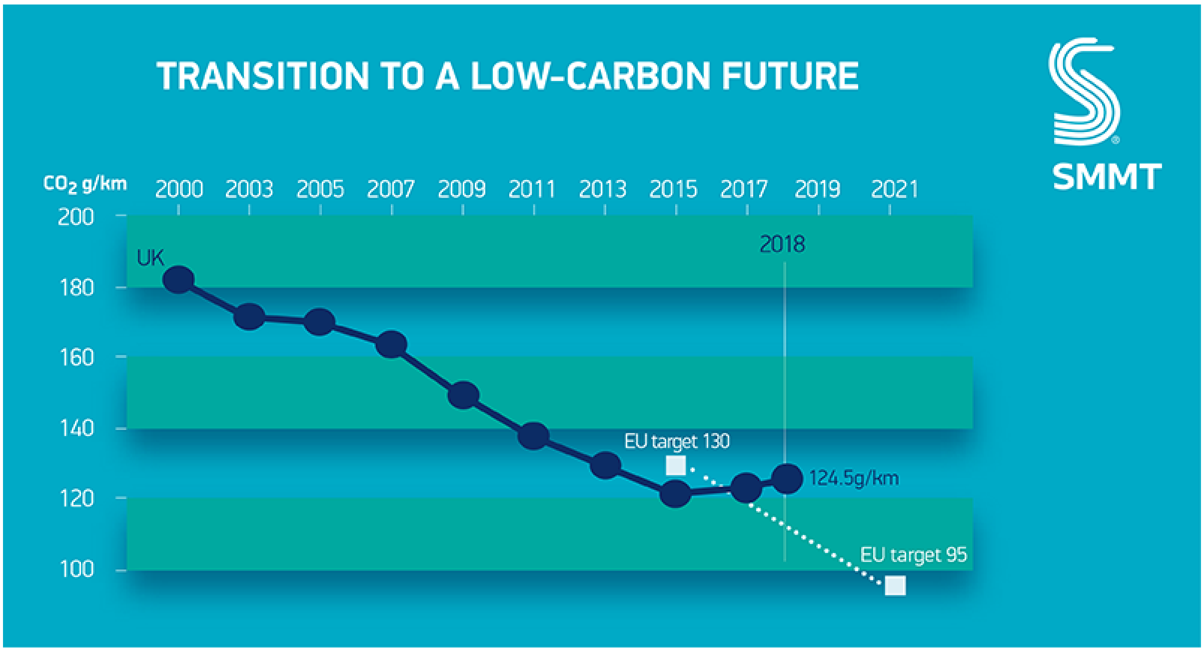
In practice, by the end of 2018, the average for all new cars was 124.5g/km.

European legislation now requires a 95g/km limit for cars to be achieved by 2021 and 147g/km for LCVs. Beyond 2021, the targets are a 15% reduction on the 2021 figures for both cars and LCVs by 2025 and a 30% reduction by 2030.

From September 2017 the EU introduced a new test procedure, known as the Worldwide Harmonized Light Vehicles Test Cycle (WLTC), it covers fuel consumption and CO_2 emissions and, although still a laboratory test, it reflects a 'real-world' driving profile and is the method by which compliance with the above limits will be determined.

The amount of CO_2 present in vehicle exhaust gases is very dependent on the fuel efficiency of the engine. It is for this reason that diesel fuel became the preferred choice for high-mileage drivers throughout Europe: like-for-like performance engines being generally more efficient when burning diesel than petrol. In the UK, this switch to diesel was encouraged by road and fuel tax incentives.

In the UK, the benefit of these incentives in reducing CO_2 can be seen in the SMMT (Society of Motor Manufacturers and Traders) graph below. This shows the year-on-year average CO_2 emissions for all ***new*** cars produced in that year. For comparision, the average of ***all*** cars on the roads of GB in 2017 was 144.3g/km.



The year-on-year downward trend in CO_2 emissions, which has been steady since 1980, when the average was typically around 250g/km, has recently reversed and this is due to the increased awareness amongst the vehicle-buying public of the adverse health implications of the emissions from the diesel engine. In 2017 and 2018 petrol-engine cars, with their higher CO_2 output, outsold diesel (62.3% to 31.7% in 2018) reversing the pattern from earlier years.

No matter how efficient the design, cars propelled just by petrol or diesel will struggle to achieve levels of CO_2 much below about 80-90 g/km. Moves to reduce CO_2 emissions from cars below this figure have seen the increasing use of electric power: either stand-alone electric or as a hybrid with internal combustion.

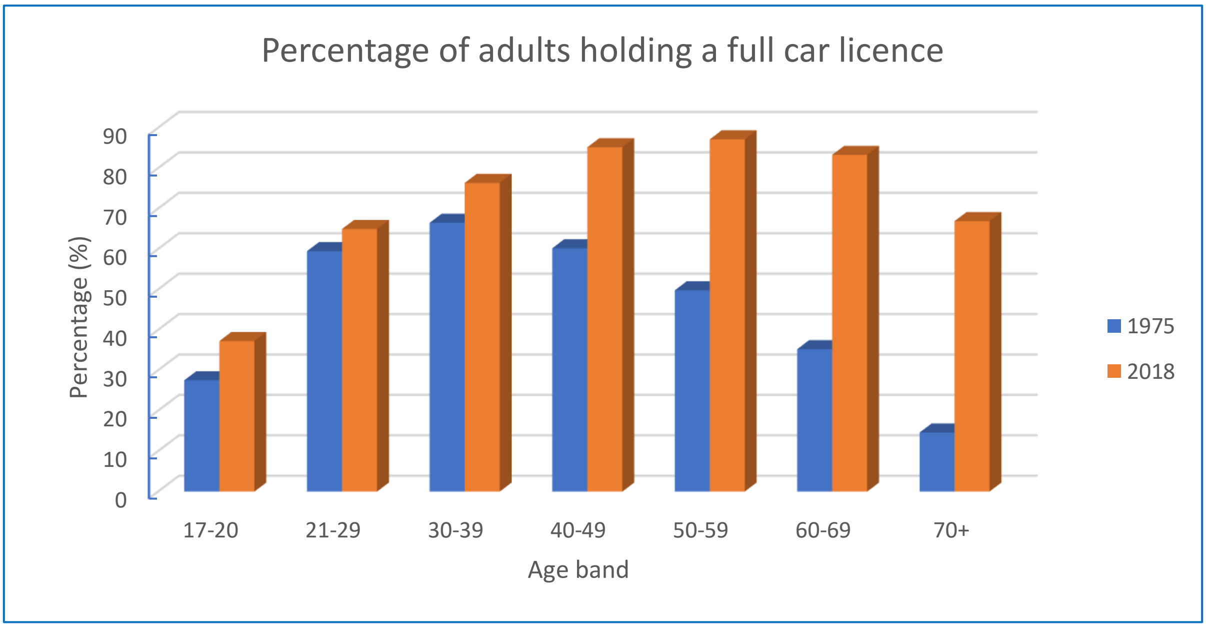
So, in summary:

- in the UK, transport is now the largest contributor to greenhouse gas emissions
- CO_2 emissions from vehicle exhausts dominates this mixture of greenhouse gases
- across Europe, 72% of vehicle emissions are generated by cars and LCVs
- EU legislation has driven down the average new car CO_2 emissions from around 250g/km in 1980 to 124.5g/km in 2018 towards a target of 95g/km in 2021
- in 2017, the average UK new car CO_2 emissions rose for the first time since the 1980s to 121g/km because of both the switch away from new diesel car registrations in favour of petrol and increased mileage[6].

4. The Future

Throughout the 20th century, as cars became 'easier' to own and drive, so the number on the roads of developed countries soared. As examples of why cars became 'easier' to own and drive, consider: the advent of the electric starter motor, avoiding the need for hand cranking an engine, pneumatic tyres, improving ride comfort, power assistance for steering and brakes, and the elimination of driver controls ranging from ignition timing to choke control to automated lights and wipers, not to mention lane keeping and collision avoidance. Couple this with the real terms decreasing cost of purchasing a car, and it is easy to see why the number of cars on UK roads has grown from 14 or 15 in 1895 to 9.97 million in 1970 to 31.8 million today.

In addition, people's life-expectancy is growing, and car manufacturers are addressing the older driver through higher seating, easier access and moves towards autonomous cars: it doesn't look as if the number of cars on the road is about to decline for the next decade at least.



[6] Although the average annual mileage per car in the UK is decreasing, because there are more vehicles, the number of miles travelled per year is increasing. See Annex for Supporting Data.

The performance of the Internal Combustion Engine (ICE) has changed beyond recognition during the 130 years that it has come to dominate our lives. Driven by market competition and global legislation, environmental performance continues to improve and that seems likely to continue with incremental improvements in the efficiency of the ICE over the first few decades of the 21st century. Techniques such as automatic stop-start, turbocharging and cylinder deactivation are now in widespread use by many manufacturers. All help to improve fuel consumption, and hence reduce CO_2 emissions, with turbocharging allowing smaller, lighter engines of equivalent power output to their larger, heavier predecessors. Also, thanks to lower weight materials plus electric rather than hydraulic actuators and improved combustion, the fuel consumption and CO_2 emission figures of the average family saloon from even 10 years ago look very poor when compared with today's figures.

Even with these improvements to the environmental performance of the ICE, legislation within many countries is aiming to move the ICE from the pedestal of prime motive power well before the middle of this century. It will be banned!

Globally, a report by the UN's Intergovernmental Panel on Climate Change has warned that:

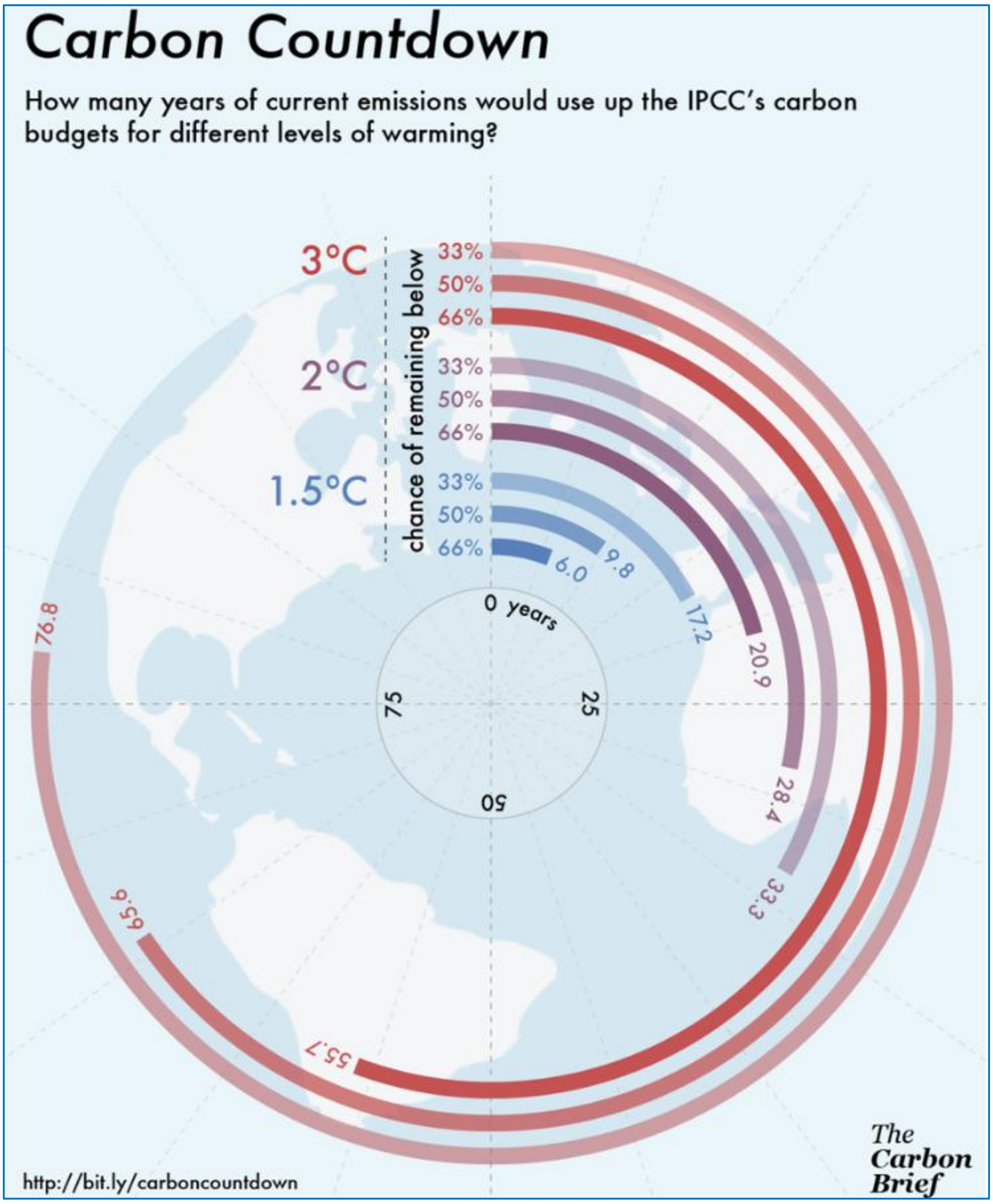
"… keeping to the preferred target [of global warming] of 1.5ºC above pre-industrial levels will mean rapid, far-reaching and unprecedented changes in all aspects of society are needed".

In the UK, the future ban on the sale of cars and vans, powered solely by petrol and diesel, is also partly a consequence of legal challenges to the government. The date currently set for the UK ban is 2040 although there is pressure to bring this forward to 2032. From China (2040) to Norway (2025) and many jurisdictions in between, similar dates have been passed into national law and some cities, which suffer particularly bad pollution, have earlier dates. In most countries, cars that use the ICE as part of a hybrid power train, will initially be exempt.

Are these dates consistent with best estimates of global warming by climate science?

Well, looking at the 2016 chart on the following page, the answer to that question seems to be "barely"! To keep global warming below 1.5ºC, with a 66% level of confidence, we can only continue to emit CO_2 at the current level until 2022. (ie 6 years beyond the date of the 2016 data). 2036 would be the equivalent date for a 2ºC increase. Given the global forecast for 2018 CO_2 emissions is likely to be an all-time high and the forecast of world oil production shows no decline until at least the end of 2020 – see Annex - there is not a lot of scope for optimism.

Battery powered electric vehicles and hybrids of ICE and battery electric are envisaged to be the immediate future, displacing the cars and vans powered solely by the ICE. Purely electric vehicles do not come without some well-known limitations such as range anxiety and limited charging infrastructure, not to mention concern over adequate capacity within the UK generation network. Furthermore, the CO_2 displacement only occurs if the recharging infrastructure is based on renewable energy: nuclear, wind, solar, tidal, wave, hydro or biomass, albeit displacing the location of the pollution from city centre to the site of generation.



It is difficult to see the hybrid vehicle – either plug-in or range-extended - as anything but a stop-gap measure. The weight penalty associated with carrying two power sources, electric motor(s) and ICE, on a single vehicle seems far from ideal.

What lies beyond the battery electric and hybrid era?

The hydrogen fuel cell was invented in 1842 by William Grove and over the last few decades has been the focus of development as a future power source for electric vehicles. Currently, the technology is still expensive in comparison with battery technology.

A fuel cell is an electrochemical, energy conversion device. It converts the chemicals hydrogen and oxygen into water, and in the process, it produces electricity. Electricity can be produced constantly if the flow of hydrogen and oxygen (from the air) continues.

Hydrogen production, for example through electrolysis of water, requires energy and unless this is derived from renewable sources, the overall CO_2 production associated with hydrogen propulsion may not be as little as first appears.

Technical challenges include:

- safe storage of hydrogen in the car. Compressed hydrogen gas – at a few hundred bar - rather than liquid hydrogen, is likely to be stored in carbon-fibre reinforced tanks
- production, distribution (99% of the transported load comprises the weight of the delivery vehicle) and storage infrastructure for hydrogen
- reliable use in cold weather
- reduction in cost through minimising the use of the expensive platinum catalyst.

Nevertheless, hydrogen powered cars are appearing on the roads. In the UK, the Toyota Mirai, Hyundai Nexo and Honda Clarity are available for purchase and in global markets Mercedes also has a fuel cell option. Range between refuelling is typically over 300 miles and refuelling time is around 5 minutes.

As with many air-quality related initiatives, that eventually assume a global scale, California is taking a leading role in establishing a hydrogen fuelling infrastructure with over 60 outlets either open for retail, under construction or awaiting approval. Within the UK there are currently around a dozen outlets but more are planned.

Non-technical, societal changes may also provide part of the solution to the negative impact of the ICE. Driven by cost of ownership and increased congestion, even of electric and hybrid vehicles with partial or complete autonomy, the perception of a car as a status symbol may wither. Less personal ownership and more rent-on-demand services from fleets of battery or fuel cell electric vehicles, with the vehicle chosen to suit the journey and planned use, may become the norm, especially in busy cities.

So, in summary:

- the sale of new cars and LCVs powered solely by an ICE will be banned in most developed countries before 2040
- by that time, most new cars and LCVs will use battery electric or hybrid power sources
- the ICE will have been relegated to a diminishing support role in hybrid vehicles: its 150-year history will be coming to an end
- hydrogen fuel cells to power electric cars, LCVs and public transport are likely to be the first choice in urban areas within the next two decades
- reduced dependency on fossil fuels, specifically oil, will ensure that those reserves that are extracted are used for the medicinal, industrial and domestic uses for which there are few alternatives – rather than burn it. That plastic dinosaur may yet be safe!

The Internal Combustion Engine – The Future

Now

Diesel: better economy, than petrol, hence better for minimising CO_2 emissions. Concern over NO_x and particulates.

Petrol: improving economy, still higher CO_2 emissions, than diesel. Lower NO_x and particulates.

Quote from Dept for Transport, Vehicle Licensing Statistics, Annual 2018: "Average CO2 emissions from cars registered for the first time were steadily falling since 2003, but began to rise from mid-2016 through to August 2018. This increase was broadly due to a shift towards registering larger cars (which have higher emissions) and increases in emissions for popular petrol car models. ".

And this is why:

New car sales in GB in 2012: 50.5% diesel, 48.1% petrol
New car sales in GB in 2018: 32% diesel, 62% petrol

2020 - 2040

Legislation in UK will ban new cars powered solely by Diesel or Petrol from 2040. Other countries are earlier.

2030 and beyond

Hybrid, plug-in hybrid, range extended electric cars and purely electric will dominate new car production from 2030

Issues with ***purely electric*** cars will include availability of public charging infrastructure and charging time.
Issues with ***hybrid*** cars include the 'dead weight' of effectively carrying two engines.
Issues with ***all*** battery powered cars will include availability of scarce materials such as lithium and cobalt

Some of these issues will be overcome by use of hydrogen fuel cells to generate electricity.

5. The Museum Display

Tucked away in a corner of the Mill Gallery at the Cotswold Motoring Museum and Toy Collection in Bourton on the Water is a display entitled "**The Impact of the Internal Combustion Engine**". It is based around a cut-away, moving model of an internal combustion engine that has been in the museum collection for some years.

It is however intended to be more than just a demonstration of the operation of an engine. The aim of the display is to encourage the visitor to ponder some of the effects that the last 130 years of the ascendancy of this piece of technology has had on our lives and the health of our planet.

Starting with "The Big Question", shown above, the display moves on to outline "The Dilemma" that we now face with the environmental and health implications of our ever-increasing dependency on fossil fuel powered transport.

"The Challenge" is to balance the undoubted benefits of our motorised society with the associated damage that is now almost universally acknowledged to be a consequence of the progress of industrial development, including our energy supply, agriculture and, now, predominantly transport.

Continuing to ponder on these major issues for ourselves, our children, grandchildren and our planet, concludes the display on the growth of "The Pollution Problem" and some of the issues around the front running alternatives to the "**The Impact of the Internal Combustion Engine**".

A few images from the display follow.

The Dilemma

The Pros

Motor vehicles have enabled us to transport goods as well as ourselves to **any place** and at **any time**. Imagine all the ways this has led to economic **prosperity** and **well-being**!

The Cons

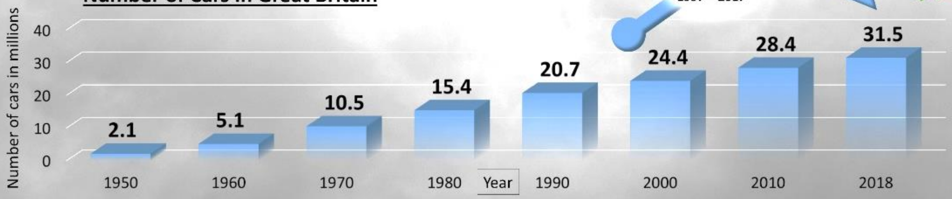
By producing carbon dioxide (CO_2), vehicles have added to the global **rise in temperature**, which has already caused more **extreme weather**. Even more CO_2 will devastate whole **ecosystems** of life.

Motoring contributes to **poor air** quality, especially in urban areas, and is estimated to kill **40,000 people** in the UK each year.

The Challenge

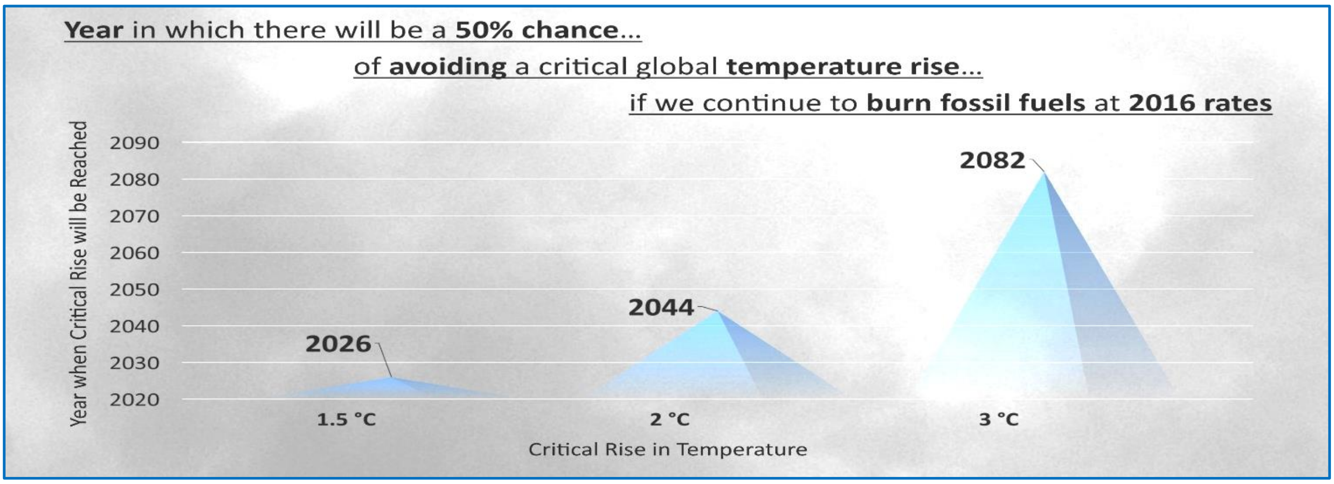
Because of the reduction in coal-fuelled power stations, our total CO_2 output has fallen. Transport now emits the most CO_2 in the UK and radical change is needed to lower emissions further.

In the 20 years up to 2017, the number of vans in Great Britain increased by 75% and having them deliver all of our internet shopping means that they travel 60% further than cars.



If current CO_2 emissions continue, by 2044 there would only be a 50%chance of avoiding the critical 2ºC rise in global temperature. Yet total global CO_2 is increasing at an alarming rate

In the UK, cars and vans powered solely by traditional engines will be banned from 2040



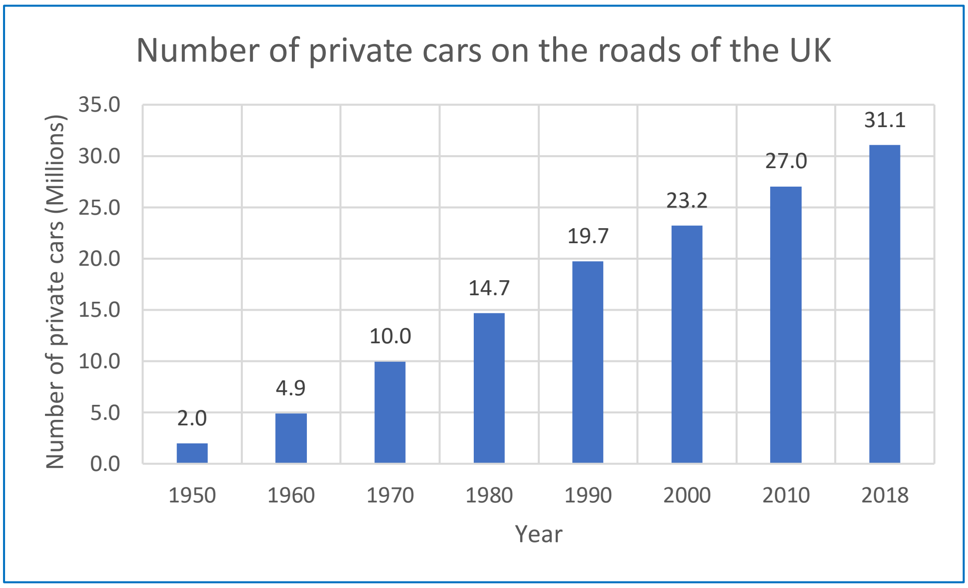
Electric cars with a useful range are becoming reality but they do have drawbacks: batteries contain scarce metals and disposing of them after their short lifespan remains problematic

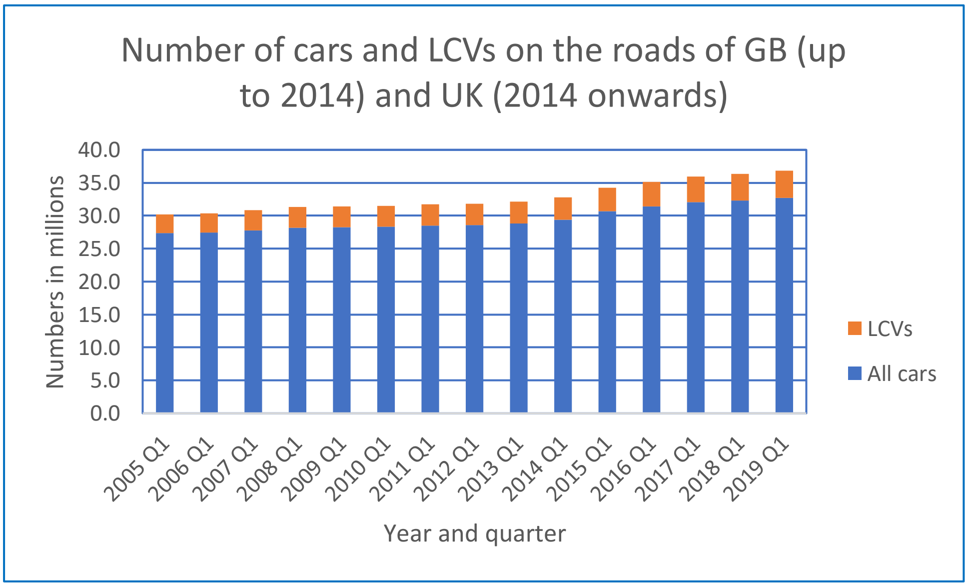
Vehicles powered by hydrogen fuel cells are on the horizon, but building the infrastructure to make and distribute enough hydrogen will need a lot of investment

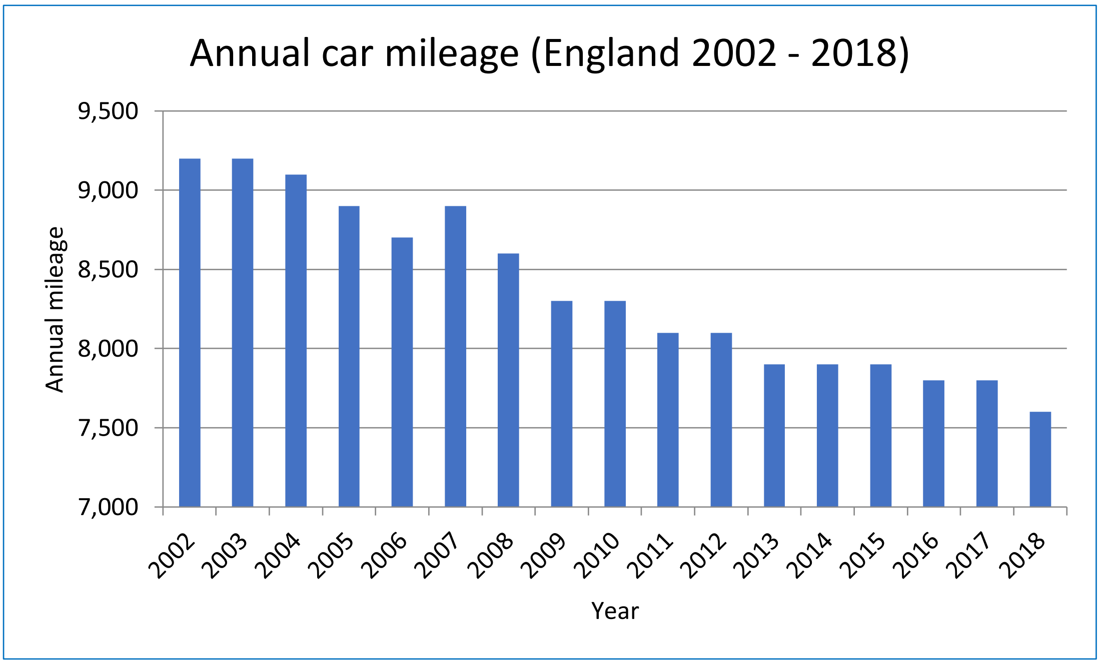
Making hydrogen fuel or recharging batteries to meet demand will require greater electricity generation. In order to produce all the energy we will require from renewable sources, we will have to invest heavily

Big changes are needed but which way will the balance swing?

Annex: Supporting Information






Annual car mileage (England 2002 - 2018)
Annual mileage
9,500
9,000
8,500
8,000
7,500
7,000
2002
2003
2004
2005
2006
2007
2008
2009
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2012
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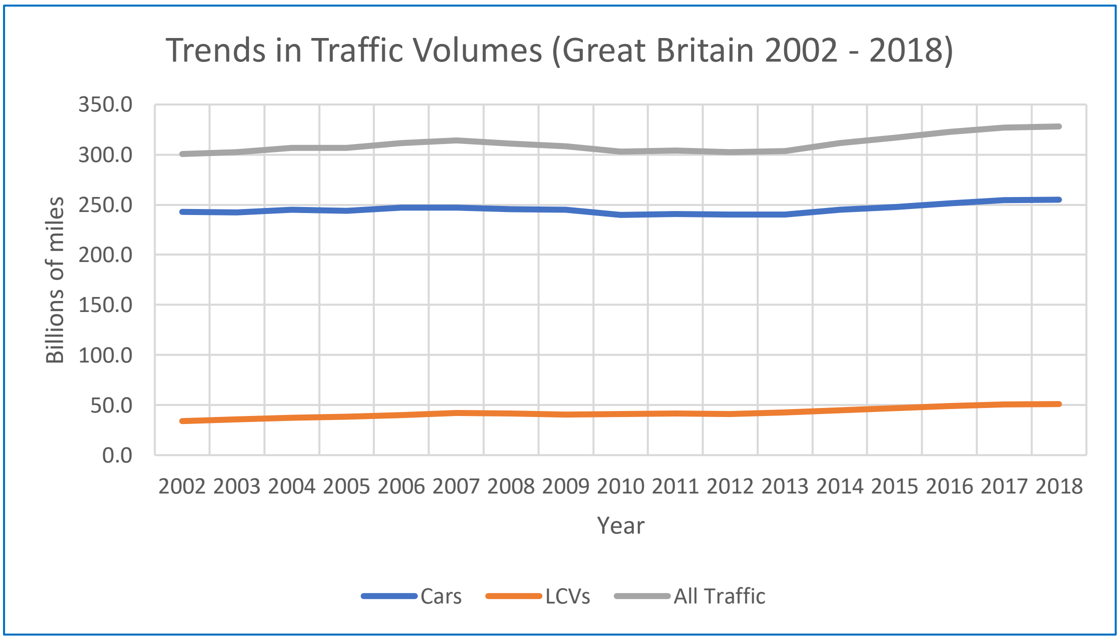
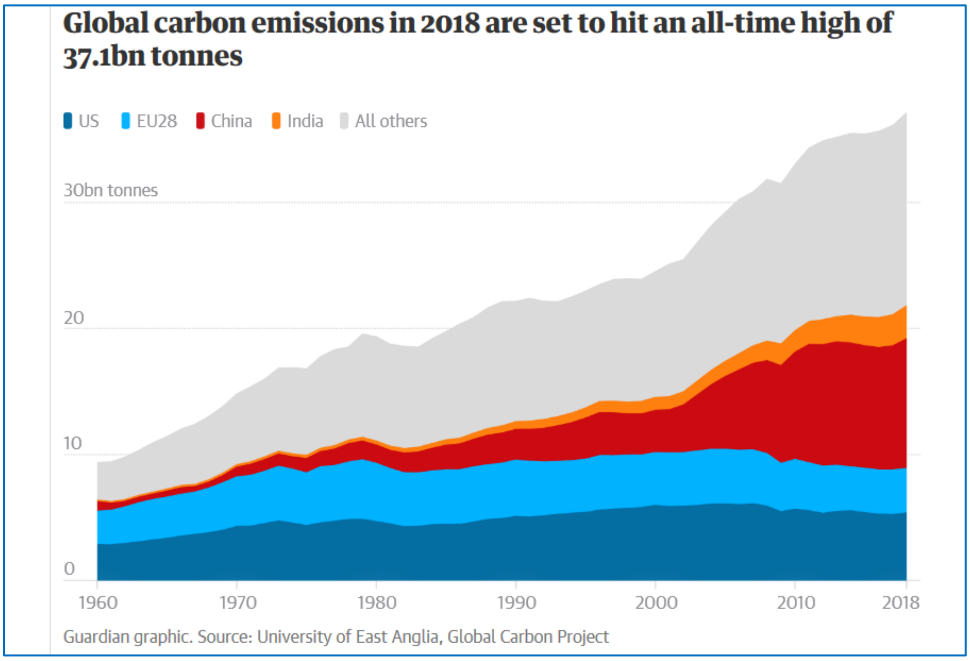
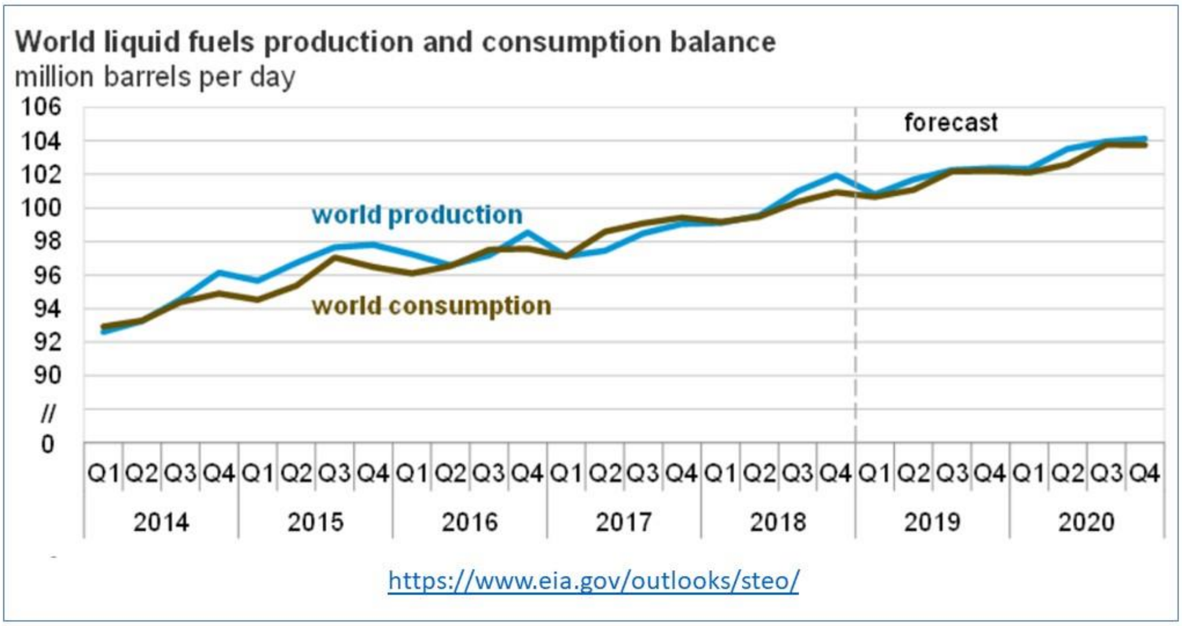
2015
2016
2017
2018
Year


Trends in Traffic Volumes (Great Britain 2002 - 2018)
Billions of miles
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Cars
LCVs
All Traffic


Global carbon emissions in 2018 are set to hit an all-time high of 37.1bn tonnes
US
EU28
China
India
All others
30bn tonnes
20
10
0
1960
1970
1980
1990
2000
2010
2018
Guardian graphic. Source: University of East Anglia, Global Carbon Project


World liquid fuels production and consumption balance
million barrels per day
106
104
102
100
98
96
94
92
90
//
0
forecast
world production
world consumption
Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4
2014
2015
2016
2017
2018
2019
2020
https://www.eia.gov/outlooks/steo/