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Electric cars and their environmental implications – an alternative to diesel?

1 Introduction

It is well known, following the 2015 'scandal' of falsified emissions results, that VW's diesel cars emit far more NOx than previously imagined. Further, even manufacturers who follow the New European Driving Cycle (NEDC) standard test sell vehicles that emit more NOx than is legally permissible when driven in real world situations. NOx, together with fine particulate matter (unburnt carbon), is the cause of polluted air in many cities that causes childhood asthma, cardiovascular and respiratory diseases and lung cancer. Polluted air is a topic of great concern in the UK at the moment because of perceived government inaction to tackle the problem of illegal levels of pollution.[1]

The NEDC is set to be replaced by the more stringent Worldwide Harmonised Light Vehicles Test Procedure (WLTP) in September 2017.[2] The WLTP defines a global harmonized standard for determining the levels of pollutants and CO_2 emissions from, and fuel or energy consumption, and electric range of, light-duty vehicles including cars and vans. Until results from the new test are available for their particular model, diesel car owners will be largely in the dark as to the relative impact of their own car on air pollution when driven under real world conditions.

In addition, all cars, whether petrol or diesel, emit the greenhouse gas carbon dioxide which has a much greater impact on global warming than any other of the exhaust products from road vehicles (for example, the impact of the emitted greenhouse gas nitrous oxide is only

[1] https://www.theguardian.com/environment/2017/apr/25/high-court-orders-uk-government-explain-clean-air-plan-delay
[2] https://www.vda.de/en/topics/environment-and-climate/exhaust-emissions/wltp-worldwide-harmonized-light-vehicles-test-procedure.html

1-3% of that of CO_2 emitted by vehicles).[3] Carbon dioxide from road vehicles can form a very significant proportion of all emissions. For example, in 2015 they formed 33% of the UK's emissions.[4]

For the above reasons, and because of current uncertainty around how unhealthy diesel car emissions will be reduced in future, whether by a price mechanism, a scrappage scheme or some other means, there is understandable interest among many owners of diesel cars in alternatives, including electric cars. Several car manufacturers run, or have run, scrappage schemes. Ford is the latest (August 2017) and, for a limited period, offers a payment for scrapping any petrol or diesel vehicle over seven years old when a new, and much cleaner, Ford model is bought.

The government published a consultation document in May 2017 which sets out the problem with NO_2 emissions, mainly from diesel cars, but puts the burden of solving it onto local authorities; it states '*local authorities must develop plans to achieve compliance within the shortest time possible'*.[5] Tackling particulate emissions was not addressed even though they have serious consequences for human health.

The consultation document also states *' Creating a cleaner transport system is central to these objectives i.e. supporting the uptake of ultra low emission vehicles (ULEVs) and rolling out charging infrastructure for electric vehicles'*. The present text examines the health and climate implications of owning an electric car. A previous WinACC study compared the climate and health impacts of petrol and diesel cars.[6]
Today diesel car owners are faced with three main options.

1. To postpone a decision on whether to keep their car until the new WLTP test reveals the real world emissions from their particular model of car.
2. To sell their car now and manage largely without a car in future.
3. To replace their car now, perhaps before diesel car prices collapse, with one of the alternative options (petrol, hybrid, plug-in hybrid or all-electric car).[7]

Option 1 is attractive in that any eventual decision can hopefully be based on a more secure foundation assuming that the WLTP test is applied retrospectively to existing models of car. Even so, because of the higher standards required it is not even certain that a new diesel car today, designed to match the Euro-6 standard, will meet the strict requirements of the WLTP when driven in the real world. Option 2 will clearly be the best solution from the point

[3] Becker, K. H., Lörzer, R. Kurtenbach, P. Wiesen, T. E. Jensen, and T. J. Wallington. "Nitrous Oxide (N_2O) Emissions from Vehicles." *Environmental Science & Technology* 33, no. 22 (November 1999): 4134–39. doi:10.1021/es9903330.
[4] https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-2015, Table 4.
[5] Anon (Defra). "Tackling Nitrogen Dioxide in Our Towns and Cities: A Consultation." London: Defra, May 2017.
[6] Speed, Robin, and Whitmarsh, Bob. "Petrol Cars versus Diesel Cars: Making a Choice Based on Climate and Health Considerations." Winchester, November 2015. http://winacc.org.uk/sites/default/files/attachments/Petrol%20versus%20diesel%20for%20web%202015_12_15.pdf.
[7] The distinction between a hybrid and a plug-in hybrid car is that the former charges its battery while being propelled by a petrol or diesel engine whereas the plug-in hybrid's battery is charged from the mains. It is not clear that their emissions differ significantly (https://www.afdc.energy.gov/vehicles/electric_emissions.php) and the here we consider only plug-in hybrid cars.

of view of health and climate change impacts, if the car owner decides to walk or cycle or to use public transport, which frequently causes fewer emissions per passenger-kilometre than a car. This option will still leave open the possibility of hiring a car for those occasional journeys which are impractical by other means. The implications of Option 3 are explored further below.

2 Exhaust pipe emissions from cars

In the EU, cars are responsible for around 12% of the total emissions of carbon dioxide (CO_2), the main greenhouse gas.[8] Greenhouse gas emissions of cars are controlled by EU regulations which have set a series of targets.[9] The average emissions level of a new car sold in 2016 was provisionally 118.1 g CO_2/km, significantly below the 2015 target of 130 g CO_2/km. By 2021 the average to be achieved by all new cars in a manufacturer's fleet is 95 g CO_2/km. Manufacturers are allowed to build heavier cars with above average emissions provided that their fleet also includes lighter, less polluting cars to meet the required average. Even stricter targets are expected to be announced later in 2017 for 2025 and 2030.[10]

Although the EU's targets are very encouraging it is salutary to be aware that their latest annual report in 2015 on the CO_2 emissions of cars states '*It is important to mention as well that, for both passenger cars and vans, the reported CO_2 emissions are based upon measurements performed in the laboratory using a standard European vehicle test cycle. Such measurements may not reflect real-world driving performance*.'[11] The deficiencies of the NEDC were mentioned earlier. However, the new WLTP test will be mandatory within the EU for all new vehicle types from September 2017 and for all new vehicles from September 2018. So, although car emissions in the EU are being driven down year on year, the absolute level of these emissions will remain in doubt for at least 18 months.

Electric cars can be either plug-in hybrid or battery electric cars. Although they can be said to have zero tail-pipe emissions, when driven in fully electric mode, the emissions caused by generating the electricity used to charge their battery, whether at a centralised power station or by PV panels, need to be considered. The EU report (ref. 11) shows that the emissions from alternative fuel vehicles (AFV; i.e. battery electric, liquefied petroleum gas, natural gas, ethanol (E85), biodiesel and plug-in hybrid vehicles) have consistently been less than petrol and diesel vehicles since 2000 and are also decreasing at a faster rate. In 2015 the figures were 122.5, 119.2 and 79.2 g CO_2/km for petrol, diesel and AFV vehicles, respectively.

[8] Over 97% of new registrations in 2014 were either petrol or diesel cars.
[9] https://ec.europa.eu/clima/policies/transport/vehicles/cars_en. Even if the UK leaves the EU it is inconceivable that UK car manufacturers will be able to circumvent these targets if they want to sell their products abroad.
[10] http://europe.autonews.com/article/20170315/ANE/170319958/why-tougher-eu-emissions-rules-put-the-combustion-engines-future-in
[11] Monitoring CO2 emissions from new passenger cars and vans in 2015. European Environment Agency Report No. 27/2016.

The emissions of electric cars alone may be even lower than the AFV average suggests. The EU report notes that in the Netherlands, some cars, mainly battery electric and plug-in hybrid vehicles, emit less than 50 g CO_2/km. However the report also mentions that electric cars have zero tail-pipe emissions which, although correct, omits the emissions caused in generating electricity from non-renewable sources. This implies that the Netherlands' average of 50 g CO_2/km is as large as it is due to plug-in hybrid vehicles which use a petrol or diesel engine as well as a battery.

Some examples of emissions which are based on official NEDC figures, for ease of comparison with the EU figures mentioned above, are given in the table.

Comparison of CO_2 and NO_x + PM emissions from electric and petrol/diesel cars

Make	Model	Type	CO_2 g/km	NOx + PM g/km
Nissan	Leaf	Acenta 24kWh Auto	75.6	0.17
Renault	Zoe	Dynamique Nav 68kW Auto	68.8	0.15
Volkswagen	e-Up	Electric Car 60kW Auto	58.8	0.13
Hyundai	Ioniq	Electric Premium Auto	57.5	0.13
EU target 2015	generic	petrol or diesel	130	
EU target 2021	generic	petrol or diesel	95	

It is clear that, even by 2021, petrol or diesel cars will in theory create between 26% and 65% more CO_2 emissions than today's electric cars listed in the table.

3 Health impact of electric cars

Clearly a purely electric car has a great advantage over a petrol or diesel car, especially in densely populated areas, in that there are no exhaust emissions of NOx or particulate matter (but see later regarding non-exhaust emissions). If the car battery is recharged from electricity generated in a central fossil-fuel power station then such emissions will be created but generally in a more rural location where they will tend to disperse before affecting large numbers of people. If the battery is recharged from renewable electricity then the NOx and PM exhaust emissions will be essentially zero.

However emissions of NOx and PM will occur on those occasions when a plug-in hybrid car is driven in petrol or diesel mode but in total these emissions will obviously be proportionally less than from a petrol or diesel car. The mode in which a plug-in hybrid is driven (battery, internal combustion engine or both together) appears to depend automatically on the current power demand during a journey but can also be determined to some extent by the driver.

4 Greenhouse gas emissions from electricity generation

In 2016 electricity which was generated centrally from a UK power station emitted 412 g CO_2e per kWh and when transmission losses in the national grid are included the total

amount was 449 g CO_2e per kWh.[12] This is the average figure for the mix of primary energy sources used in 2016. To compute the emissions per mile from a purely electric car recharging from power station electricity we need to know the energy (kWh) consumed per mile. This can be roughly estimated from the maximum range of the car, which presumably leaves the battery fully discharged, and an estimate of the charging efficiency of the battery (typically 70-90%).[13] For example, a Nissan Leaf Acenta Auto, driven normally under real-world conditions, is said to deliver a range of 124 miles from a 24 kWh battery. This implies that 0.22-0.28 kWh is consumed per mile, depending on the charging efficiency, thereby emitting 60-78 g CO_2/km.

A more exact source of information is the web site NextGreenCar.[14] This site calculates CO_2 and NOx plus particulate matter (PM) indirect emissions of electric cars from fuel production (electricity generation) and manufacture. It assumes an annual mileage of 10,000 miles and a normal driving style (obviously, adopting an ecodriving style will generate fewer emissions per kilometre) but makes no allowance for non-exhaust emissions (see next section). According to the NextGreenCar web site the Nissan Leaf Acenta emits 95 g CO_2/km.

It is not clear why the two calculations differ so much unless the range of the car has been exaggerated. A real-world test of the Nissan car actually achieved a range of 99 miles, and not 124 miles, which suggests the rough calculation would indicate emissions of 75-98 g CO_2/km which agrees much better with NextGreenCar.[15]

There is also a seasonal effect in that in summer, when demand is lower and coal-burning power stations are used less, a greater proportion of electricity is generated from renewable energy so the emissions per kWh are lower than in winter.

Of course, if an electric car is charged with electricity that is entirely from a renewable source then its CO_2 emissions will be close to zero.

5 Non-exhaust emissions from cars

The discussion so far has not recognised the fact that non-exhaust emissions comprise a significant proportion of all air pollution from road vehicles. One study has pointed out that non-exhaust emissions (from the wear of brake pads and the corresponding drums or discs, and the abrasion of tyres and the road surface) already account for over 90% of PM10 and 85% of PM2.5 emissions from traffic.[16] These emissions are independent of the source of energy used to drive a road vehicle, whether from a fossil fuel or electricity. So, although EVs do not emit NO_2, as already mentioned, they will still cause non-exhaust emissions of

[12] https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2016
[13] https://dothemath.ucsd.edu/2011/08/mpg-for-electric-cars/
[14] http://www.nextgreencar.com/electric-cars
[15] http://www.nextgreencar.com/view-car/49677/nissan-leaf-electric-car-acenta-24kwh-auto-electric-(av-uk-mix)/
[16] Timmers, Victor R.J.H., and Peter A.J. Achten. "Non-Exhaust PM Emissions from Electric Vehicles." *Atmospheric Environment* 134 (June 2016): 10–17. doi:10.1016/j.atmosenv.2016.03.017. PM10 signifies the quantity of all particles less than 10 millionths of a meter in diameter.

unhealthy PMs. The problem is made worse by the fact that, because of the batteries, on average EVs are almost one-quarter heavier than the equivalent petrol/diesel car and the non-exhaust emissions of vehicles have been shown to increase with vehicle weight.[17] Presumably brake and road and tyre wear emissions also increase with the speed of a vehicle. Other factors to consider include tyre pressure, air temperature and whether the road surface is wet.[18]

On the other hand, EVs use regenerative braking, whereby the vehicle is slowed electrically with less dependence on the use of brake pads and drums. This means that brake wear is lower on EVs.[19] In a petrol/diesel car brake wear appears to contribute around one third of all non-exhaust PM10 emissions so, because it experiences less brake wear, an EV of the same weight is expected to have lower non-exhaust emissions of PM10.[16] It is not clear to what extent, if at all, the increase in non-exhaust PM10 emissions from heavier EVs are offset by the decrease in such emissions from using regenerative braking.

6 The emissions embodied in a new electric car

It is often forgotten that the purchase of any new appliance or electronic device has an associated environmental cost viz. the emissions embodied in its manufacture (and in all the other stages in the process of getting the new car into the showroom). Mike Berners-Lee reports that 'the embodied emissions of a car typically rival the exhaust pipe emissions over its entire lifetime'. For example, he estimates the footprints of a new car to lie between 5 tonnes CO_2e (Citroen C1) and 35 tonnes CO_2e (Land Rover Discovery).[20] There is no reason to believe that the embodied emissions of an electric car will be substantially less than those of a petrol/diesel car. Indeed, until they become part of a circular economy, the batteries in an electric car may increase the emissions.

Therefore, given that a diesel car typically has lower emissions per kilometre than a petrol car and that diesel engines are well known to be capable of being driven well over 100,000 miles, it may make sense to keep hold of a diesel car until it becomes too unreliable to use. By then the price, embodied emissions and environmental impact of electric cars may have fallen to well below what they are today.

When a car is bought second-hand obviously no new embodied emissions arise but it can be argued that if the original embodied emissions are spread out over the lifetime of the car then the new owner 'inherits' a proportion of these emissions depending on the age and

[17] Simons, A., 2013. Road transport: new life cycle inventories for fossil-fuelled passenger cars and non-exhaust emissions in ecoinvent v3. Int. J. Life Cycle Assess. 1-15.
[18] Non-exhaust particulate matter emissions from road traffic: summary report. TRL Ltd., report PPR231, April 2007.
[19] Barlow, T., 2014. Briefing Paper on Non-exhaust Particulate Emissions from Road Transport [Internet], first ed. Transport Research Laboratory, Wokingham, UK [cited 14 August 2015]. Available from: http://www.lowemissionstrategies.org/ downloads/Jan15/Non_Exhaust_Particles11.pdf.
[20] Berners-Lee, M. *How Bad Are Bananas? The Carbon Footprint of Everything*. London: Profile Books, 2010.

expected lifetime of the car. Other schemes use the price paid for the car compared to that of a new car.[21] This topic is too complex to be discussed further here.

7 Will the UK's infrastructure be able to meet the demand for charging electric cars?

Although this article aims to provide owners of diesel cars with advice about switching to alternative vehicles it cannot avoid the reality that electric cars are likely to place an added load on the UK's ability to generate electricity. In fact the ability of electricity generation capacity to meet the demands of electric cars is fast becoming a wider problem in the developed world. For example, in July 2017 France announced that sales of new petrol and diesel cars will be banned by 2040. And the electric car and battery markets are already advanced in Asia and the USA.

Charging a single electric car from scratch, as opposed to overnight topping up, might require as much electricity as an average household uses over three days. In the UK the National Grid recently predicted that the number of electric cars might increase one hundred fold by 2030[22] and, depending on the time of day when charging occurred, the peak demand might grow by an amount that exceeds the output of the two Hinkley Point C nuclear reactors currently being built.[23] On the other hand charged car batteries could, as part of a national smart grid, represent a means of storing electricity and delivering energy back to the grid when required.

An alternative view, in a report by Cambridge Econometrics, is that 'Electric vehicles would lead to an increase in electricity demand of only 10% by 2040'. This apparently strongly contrasting conclusion is based on assumptions about the mix of vehicle sales and vehicle survival rates, the efficiency of new vehicles and that EVs would make up 70% of new road vehicle sales by 2040.[24] However, the likely annual output of the two 1600 MW Hinkley Point reactors is around 17 TWh which represents only about 5% of today's total electricity consumption so the estimates are not necessarily in conflict.

8 Conclusion

Other factors such as the availability and cost of charging points, the present relatively limited range of electric cars, the current high cost of a new electric or hybrid car, and battery hire charges or eventual battery replacement costs may deter some drivers from buying an electric car at the present time. However there is little doubt that electric cars

[21] https://sustainability.stackexchange.com/questions/4441/how-to-account-for-environmental-impact-of-second-hand-goods

[22] Over 108,000 electric cars and vans had been registered by April 2017.

[23] http://fes.nationalgrid.com/fes-document/

[24] Evans, Simon. "Analysis: Switch to Electric Vehicles Would Add Just 10% to UK Power Demand." *Carbon Brief*, July 27, 2017. https://www.carbonbrief.org/analysis-switch-to-electric-vehicles-would-add-just-10-per-cent-to-uk-power-demand?ct=t(Carbon_Brief_Weekly_28_07_2017).

represent the future and costs will fall. One car manufacturer, Volvo, has recently stated it would launch only hybrid, plug-in hybrid or 100% electric cars from 2019![25]

Looking even further ahead than the lifetime of a new car bought today future cars may involve autonomous or driverless driving and possibly cars may no longer be owned by individuals but be used in a shared mode as a form of public transport.

Moving to an all-electric or plug-in hybrid car will reduce carbon dioxide emissions from driving and eliminate air pollution caused by nitrogen dioxide, other things being equal. However an electric vehicle still emits small, non-exhaust particles that can cause serious health problems. It is presently unclear whether these emissions are more or less than from an equivalent petrol/diesel car. The small particles include those less than 2.5 microns in diameter which have the most serious impact on health. Replacing a diesel car by an electric car will not necessarily reduce these small particle emissions. Finally, it has to be remembered that any new car, of whatever sort, comes with significant embodied emissions involved in its manufacture.

So, unless a diesel car is used mainly within cities where air pollution is a concern, hanging on to it until it is no longer reliable may be the better option from the environmental point of view. But eventually, and ideally, it should be replaced by an electric car. Preferably this car should be charged with electricity from a renewable source.

Bob Whitmarsh, July 2017

What should I do (to combat climate change)?

- **Unless you use a diesel car mainly within cities where air pollution is a concern, hanging on to your car until it is no longer reliable is the best option from the environmental point of view.**

- **Eventually it should be replaced by an electric car. By then the price, range, embodied emissions and environmental impact of electric cars are likely to have fallen.**

- **If much of your driving is urban, then changing to an electric car is recommended.**

(WSID added Dec 2018)

[25] Adam Vaughan, The Guardian, 14 July 2017.