K4D Knowledge, evidence and learning for development

Emission reductions and health impacts of LEVs

William Avis
University of Birmingham
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Question

Provide a comparison of emission reductions and health impacts associated with different types of low emission vehicles (LEVs e.g. PHEVs, BEVs, HFCEVs and bio fuels) and an exploration of the factors that influence these reductions

Contents

1. Summary

This rapid literature review summarises evidence on *Emission reductions and health impacts of Low and Zero Emission Vehicles (LEVs and ZEVs)*. The review found a disparate but emerging evidence base derived from studies exploring the issue in a range of settings (predominantly high and middle income countries). The evidence base provides a mixed and complex picture given the heterogeneity of methodological approaches and contextual analyses to assessing reductions and health impacts. The report found a focus on carbon emission reduction and less evidence on other emissions. Given the above, evidence has been collected and presented in an annotated bibliography. A note of caution should be raised when drawing lessons from particular studies, with findings influenced by a range of contextual factors. This review should be read alongside an earlier study that explored **Electric Vehicle Uptake and Health.** The report is structured as follows:

- Section 2 provides an overview of the contribution of transport to air pollution
- Section 3 provides an overview of different types of "Low" and "Zero" Emission Fuels and Vehicles
- Sections 4 provides an overview of CO_2 and different types of vehicles
- Section 5 provides an annotated bibliography that explores emissions and different types of vehicles

Key messages from the report are as follows:

Road transport is a major source of air pollution that harms human health and the environment. The contribution of transport to urban air pollution has been evidenced by a wide body of research. Vehicles emit a range of pollutants including nitrogen oxides (NOx) and particulate matter (PM). The transport sector also accounts for over 20% of global carbon dioxide (CO_2) emissions.

Efforts to develop emission standards for vehicles alongside technological advances have significantly reduced the impact of vehicular emissions, though in some settings, air pollution levels continue to exceed guideline amounts. The EU, for example, has set limit values for the maximum amount of air pollution citizens should breathe.

Technological advances have seen the development of a range of vehicles/fuel types that have attempted to address some of the emissions related to transport. These include:

- **Hydrogen fuel cells:** Fuel cell electric vehicles (FCEV) that run on compressed hydrogen are considered zero emission vehicles in EU legislation, only emitting water. However, the technology remains expensive.
- **Sustainable advanced biofuels:** For passenger cars the drop-in options that can be blended to fossil fuels in current vehicles are different types of bioethanol and biodiesel. Starch and sugar crops are typically grown on agricultural land for the production of bioethanol or biomethane, also result in indirect land-use change.
- **Electrofuels (synthetic diesel and petrol)** are electricity based gaseous or liquid fuels which can be used in internal combustion engines, in the form of synthetic petrol or synthetic diesel. They would only have meaningful climate benefits if strict sustainability criteria are observed throughout the production process.

- **Battery electric vehicles (**BEVs) are considered the most promising and optimal zero emission technology to decarbonise car fleets: they have zero exhaust, GHG, air pollutant or noise emissions, are the most efficient option considering the power needed to directly charge the battery, and are cost-competitive in some markets given low running and maintenance costs.
- **Other -** There are also various transitional and combined solutions available. Plug-in hybrids (PHEV) are regarded as the main transition technology from Internal Congestion Engine Vehicles (ICEV) to full EV. PHEVs may have a brief role to play as a transitional technology, but they are ultimately unable to deliver zero emission mobility and cannot be relied upon for longer term decarbonisation.

A number of factors influence the emission reduction potential of vehicles these include:

- **To assess full environmental impact of different technologies, we need to consider all emissions that occur in the whole energy supply chain.** Total GHG emissions of vehicles are dependent on energy used in cars. The total carbon intensity of grid electricity is dependent on the emissions caused during fuel upstream production, fuel combustion at power plants, and the electricity losses in transmission and distribution. Performance of different technologies thus varies from country to country.
- **The source of electricity influences the carbon reduction potential of different types of vehicles.** Where electricity is derived predominantly from coal power stations the potential impact of EVs is significantly reduced when compared to those grids where electricity is generated from renewable sources.
- Despite this, studies have shown that **Small EVs have the lowest carbon footprint of travel compared to other light duty vehicles.**
- **There exists a relationship between weight and non-exhaust PM emission factors**. EVs are often heavier than equivalent ICEVs. As a result, total PM_{10} emissions from EVs were found to be equal to those of modern ICEVs. $PM_{2.5}$ emissions were only 1–3% lower for EVs compared to modern ICEVs[1].
- **Different alternative fuels will have variable impacts, for example biofuels blends would have a beneficial effect on particulate matter ($PM_{2.5}$) emissions reduction but an overall negative effect on nitrogen oxides (NOx) emissions**.
- **Comparison between different types of vehicle show that EVs in some contexts and with existing national grids would produce an average of 7% more GHG emissions than HEVs** over the same distance. However, they will produce an average of 19% less GHG emissions than the ICEVs. Overall, the GHG emissions produced through the usage of EVs are substantial based on the well-to-wheel analysis, as the environmental profile of EVs is linked with the national grid. in order to accrue the benefit of EVs in terms of climate change and global warming mitigation, modernisation and transformation of national grids is required.

[1] Particulates – also known as atmospheric aerosol particles, atmospheric particulate matter, particulate matter (PM), or suspended particulate matter (SPM) – are microscopic particles of solid or liquid matter suspended in the air.

- **As vehicle exhaust emissions have decreased, non-exhaust emissions have become relatively more important**. In particular, PM emitted from tyre and brake wear is now comparable to exhaust emissions. BEVs and ICE vehicles can have different emission levels. Tyre wear is a function of many factors: heavier BEVs are expected to give more tyre wear PM emissions while brake wear PM emissions can be lower on electrified vehicles, which use regenerative braking.
- **In terms of recent EURO class emission trends, NO and NOx emissions decrease from EURO 5 to EURO 6 for nearly all vehicle categories.** Interestingly, taxis show a marked increase in NO_2 emissions from EURO 5 to EURO 6. Perhaps most concerning is a marked increase in PM emissions from EURO 5 to EURO 6 for HGVs.
- **Analysis revealed that EVs running in the Malaysian electricity mix will, on average, produce at least 6.4% to 7.9% more GHG emissions (g CO_2 e.q.) than HEVs at the same distance. However, they will produce an average of 16 –22.5% fewer GHG emissions than the ICEVs.**

2. Contribution of Transport to Air Pollution

The contribution of transport to urban air pollution has been evidenced by a wide body of research, see for example (Jiao et al., 2020). Road transport is a major source of air pollution that harms human health and the environment. Vehicles emit a range of pollutants including nitrogen oxides (NOx) and particulate matter (PM). The transport sector also accounts for over 20% of global carbon dioxide (CO_2) emissions (Ritchie, 2020). Sustained effort has been made to establish emission standards to reduce the impact of transport (particularly road transport) on public health and explore how technological advances can support a transition to a greener, healthier, carbon-free transport system e.g. Ghaffarpasand et al., (2020). Efforts to develop emission standards for vehicles alongside technological advances have significantly reduced the impact of vehicular emissions, though in some settings, air pollution levels continue to exceed guideline amounts. This is particularly the case in the global south where the import of older, more polluting vehicles is common.

Human exposure to transport-related air pollutants

Exposure to transport-related air pollution varies according to area and population group, dependent on length of stay and activities in polluted areas. Studies have shown that exposure concentrations are higher near busy roads when compared with background measurement sites (see Pope et al., 2018). Exposures can also be significant inside vehicles with primary exhaust gases where PM are often recorded at elevated levels. Patterns of exposure are complex and vary, depending on pollutant and behaviour of the particular population groups. Further to this, the intake of pollutants differs among drivers, bicyclists and pedestrians. Finally it is also important to note that it is difficult to separate exposure to transport-related air pollution from exposure to the pollution from other sources (Krzyzanowskiet et al., 2005).

Despite this complexity, evidence from a range of epidemiological and toxicological studies illustrates that transport-related air pollution affects a number of health outcomes. Pollution contributes to increased risk of death, particularly cardiopulmonary causes, and increases the risk of non-allergic respiratory symptoms and disease (Krzyzanowskiet et al., 2005).

Studies also indicate an increased risk of various types of cancer in people with prolonged exposure to transport-related air pollution. One such example is occupational exposure (e.g. professional drivers and railway workers), which has been shown to increase the incidence of (and mortality from) lung cancer. Evidence has also reported adverse effects on pregnancy, as foetuses are considered susceptible to a variety of toxicants present in transport -related air pollution. Birth outcomes, such as an increase in post-neonatal infant mortality, and a decrease in male fertility may also be affected by transport-related air pollution (Krzyzanowskiet et al., 2005).

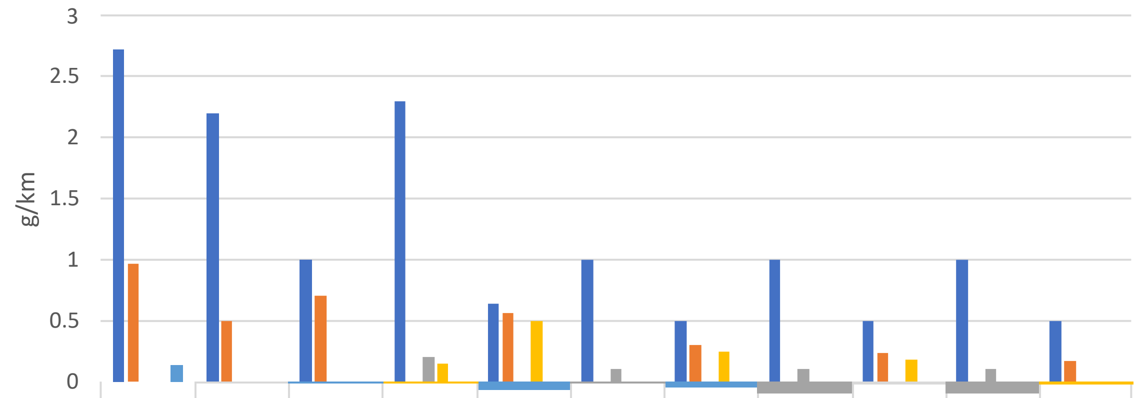
The WHO have identified airborne particulates as a Group 1 carcinogen. Particulates are the most harmful form of air pollution due to their ability to penetrate deep into the lungs, blood streams and brain, causing health problems including heart attacks, respiratory disease, and premature death. Raaschou-Nielsen et al (2013) conducted a study involving 312,944 people in nine European countries and concluded that there was no safe level of particulates and that for every increase of 10 μg/m3 in PM_{10}, the lung cancer rate rose 22% [95% CI 1·03–1·45]. The smaller $PM_{2.5}$ were particularly deadly, with a 18% increase in lung cancer per 5 μg/m3 ([CI 95 % 0·96–1·46]) as it can penetrate deeper into the lungs.

Emission Standards

A range of emission standards for vehicles have been developed at national and regional levels to reduce levels of air pollution and improve health. The EU, for example, has set limit values for the maximum amount of air pollution citizens should breathe. Despite these standards, many urban populations are still exposed to levels of nitrogen dioxide (NO_2) and PM that exceed acceptable limits. The first European exhaust emissions standard for passenger cars was introduced in 1970. These were amended in 1992 when the 'Euro 1' standard accompanied the fitting of catalytic converters to petrol cars to reduce carbon monoxide (CO) emissions. The latest standard, 'Euro 6', applies to new type approvals from September 2014 and all new cars from September 2015 and reduces some pollutants by 96% compared to the 1992 limits. The Euro 6 test became more stringent from September 2017 with the addition of an extended on-road emission test known as Real Driving Emissions or RDE. Other countries have also developed emission standards (see Continental-Automotive, 2019 for an overview of EU, US, China, Japan, South Korea, India and Brazil)[2].

[2] https://www.continental-automotive.com/getattachment/8f2dedad-b510-4672-a005-3156f77d1f85/EMISSIONBOOKLET_2019.pdf

Figure 1: ***Limits to improve air quality and health***



	Euro 1	Euro 2 (petrol)	Euro 2 (diesel)	Euro 3 (petrol)	Euro 3 (diesel)	Euro 4 (petrol)	Euro 4 (diesel)	Euro 5 (petrol)	Euro 5 (diesel)	Euro 6 (petrol)	Euro 6 (diesel)
CO	2.72	2.2	1	2.3	0.64	1	0.5	1	0.5	1	0.5
HC +NOx	0.97	0.5	0.7		0.56		0.3		0.23		0.17
HC				0.2		0.1		0.1		0.1	
NOx				0.15	0.5	0.08	0.25	0.06	0.18	0.06	0.08
PM	0.14		0.08		0.05		0.025	0.005	0.005	0.005	0.005

CO HC +NOx HC NOx PM

Source: Author's own, using data from https://www.theaa.com/driving-advice/fuels-environment/euro-emissions-standards

3. "Low" and "Zero" Emission Fuels and Vehicles

Alongside the development of emission standards for existing Internal Combustion Engine Vehicles (ICEVs), new fuel types and vehicle configurations have emerged that are heralded as potential solutions to the issue of emissions. Some of the most prominent of these are presented below. Whilst various technological advances have received mixed reviews from academics to date, few studies have directly compared emission reductions of vehicles in real world settings. The below is drawn from Transport and Environment (2018).

Hydrogen Fuel Cells

Fuel cell electric vehicles (FCEV) that run on compressed hydrogen are considered zero emission vehicles in EU legislation, only emitting water. Fuel cells convert hydrogen to electricity, which in turn powers an electric motor. FCEV have longer range than BEVs (with ranges similar to conventional cars) and require less frequent re-filling. There are several reasons why manufacturers have not been pursuing this technology (Transport & Environment, 2018: 15):

- the technology remains expensive. With limited models available. Limited choice and persisting safety concerns mean that it is unlikely to drop significantly.
- producing hydrogen by electrolysis and converting it into electricity in the fuel cell requires large amounts of energy, making the technology inefficient, and comparatively expensive. FCEVs requires 2 to 3 times more energy to run when compared to battery electric cars that use electricity to power the battery directly.

- hydrogen largely comes from fossil fuel processes, derived either via steam methane reforming or coal gasification. Making “green” hydrogen from renewables is possible by water electrolysis but only a small amount of hydrogen is produced this way (<10%) largely because it is more expensive. The additional electricity required for hyd rogen could slow down the decarbonisation of the grid because of the higher demand.

Sustainable Advanced Biofuels

Biofuels according to EU legislation are “liquid or gaseous fuels produced from biomass”. A biofuel can be ethanol, methanol, fatty acid methyl ester (FAME), hydro treated vegetable oil (HVO) or biomethane (either compressed or liquefied). These biofuels can also be split into generations of biofuels, first generation (or conventional) being produced from sugars, starch crops, or vegetable oils, and advanced biofuels that are produced from wastes, residues or novel feedstock’s such as algae. Biofuels are usually blended into fossil fuels in low proportions without the need to modify engine technology (Transport & Environment, 2018: 15-16).

For passenger cars the drop-in options that can be blended to fossil fuels in current vehicles are different types of bioethanol and biodiesel. Biomethane can be used to substitute in compressed natural gas (CNG) cars. First generation vegetable oil-based biodiesel is not a decarbonisation option as when both direct and indirect emissions are taken into account, all biodiesels have higher greenhouse gases than fossil-derived diesel. This is due to indirect land-use change (ILUC) emissions. Palm oil, is the second largest feedstock for biodiesel in the EU (31%), and has significant ILUC emissions due to tropical deforestation and peatland drainage. Starch and sugar crops (e.g. maize or sugar beet) are typically grown on agricultural land for the production of bioethanol or biomethane, also resulting in ILUC.

In T&E’s 2050 series, sustainable advanced biofuels based on wastes and residues were analysed in more detail, but their potential contribution is finite as the sustainable feedstock’s are limited. The maximum potential of advanced biofuels in road transport is also very much dependant on the other sectors potentially using the same raw materials or fuels (Transport & Environment, 2018: 15-16).

Electrofuels: Synthetic Diesel and Petrol

Electrofuels, also known as power-to-liquid or power-to-gas, are electricity based gaseous or liquid fuels which can be used in internal combustion engines, in the form of synthetic petrol or synthetic diesel. They would only have meaningful climate benefits if strict sustainability criteria are observed throughout the production process. Key factors determining sustainability are:

- the source of electricity;
- the source of CO_2 (it should be air capture);
- and impacts on land and water.

Electrofuels are not considered a credible or cost-effective solution to decarbonise road transport. This is because the production of electrofuels is inefficient and costly. To fuel Europe’s car fleet after applying the demand reduction with electrofuels would require adding 2619 TWh to EU electricity generation (equivalent to 81% of generation in 2015) and this additional electricity would have to be zero carbon (Transport & Environment, 2018: 16).

Battery Electric

Battery electric vehicles (BEV) have seen technology improvement and cost reduction in recent years, recording a circa 35% increase in sales across Europe in 2018. BEVs are considered the most promising and optimal zero emission technology to decarbonise car fleets: they have zero tailpipe, GHG, air pollutant or noise emissions, are the most efficient option considering the power needed to directly charge the battery, and are cost-competitive in some markets (on the total cost of ownership basis) given their low running and maintenance costs (Transport & Environment, 2018: 17).

The largest part of BEV life-cycle CO_2 emissions comes from charging, i.e. its use phase, which will improve as the electricity sectors decarbonises. A BEV is considerably cleaner than a comparable diesel car over its lifetime, even in EU member states with carbon-intensive grids.

Charging issues (lack of charging infrastructure, range anxiety) will be resolved as the number of BEVs on the road increases and the business case for infrastructure providers improves. Innovative solutions are emerging, e.g. street light posts being converted to chargers. Fast charging is important for interurban trips and to deal with range anxiety. Fast charging networks of up to 350 kW are being developed which means that a BEV with a 100 kWh battery (range of more than 500 km) could be fully charged in around 15 minutes. The impact from the increasing BEV fleet is manageable: studies have shown that, if managed properly, electric cars are not a burden on the electricity grid. If smart charging and vehicle-to-grid technology is rolled-out, BEVs can provide flexibility services and an opportunity to incorporate more renewables and avoid clean electricity curtailment (Transport & Environment, 2018: 17).

Concerns have also been raised around environmental and ethical considerations stemming from mining materials needed for batteries, (e.g. cobalt and lithium). Issues around transparency and accountability in global supply chains, are required. Innovation in battery manufacturing will also support the use of less cobalt and moves to cobalt-free solid-state batteries. Repurposing and recycling of batteries will increase availability of secondary materials and improve CO_2 balance of battery manufacturing.

Other

There are also various “transitional” and combined solutions available to decarbonise the car fleet. Plug-in hybrids (PHEV) are regarded as the main transition technology from ICE to full EV; they have a small battery with a limited electric range and an internal combustion engine. On the road most PHEVs have relatively high average emissions of around 120g/kml, but as the electric range and battery capacity increase, evidence suggests the real world emissions fall sharply. Popularity among policy-makers stems from the fact that they do not disrupt the automotive supply chain to the same degree as a complete transition to BEVs and require around 20% more people to build each vehicle. However, plug-in hybrid technology where the ICE is running on fossil fuels will never be zero emission and the emissions per kilometre largely depends on drivers charging behaviour. Having two different powertrains in the one vehicle tends to result in a higher purchase price than either a full ICE of BEV. Thus, PHEVs may have a brief role to play as a transitional technology, but they are ultimately unable to deliver zero emission mobility and cannot be relied upon for longer term decarbonisation (Transport & Environment, 2018: 18).

Dual fuel cell-battery vehicles are another approach (even though most fuel cell cars already have an auxiliary battery). In this case, the BEV would have larger battery giving greater autonomy, and use an on board hydrogen fuel cell as a range extender. As noted above for PHEVs, combining two drivetrains in one vehicle increases cost. With positive developments in battery density, costs, and lifetime, and because of the aforementioned limitations of hydrogen fuel cell technology, this solution does not at this time appear to be economically viable (Transport & Environment, 2018: 18).

Finally, a PHEV could be run on synthetic fuel (or power-to-liquid, PtL). The inhibitive costs and inefficiencies aside. PHEVs operating on PtL would still emit pollutants (NOx and PM) at the tailpipe (Transport & Environment, 2018: 18).

Figure 2: ***Efficiency of different passenger cars technology pathways based on renewable electricity***

This Figure has been removed for copyright reasons. The figure can be viewed at (https://www.transportenvironment.org/wp-content/uploads/2021/07/2050_strategy_cars_FINAL.pdf)

Source: Transport and Environment, 2018: 19

Electric Vehicles and Air Pollution

When considering EVs, it is important to note that non-exhaust vehicle emissions arise irrespective of the fuel source (conventional fuel, electric, fuel-cell, hydrogen, etc.). As such it is important to consider the displacement of emissions from the vehicle to further up the energy-supply chain, .e.g. an electricity generating facility, depending on the source of the electricity.

As illustrated below, the generation of electricity used to both charge EVs, as well as in the manufacturing process accounts for a significant percentage of emissions related to EVs. ICCT (2018) comment that increased renewable energy and more efficient power plants will support the decarbonisation potential of EVs. According to ICCT (2018: 6-7), “the carbon intensity of electricity is expected to drop by more than 30% by 2030 in most markets that still have relatively high fossil fuel combustion”.

Image 1: ***Schematic of different types of Electric Vehicles (EVs) and their sources and consumption of energy and emission from tailpipe and energy generation***

This image has been removed for copyright reasons. The image can be viewed at (https://doi.org/10.1016/j.atmosenv.2018.04.040)

Source: Requia et al., 2018: 66

A further consideration is that as tailpipe emissions are either reduced or eradicated by EVs, the impact of non-exhaust emissions associated with usage becomes important. As noted by the UK Governments Air Quality Expert Group (2019), non-exhaust emissions from road traffic contribute to airborne concentrations of both fine and coarse particles and that estimates from the National Atmospheric Emissions Inventory indicate that the emissions from brake wear, tyre wear and road surface wear collectively now exceed those from the exhaust of the UK vehicle fleet.

Pollution and EVs

Particles: Energy generation accounts for a significant amount of PM emissions from EVs. However, with the introduction of renewable energy into the grid, non-exhaust PM emissions (e.g., brake, tyre wear) may become the main source of PM. Some studies have shown that fleet electrification has a limited contribution in reducing non-exhaust emissions. In some cases, EVs can increase non-exhaust emissions (Timmers & Achten, 2016). The important factor here is vehicle weight (Requia et al., 2018). Non-exhaust particles arise from a range of vehicle-related sources. The main contributors are the following (see also footnote on regenerative brakes[3]):

- **Brake wear**. Via the application of pressure to the braking system, the frictional process causes abrasion both of the brake pad and of the surface of the disc or drum leading to the release of particles.
- **Tyre wear**. Tyres are abraded through use, which leads to release of quantities of small rubber particles covering a wide range of sizes. Smaller abraded particles are liable to become airborne contributing to non-exhaust particles in the atmosphere.
- **Road surface wear**. Road surface wear particles are released through use.
- **Re-suspended road dust**. Dusts from a number of sources accumulate on road surfaces. These originate from dry and wet deposition of airborne particles. Abrasion products from the vehicle may deposit on the road, contributing to the road surface dusts.

Gaseous Pollutants: Quantitative analysis presented by Requia et al. (2018) indicates that EVs may have a significant impact on gaseous emission reduction, especially on NO_2, VOCs, and CO. According to the literature, regional differences, ambient concentrations, and energy sources are strong modifiers of the association between EVs and gaseous pollutants. This is related to the significant impact of the energy sector on gaseous emissions.

GHG Emissions: According to the literature reviewed, CO_2 emissions due to EV penetration are less sensitive to the variation of source of energy generation than particulate and gaseous pollutants. A number studies have shown that even with a high percentage of electricity generated by coal power plants, EVs may still reduce emissions of CO_2. For example, in China where the electricity grid is mostly dominated by coal generation, BEVs can reduce CO_2 emissions by 20%, but increase PM_{10}, $PM_{2.5}$, NO_x, and SO_2 emissions (Requia et al., 2018).

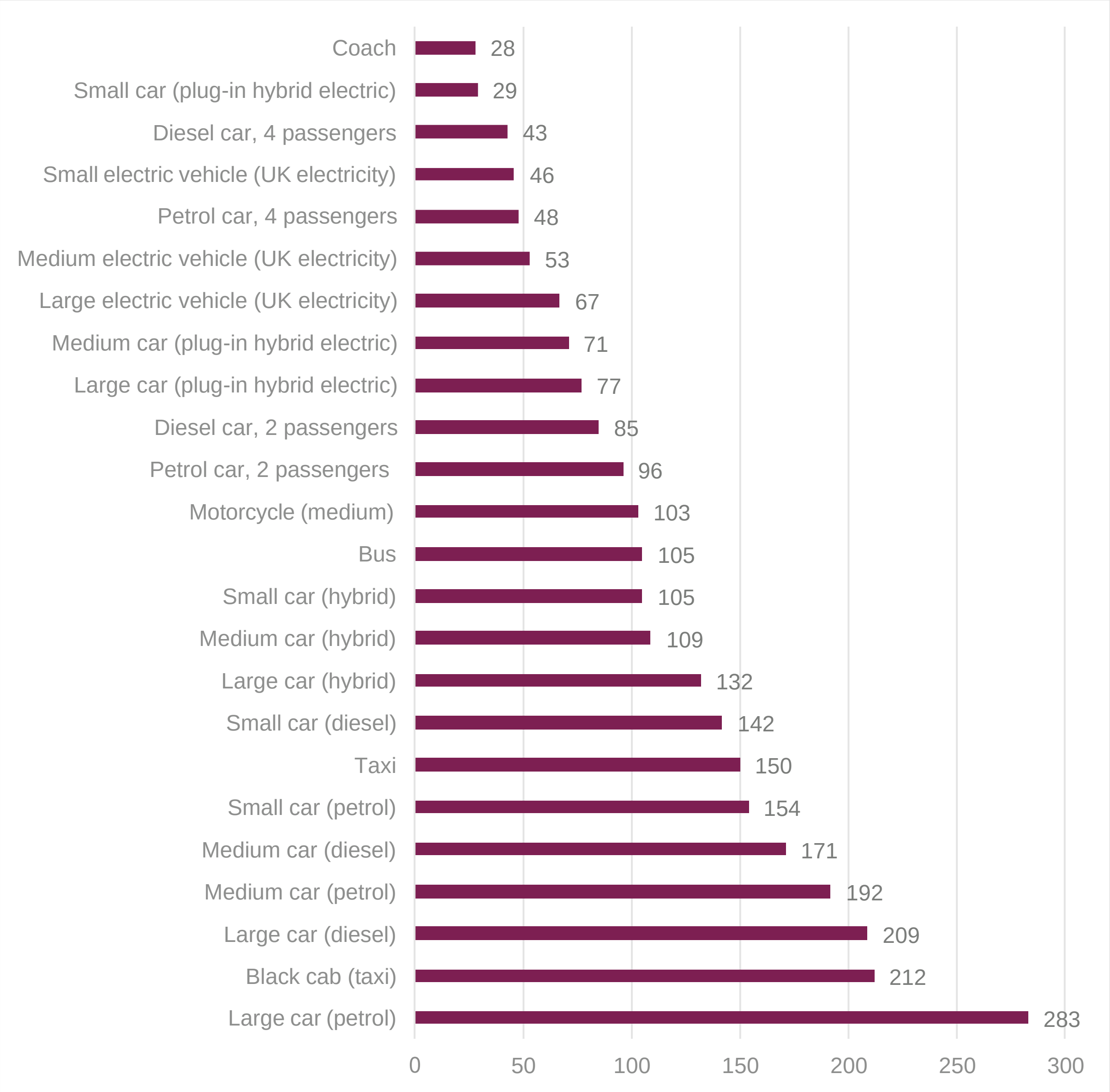
4. CO_2 and Different Types of Vehicles

Transport accounts for around one-fifth of global carbon dioxide (CO_2) emissions (24% if CO_2 emissions from energy are included). Road travel accounts for three-quarters of transport emissions. Most of this comes from passenger vehicles, cars and buses, which contribute 45.1% (Ritchie, 2020).

[3] EVs often deploy regenerative braking which does not rely on frictional wear of brake materials so should have lower brake wear emissions. However, tyre and road wear emissions increase with vehicle mass.

Figure 3 presents a comparison of on-road travel modes according to carbon footprint. Carbon footprint is estimated by the amounts of greenhouse gases (GHG) emitted per person travelling one kilometre. This figure is sourced from the UK government methodology for GHG reporting (DBEIS, 2021). GHGs are measured in CO_2 equivalents (CO_2eq). Small electric vehicles (EVs) have the lowest carbon footprint of travel compared to other light duty vehicles.

Figure 3: ***Carbon footprint of travel per kilometre 2018***



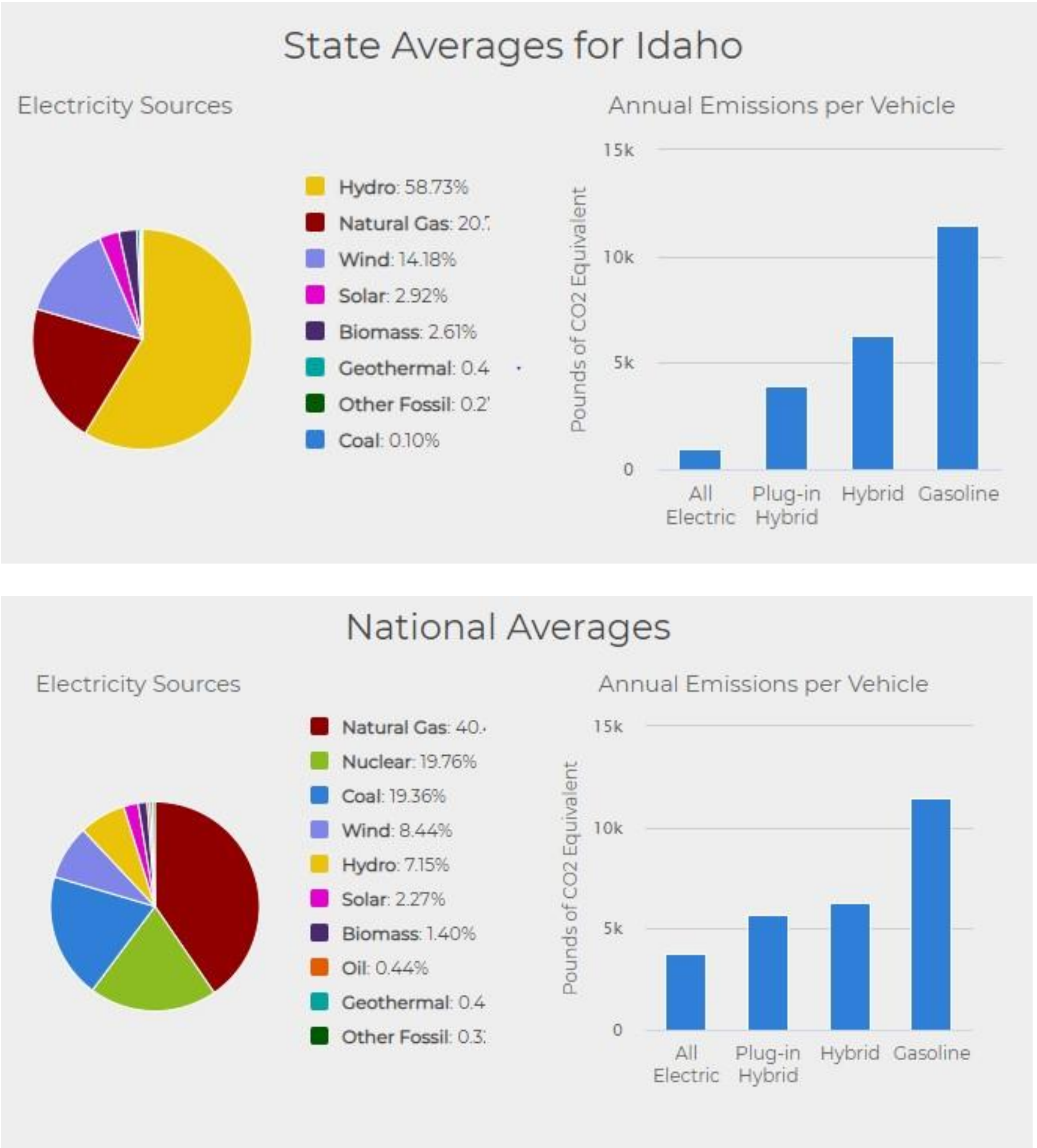
Source: Ritchie, H. (2020), licensed under Creative Common Licence (CC Attribution BY 4.0 International), https://ourworldindata.org/travel-carbon-footprint

Emissions and Electricity Generation

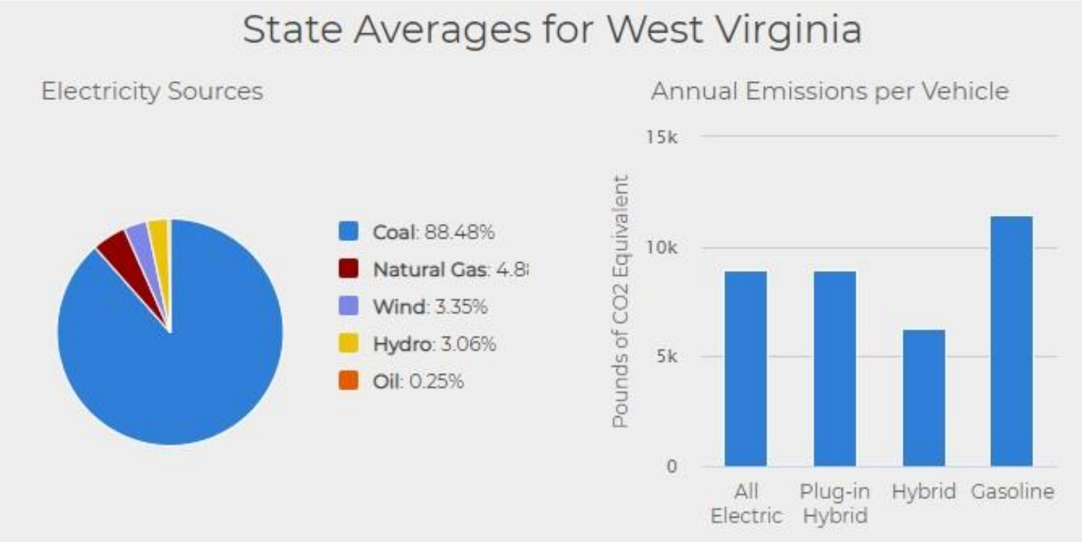
An example of the impact that the source of electricity has on the carbon reduction potential of different types of vehicles can be drawn from the US (US Department of Energy – Alternative

Fuels Data Centre[4]). Here it is shown that where electricity is derived from coal power stations the potential impact of EVs is significantly reduced when compared to those states where electricity is generated from renewable sources (see figure 4 and table 1).

Figure 4: ***Electricity Sources and Emissions (US Department of Energy – Alternative Fuels Data Centre)***



[4] https://afdc.energy.gov/vehicles/electric_emissions.html



Source: US Department of Energy, reused under copyright permissions from the US Department of Energy (DOE), https://afdc.energy.gov/vehicles/electric_emissions.html

Table 1: ***Electricity Sources and Emissions***

	All Electric	Plug in Hybrid	Hybrid	Gasoline
Idaho - CO2 Equivalent	952	3,899	6,258	11,435
National Average - CO2 Equivalent	3,774	5,680	6,258	11,435
West Virginia - CO2 Equivalent	8,945	8,941	6,258	11,435

Source: US Department of Energy, reused under copyright permissions from the US Department of Energy (DOE), https://afdc.energy.gov/vehicles/electric_emissions.html

5. Annotated Bibliography - Emissions and Different Types of Vehicles

Non-Exhaust Particulate Emissions

Timmers, V. & Achten, P. (2016). Non-exhaust PM Emissions from electric vehicles. Atmospheric Environment 134. http://www.soliftec.com/NonExhaust%20PMs.pdf

By analysing the existing literature on non-exhaust emissions of different vehicle categories, this review found that there is a positive relationship between weight and non-exhaust PM emission factors. In addition, electric vehicles (EVs) were found to be 24% heavier than equivalent internal combustion engine vehicles (ICEVs). As a result, total PM_{10} emissions from EVs were found to be equal to those of modern ICEVs. $PM_{2.5}$ emissions were only 1–3% lower for EVs compared to modern ICEVs. Therefore, it could be concluded that the increased popularity of electric vehicles will likely not have a great effect on PM levels. Non-exhaust emissions already account for over 90% of PM_{10} and 85% of $PM_{2.5}$ emissions from traffic. These proportions will continue to increase as exhaust standards improve and average vehicle weight increases. Future policy should consequently focus on setting standards for non-exhaust emissions and encouraging weight reduction of all vehicles to significantly reduce PM emissions from traffic.

- A positive relationship exists between vehicle weight and non-exhaust emissions.
- Electric vehicles are 24% heavier than their conventional counterparts.
- Electric vehicle PM emissions are comparable to those of conventional vehicles.
- Non-exhaust sources account for 90% of PM_{10} and 85% of $PM_{2.5}$ from traffic.
- Future policy should focus on reducing vehicle weight.

Table 2: ***Comparison between expected PM_{10} emissions of EVs, gasoline and diesel ICEVs***

This table has been removed for copyright reasons. The table can be viewed at https://www.sciencedirect.com/science/article/pii/S135223101630187X

Source: Timmers & Achten, 2016: 15

Table 3: ***Comparison between expected $PM_{2.5}$ emissions of EVs, gasoline and diesel ICEVs***

This table has been removed for copyright reasons. The table can be viewed at https://www.sciencedirect.com/science/article/pii/S135223101630187X

Source: Timmers & Achten, 2016: 15

OECD (2020). Non-exhaust Particulate Emissions from Road Transport: An Ignored Environmental Policy Challenge. OECD. https://www.oecd.org/env/highlights-non-exhaust-particulate-emissions-from-road-transport.pdf

This report estimates the non-exhaust PM emission factors from electric vehicles and compares these factors with those of ICEV. Assuming lightweight EVs (i.e. with battery packs enabling a driving range of about 100 miles), the report finds that EVs emit an estimated 11 -13% less non-exhaust $PM_{2.5}$ and 18-19% less PM_{10} than ICEVs. Assuming that EV models are heavier (with battery packs enabling a driving range of 300 miles or higher), however, the report finds that they reduce PM_{10} by only 4-7% and increase $PM_{2.5}$ by 3-8% relative to conventional vehicles. Additional simulations indicate that the uptake of electric vehicles will lead to very marginal decreases in total PM emissions from road traffic in future years. In scenarios where electric vehicles comprise 4% and 8% of the vehicle stock in 2030, their penetration reduces PM emissions by 0.3%-0.8% relative to current levels.

Table 4: ***Net Change in Total Non-Exhaust Emission Factors of BEVs Relative to Gasoline ICEVs (Percentage Points)***

	Assumed electric vehicle weight	Passenger cars	Sport utility vehicles	Light commercial vehicles
PM2.5	Lighter weight	-12.8	-11.2	-13.3
	Heavier weight	+2.6	+7.5	+7.8
PM10	Lighter weight	-17.8	-18.0	-19.3
	Heavier weight	-6.5	-4.5	-5.5

Source: OECD, 2020. Reproduced with permission from OECD Publications.
https://www.oecd.org/env/highlights-non-exhaust-particulate-emissions-from-road-transport.pdf

The report concludes that:

- Developing effective mitigation policies for non-exhaust emissions will require a robust evidence base regarding the factors that influence the magnitude of their negative impacts. To this end, policy makers should prioritise advancing the state of knowledge on non-exhaust emissions and establishing standardised approaches to measuring them.
- Promising mitigation measures include vehicle light-weighting, regulations on tyre composition, urban vehicle access regulations and the promotion of public transport, walking and cycling.

Criteria Pollutants (PM, NOx, CO, HCs)

Winkler, S. et al. (2018). Vehicle criteria pollutant (PM, NOx, CO, HCs) emissions: how low should we go? Climate and Atmospheric Science, 1 (26), pp. https://www.nature.com/articles/s41612-018-0037-5#Tab1

This article reviews historical vehicle emission and air quality trends, discuss the future outlook for air quality, and notes that modern ICEV typically have lower exhaust emissions than BEV upstream emissions.

As vehicle exhaust emissions have decreased, non-exhaust emissions have become relatively more important. In particular, PM emitted from tyre and brake wear is now comparable to exhaust emissions, as shown in Table 5 but BEVs and ICE vehicles can have different emission levels. Tyre wear is a function of many factors: heavier BEVs are expected to give more tyre wear PM emissions while brake wear PM emissions can be lower on electrified vehicles, which use regenerative braking.

Table 5: Comparison of US and EU vehicle emission standards with emissions from selected gasoline ICE vehicles and BEVs, and non-exhaust brake wear and tyre wear emissions (Winkler, et al., 2018: 3)

	mg/km				
	PM2.5	**NO*x* + HC**	**NO*x***	**SO2**	**CO**
Vehicle standards (test cycle)					
US Tier 3	2	53		0.6a	1057
Euro 6 (gasoline)	0.3b	170	60		500
Euro 6 (diesel)	0.3b		80		
US 2017 ICE					
Best-in-class (HEV) (test cycle)	0.06c	2	0.3		31
2016 fleet averaged (on-road)		66	28		231
EU ICE					
Average Euro 6 gasoline DI ICE (RDE)	0.2–0.4b		12–20		17–100
Typical 2017 BEV electricity emissions					
2014 US elec. grid	7	71	70	123	
2016 US elec. grid			37	41	
2030 US elec. grid			30	32	
Brake and Tire Wear					
Brake wear	2–6				
Tire wear	1–5 (PM2.5)				
	4–13 (PM10)				

Source: Winkler et al. (2018). Reproduced under Creative Commons Attribution 4.0 International

Data and observations indicate ICE vehicle emissions may be approaching a ZEV-equivalent level. Modelling shows that successively more stringent vehicle regulations provide diminishing air quality benefit. As the vehicle sector emits a smaller share of the total emissions, other emission-reduction strategies can be more cost-effective in improving air quality. For example, reducing emissions from non-vehicle sources (power generation, house heating, off-road equipment) will yield a greater impact on air quality. Future vehicle emission-reduction efforts might be more profitably targeted on reducing the effect of gross emitters, which represents 2 – 5% of the fleet but can produce up to half the emissions. PHEVs may be used in electric mode where ICE bans are present, offering a solution for commercial, medium-, and heavy-duty vehicles whose duty cycles are not amenable to a fully electric platform. Going forward it will be important to have a more holistic view of emission sources and to assess the most cost-effective actions to achieve the desired air quality improvements.

Ghaffarpasand, O. et al. (2020) Real-world assessment of vehicle air pollutant emissions subset by vehicle type, fuel and EURO class: New findings from the recent UK EDAR field campaigns, and implications for emissions restricted zones. Science of The Total Environment, 734. https://doi.org/10.1016/j.scitotenv.2020.139416

This paper reports upon and analyses vehicle emissions measured by the Emissions Detecting and Reporting (EDAR) system, a Vehicle Emissions Remote Sensing System (VERSS) type device, used in five UK based field campaigns in 2016 and 2017. In total 94,940 measurements were made of 75,622 individual vehicles during the five campaigns. The measurements are subset into vehicle type (bus, car, HGV, minibus, motorcycle, other, plant, taxi, van, and unknown), fuel type for car (petrol and diesel), and EURO class, and particulate matter (PM), nitric oxide (NO) and nitrogen dioxide (NO_2) are reported. In terms of recent EURO class emission trends, NO and NOx emissions decrease from EURO 5 to EURO 6 for nearly all vehicle categories. Interestingly, taxis show a marked increase in NO_2 emissions from EURO 5 to EURO 6. Perhaps most concerning is a marked increase in PM emissions from EURO 5 to EURO 6 for HGVs. Another noteworthy observation was that vans, buses and HGVs of unknown EURO class were often the dirtiest vehicles in their classes, suggesting that where counts of such vehicles are high, they will likely make a significant contribution to local emissions.

Green House Gas Emissions

Onn, C. et al. (2017). Greenhouse gas emissions associated with electric vehicle charging: The impact of electricity generation mix in a developing country. Transportation Research Part D 64. https://doi.org/10.1016/j.trd.2017.06.018

The object of this paper was to perform a well-to-wheel life cycle assessment for calculating the greenhouse gas emissions attributable to the usage of ICEVs, HEVs and EVs in Malaysia. The results show that running EVs with the existing national grid will produce an average of 7% more GHG emissions than HEVs over the same distance. However, they will produce an average of 19% less GHG emissions than the ICEVs. Overall the GHG emissions produced through the usage of EVs are substantial based on the well-to-wheel analysis, as the environmental profile of EVs is linked with the national grid. Therefore, in order to accrue the benefit of EVs in terms of climate change and global warming mitigation, modernisation and transformation of the national grid towards greener sources should be undertaken.

The well-to-wheel analysis were conducted to calculate the potential greenhouse gas (GHG) emission generated by usage of EVs, HEVs and ICEVs in Malaysia. The well-to-wheel analysis revealed that EVs running in the Malaysian electricity mix will, on average, produce at least 6.4% to 7.9% more GHG emissions (g CO_2 e.q.) than HEVs at the same distance. However, they will produce an average of 16–22.5% fewer GHG emissions than the ICEVs. The Nissan Leaf in all analysis produced more GHG emissions than all HEVs at the same driving distance. It even performs badly under the JC08 test when compared to the Honda Jazz Petrol and the Honda City Petrol. However, the Mitsubishi I-Miev, which is the smallest among all models, produced remarkably low emissions in the JC08 test, outperforming all models except the Toyota Prius C. In the EPA test, the Mitsubishi I-Miev produced more GHG emissions than the Toyota Prius Hybrid, Toyota Prius C and Honda Jazz Hybrid.

Figure 5: Climate change impact (kg CO_2eq) VS Car Model

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Source: Onn et al, 2018: 20

The study indicates that Malaysia is not ready for EVs as its electricity generation is still largely dominated by fossil fuels. Based on the well-to-wheel analysis, the GHG emissions produced through the usage of EVs are substantial and it will continue to be so if no change is made to the electricity generation in the near future. Therefore, in order to accrue the benefit of EVs in terms of climate change and global warming mitigation, modernisation and transformation of the national grid towards greener sources should be undertaken.

Alternatively, the introduction of EVs could act as a potential drive for improving and cleaning up the national electricity grid, as well as a catalyst that would create a sustainable long-term solution for the policymaker to easily regulate and optimise the urban transportation system through combining millions of mobile emissions into a few stationary emissions (power plants). These calculations will assist policymakers, automakers, researchers, investors and consumers in assessing the level of GHG emissions produced by different types of vehicles (ICEVs, HEVs and EVs) and also providing a foundation for effective decisions on policies, research and investments in future transport energy.

Table 6: ***The Projected GHG emission for each vehicle in per 100 km.***

This Figure has been removed for copyright reasons. The figure can be viewed at https://www.sciencedirect.com/science/article/pii/S1361920916308823?casa_token=2msHQz9oDdYAAAAA:gTTT8myXh9T4seS8NZXzOu8_-y_EqyxbnQWt4uaM4bajP7ipQh0xjvfA556QF7-HtjzQAHM

Source: Onn et al, 2018: 20

Biofuels

Dias, D. et al. (2019). Modelling of Emissions and Energy Use from Biofuel Fuelled Vehicles at Urban Scale. Sustainability. https://www.mdpi.com/2071-1050/11/10/2902

The main objective of this paper was to estimate the emissions and energy use from bio-fuelled vehicles by using an integrated and flexible modelling approach at the urban scale in order to contribute to the understanding of introducing biofuels as an alternative transport fuel. The results of this study indicate that the increase of biofuels blends would have a beneficial effect on particulate matter ($PM_{2.5}$) emissions reduction for the entire road network (−3.1% [−3.8% to −2.1%] by kg). In contrast, an overall negative effect on nitrogen oxides (NOx) emissions at urban scale is expected, mainly due to the increase in bioethanol uptake. Moreover, the results indicate that, while there is no noticeable variation observed in energy use, fuel consumption is increased by over 2.4% due to the introduction of the selected biofuels blends.

Table 7: ***Variation (average and uncertainty range) of PM2.5 and NOx emissions within Coimbra for selected biofuels scenarios***

The table has been removed for copyright reasons. The table can be viewed on https://www.mdpi.com/2071-1050/11/10/2902/htm

Source: Dias et al, 2019: 10

Balali, Y. & Stegen, S. (2021). Review of energy storage systems for vehicles based on technology, environmental impacts, and costs. Renewable and Sustainable Energy Reviews 135. https://ideas.repec.org/a/eee/rensus/v135y2021ics1364032120304755.html

This paper provides a review of energy systems for light-duty vehicles and highlights the main characteristics of electric and hybrid vehicles based on power train structure, environmental perspective, and cost. The review provides an overview of different solutions possible, which have the potential to significantly reduce GHG emissions in the transportation sector.

Table 8: ***The comparison of the main characteristics of Electric Vehicles (BEVs, PHEVs, HEVs, FCEVs)***

The table has been removed for copyright reasons. The table can be viewed at https://ideas.repec.org/a/eee/rensus/v135y2021ics1364032120304755.html

Source: Balali, Y. & Stegen, S. (2021: 9)

Ajanovic, A. & Haas, R. (2017). Electric vehicles: solution or new problem? Environ Dev Sustain, 20. https://doi.org/10.1007/s10668-018-0190-3

In this paper, some of the major barriers and the future challenges of EVs are discussed. The current problems are mainly attributed to two categories: (1) the battery performances and costs, as well as battery production including issue of material availability and (2) environmental benefits of EVs depending on the sources used for the electricity generation and their carbon intensity. The major conclusions are that (1) research and development with respect to batteries has by far the highest priority and (2) it has to be ensured that the electricity used in EVs is generated largely from renewable energy sources.

To assess full environmental impact of different types of automotive technologies, we need to consider all emissions that occur in the whole energy supply chain. Total GHG emissions of vehicles are dependent on energy used in cars. The total carbon intensity of grid electricity is dependent on the emissions caused during fuel upstream production, fuel combustion at power plants, and the electricity losses in transmission and distribution. It can be very different from country to country depending on the energy mix used in electricity production.

If the same type of BEV is charged by electricity mix in different countries, total CO_2 emissions per kilometre driven are very different. In countries with high use of RES, EVs could significantly reduce GHG emissions. In some countries (e.g., China), EVs could contribute just to the reduction in the local air pollution.

Another important issue currently discussed is the availability of materials for electric vehicles production. It could happen that due to the switch from gasoline and diesel cars to EVs we will change the dependency from oil-producing countries to lithium-producing countries, which are mainly concentrated in South America. However, with the increasing demand for EVs new and cheaper technological solutions will likely emerge in the future, mainly due to competition.

The authors conclude that electric vehicles could contribute to the reduction in some problems in the transport sector, especially to the reduction in local air pollution. However, their contribution to the reduction in GHG emissions is very dependent on the electricity mix used in EVs. Electric vehicles could bring about environmental benefits only in countries with a very high share of RES in electricity generation.

6. References

Air Quality Expert Group (2018). Non-Exhaust Emissions from Road Traffic. Department for Environment, Food and Rural Affairs; Scottish Government; Welsh Government; and Department of the Environment in Northern Ireland Group. https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1907101151_20190709_Non_Exhaust_Emissions_typeset_Final.pdf

DBEIS (2021) 2020 Government greenhouse gas conversion factors for company reporting: Methodology paper. *Department for Business, Energy, and Industrial Strategy*. https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2021

Ghaffarpasand, O., et al. (2020a) Real-world assessment of vehicle air pollutant emissions subset by vehicle type, fuel and EURO class: New findings from the recent UK EDAR field campaigns, and implications for emissions restricted zones. Scienc e of The Total Environment, 734. https://doi.org/10.1016/j.scitotenv.2020.139416

ICCT (2018). Effects of battery manufacturing on electric vehicle life-cycle greenhouse gas emissions. ICCT. https://theicct.org/sites/default/files/publications/EV-life-cycle-GHG_ICCT-Briefing_09022018_vF.pdf

Jiao, J., et al. (2020) Co-benefits of reducing CO2 and air pollutant emissions in the urban transport sector: A case of Guangzhou. Energy for Sustainable Development, 59, 131-143.

Onn, C., et al (2018). Greenhouse gas emissions associated with electric vehicle charging: The impact of electricity generation mix in a developing country . Elseiver. https://www.sciencedirect.com/science/article/pii/S1361920916308823?casa_token=2WKgrACRfR0AAAAA:ew8Hoo7QSdSmfYDHxo4wCfmIMUcwjCZF_Z7wn3XFbbng27eaFRyz8VaQwNu8-1S4ykdl4Qk

Pope, F. et al. (2018). Airborne particulate matter monitoring in Kenya using calibrated low-cost sensors. Atmos. Chem. Phys., 18. https://acp.copernicus.org/articles/18/15403/2018/acp-18-15403-2018.html

Raaschou-Nielsen, O. et al. (2013). Air pollution and lung cancer incidence in 17 European cohorts: prospective analyses from the European Study of Cohorts for Air Pollution Effects (ESCAPE). The Lancet Oncology. VOLUME 14, ISSUE 9. https://doi.org/10.1016/S1470-2045(13)70279-1

Requia, W. et al. (2018). How clean are electric vehicles? Evidence-based review of the effects of electric mobility on air pollutants, greenhouse gas emissions and human health. Atmospheric Environment 185. https://doi.org/10.1016/j.atmosenv.2018.04.040

Ritchie, H. (2020) Which form of transport has the smallest carbon footprint? Our World in Data. https://ourworldindata.org/travel-carbon-footprint

Transport and Environment (2018). Roadmap to Decarbonising European Cars. Transport & Environment. https://www.transportenvironment.org/sites/te/files/publications/2050_strategy_cars_FINAL.pdf

Timmers, V, R.J.H., and Achten. P, A.J., Non-exhaust emissions from electric vehicles. Elsevier. https://www.sciencedirect.com/science/article/pii/S135223101630187X?casa_token=43gvMoyeo7cAAAAA:BJByt2IwTu8H127ii-GA36XxH7xM3VJvwnfxxfmmOGxZf9RRDiW0bYxanxyT2vp8K5ZXYMw

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