Q1c. Transport: What is the potential to reduce our carbon footprint through adoption of different modes of private and public transportation?

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Introduction

One of the major questions in tackling climate change is whether private and public transportation can become carbon-neutral within the next few decades. Transportation has evolved dramatically within the last century with the invention of the internal combustion engine and most recently electrified vehicles (EVs), but all current forms either directly or indirectly produce CO_2, and despite the need to reduce our emissions, international trade and the need for global mobility are still increasing. The challenge to produce more energy-efficient and carbon-neutral vehicles is therefore becoming increasingly important in the quest to mitigate the effects of human-induced global warming.

The majority of transport related CO_2e (carbon dioxide equivalent) comes from tailpipe emissions, and so finding a way in which we can eliminate this is crucial. Our options for the near future include electric, and possibly hydrogen fuel cells. This discussion is timely because the UK government recently brought forward the ban of the sale of all fossil-fuel (FF) and hybrid cars from 2040 to 2035, with the intention to reach net-zero by 2050 [1]. These laudable new aims are pushing the industry faster towards such carbon-neutral modes of transport, but are making some question if we can really reach these targets in time, because this not only requires an increase in renewables (i.e. low-carbon energy generation), but also major changes in human behaviour which may be even more difficult to achieve within such time frames.

Public perception of the need for such change is key since they are unlikely to give up their freedom of mobility anytime soon. Different ways to travel will require changes in lifestyle, and most people are unlikely to be keen to even consider changes in their daily routines.

Is mass electrification the answer?

At present electric powered transportation is the most dominant form due to it being the only tailpipe emission-free transport available to purchase, with an accessible and relatively cheap fuel source. EVs also have a good public perception, with buying an electric car currently considered a major factor in the way we can all help to 'save the planet'. However, this is seen by some as 'virtue signalling', with legitimate questions about its overall likelihood of achieving this goal, and whether it is even truly carbon-neutral in the first place. For example, the International Energy Agency reports that a car with a 249-mile range already has a significant carbon deficit, meaning it must drive more than 37,000 miles before emissions are saved [2]. This problem is compounded by the fact that most people use their EVs for short journeys due to their limited range. Therefore, until most of the population adopts EVs for all journeys, the impact of EVs on carbon emission will not be fully realised.

To consider the likelihood of achieving this aim it is important to understand how EVs operate, how they charge, and how renewable sources of electricity can be stored and distributed into these charging points. EVs are typically powered by rechargeable batteries and so generally weigh more than their FF equivalent, shown by the typical size of a battery in Figure 1. Despite this drawback they are quieter and smoother to drive, and are able to accelerate faster, thus making them feel lighter to drive. The use of an electric motor also allows their kinetic energy to be returned to the battery when braking [3][4].

Figure-1. *EV diagram illustrating size of a typical battery (in blue)[5].*

The average range of a typical EV on the market is around 200 miles, with only high-end models from e.g. Tesla being able to reach or exceed 300 miles. Manufacturers are currently developing longer-range models, but this would rely on more energy-dense batteries which are more expensive to produce due to the raw materials required for their production such as lithium. With the cheapest electric cars such as the Skoda CITIGOe iV costing £16,955, and more expensive models like the Tesla Model S Performance costing greater than £90,000, these initial costs are only marginally offset by their reduced running costs (i.e. electricity)[6][7][8]. For some FF cars this can be as much as £1,800 annually, whereas an equivalent EV might cost only £410. However currently electricity is not taxed in the same way as petrol/diesel [9].

Another way to increase their range would be to improve their efficiency, but most EVs are already over 90% efficient, this is twice that of a traditional internal combustion engine, which converts most of its energy to heat [10]. For example, a full battery of a Nissan Leaf e+ contains 56kWh of usable energy, equating to around 6 litres of petrol (9.1 kWh per litre)[11][12]. With this amount of energy an equivalent FF Nissan Versa Note would cover only 55 miles in comparison to its EV equivalent model which has a 205-mile range [13].

Another important consideration is that if all forms of transportation, not just private vehicles were to become electric, then the market for electric light vans and heavy goods vehicles (eHGVs) would also have to expand enormously. Some companies are starting to develop such EVs. For example, DAF, a traditional HGV manufacturer has already started to sell eHGVs, such as the ‘CF Electric’ aimed for high loads and volumes in urban areas and the ‘LF Electric’ aimed at city distribution. The CF Electric was named Green Truck Logistics Solution for 2019, and despite it only having a 62-mile range, compared to the 137-mile range of the LF, overall the CF has accumulated more than 90000 miles from customers so far [14]. Tesla has also embarked on a similar project with the Tesla Semi, an all-electric HGV first introduced in 2017 (and now available to pre-order) has an energy consumption of less than 2 kWh per mile, with the option for a 300/500 mile range model, predicted to save more than $200,000 in FF running costs [15]. However, if such vehicles were to become standard, different mindsets would have to be introduced with careful planning of routes where eHGVs can stop and quickly charge. It would also require a major change in supply chain logistics, both nationally and internationally.

For a global reduction in transport CO_2 emissions to be achieved via electrification, then other larger-scale transport activities like shipping and air travel would also have to become electric. The main challenge here is the vehicle:cargo weight ratio, because when the weight of cargo increases, the power needed to drive the ship or plane also needs to increase if the journey is to be completed within the same timeframe. This usually means a higher battery capacity is needed, increasing the weight and size of the battery, thus limiting the cargo that can be carried. Another solution would be to further increase battery capacity, but even the highest capacity batteries do not yet contain enough power to run the weight of a container ship or get a large freight plane into the air.

Several modes of mass public transport such as trains and buses are already being electrified across the UK. Buses are at the front of electrification with 2,669 hybrid, and 155 all-electric buses already in London [16]. Such hybrid and all-electric buses reduce CO_2 emissions per passenger by 0.5 kg and 1.5 kg respectively for every ride [17]. The Government has planned to invest £50m into all-electric buses over the country, as well as the Department of Transport aiming for the use of all-electric buses nationally by 2025.

The Government has also endorsed the construction of HS2, the largest high-speed electric train network in the UK [18][19]. HS2 aims to release the capacity of passengers and freight trains from other lines, but its development comes at a significant carbon cost, with 1.45m tonnes of CO_2e emissions predicted from both its construction and operation across the next 120-year timeframe. For this infrastructure to work as planned, the public will need to use HS2 in preference to more carbon-intensive modes of transport. However this is not easily put into practice due to its limited stopping points and there are worries that the £106bn headline price of the network may starve development of other less carbon-intensive modes of transport as well as impacting existing rail networks that make point-to-point transport more attractive [20][21].

If all road transportation were to eliminate their tailpipe CO_2 emissions this is predicted to save 118 million tonnes of CO_2e being put into the atmosphere per year, and if done globally within the near future the result might place the target of +1.5°C increase in global temperature within reach [22]. However, implementing such technology around the world comes with major issues of both affordability and availability, due to the economic status of individual nations that will not only define who can afford to run an EV, but also who can purchase one in the first place.

Infrastructure and public behaviour

Large-scale improvements in the electricity distribution and charging network will also be required to support full electrification. Currently the UK national grid does not have the capacity to charge all cars if they were to become electric. The grid at the moment has a maximum generation capacity of 106 GW, with a contribution of 44 GW from renewables, the rest coming from FF or nuclear [23]. In 2019 more than 72,000 electric cars were registered and are predicted to increase to approximately 100,000 per year by 2021. To support this growing fleet of EVs an increase in electricity generation capacity of 30% would be required by 2050 if EVs are being charged as they currently are, i.e. mostly within peak-demand times when people are at home [24].

The main problem is the type of charging infrastructure required to reduce the impact on the national grid. Smart charging schemes such as real-time pricing, where the price of electricity depends on the live energy supply, and the number of vehicles being charged at any one time, may help guide demand to off-peak times. Centralised schemes could also be put in place, where each car is controlled from a central system charging according to the customers' needs, live grid capacity and demand [25]. Another option might be the vehicle-to-grid method, where an EV discharges during low capacity times to supply electricity back to the system with this rewarded financially. Also, battery-swap systems could be used, where batteries are pre-charged off-peak and distributed when needed. This scheme is currently being trialled in China; however battery designs are not currently universal throughout EVs making this difficult to roll out.

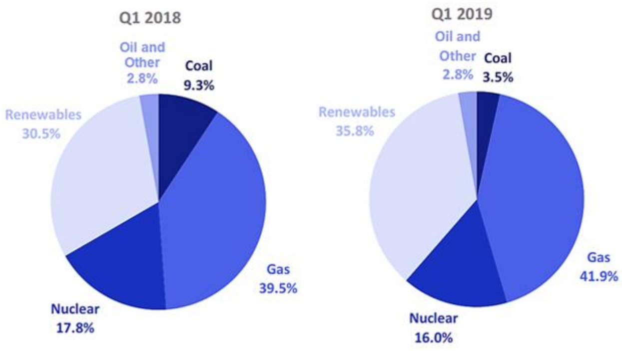

Figure-2. *Electricity generated 1st quarter 2018 vs. 2019[26].*

Grid management schemes would also have to be implemented so they can define where this energy is coming from (i.e. FF vs renewable) and where it is then distributed. The percentage of energy from renewables is currently increasing (Fig.2) with wind and solar accounting for 23.6% of all UK generation in the 1st quarter of 2019, but its generation is unpredictable due to inconsistent weather conditions [26]. To support such infrastructure, the National Grid has plans to invest almost £1bn over the next 5 years in renewable generation. This aims to produce a more reliable, cleaner and easier network connection, on top of a 22.5 GW increase in network capacity at an annual cost of only £23.6 per household [27]. However, reducing FF use will come with additional costs to the public purse. Fuel duties currently bring in £28.4bn annually, which help support road maintenance and other public services, therefore new taxes to compensate for this huge loss in revenue may be inevitable [28].

Alternatives to electrification

Although electrification is currently considered the main option for powering transport other alternatives exist. For example, large naval vessels are nuclear powered, though this is unlikely for civilian transport, but could be used more widely in selected cases. Another tailpipe emission-free option are hydrogen fuel cells (HFCs). The electricity produced by an HFC come from the chemical fusion of pressurised hydrogen with oxygen in the air, forming steam [29]. One of the factors that favour traditional battery EVs over HFCs are the challenges associated with the production of hydrogen. At present hydrogen is obtained through steam-methane reforming, which produces CO and CO_2 in a two-step process. A carbon-neutral alternative would be to generate hydrogen through electrolysis using renewable electricity [30]. This is currently being done but only on a small scale. For HFCs to become mainstream greater investment into low-carbon methods for the mass production of hydrogen will be required before manufacturers will start mass producing such vehicles [31].

Next-Generation Batteries

The demand for raw materials used in battery production is at an all-time high with the increasing number of EVs. But to become fully carbon-neutral, the materials used in their manufacture will have to change, as currently a third of an EVs lifetime emissions comes just from the production of the battery (Fig.3).

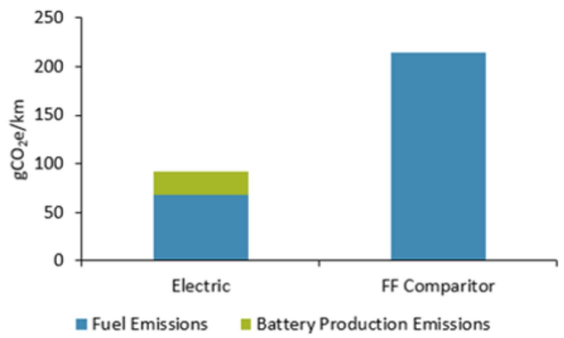

Figure-3*. CO_2/km of an EV vs. FF comparator[32].*

Lithium-ion batteries are currently preferred due to their high energy density and ability to charge/recharge many times. Despite the environmental costs of mining for lithium, the industry is predicted to increase 8-fold within the next decade [33]. Researchers are therefore looking into other alternatives such as aluminium, fluoride and solid-state batteries [34]. Solid-state devices still incorporate lithium, but have a much higher energy density, durability, and are also safer, resulting in smaller longer-lasting batteries. Lithium-sulphur with molybdenum metal batteries also have a higher energy density and are able to reduce battery and environmental costs as a result of incorporating less lithium [35].

Is it possible to adopt these changes globally?

Changing the UK to low-carbon and energy-efficient transportation networks may be achievable within the required timeframe but implementing this globally is another matter. Economically advanced areas such as North America, Europe and parts of Asia are already incorporating such approaches into their transportation systems, but targeting areas with fast-rising populations would have the greatest impact.

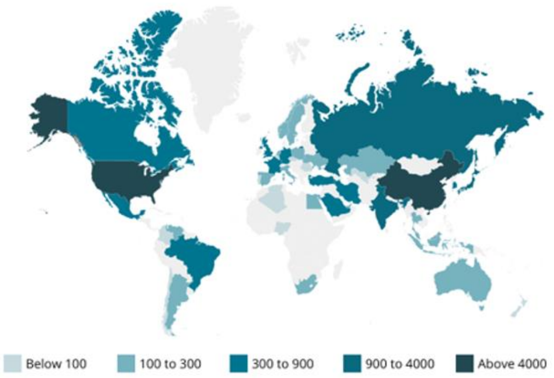

Figure-4. *Global electricity generation 2018 by country (TWh)[36].*

For example Africa is estimated to become 25% of the world's population by 2050, but most African countries would be unable to afford to invest in such infrastructure [37]. Therefore introducing this technology into other economically under-developed countries with poor electricity generation networks (Fig.4) and consumers who could not afford it, may be implausible in the short to medium time-frame.

Conclusion

In the last few decades the future of low-carbon transport has been focused on the electrification of smaller private vehicles, and in time larger EVs may or may not become viable for mass forms of transport. Whilst carbon-neutral transportation remains the UK target for 2050, huge changes in human behaviour will be required in addition to major investment in the infrastructure needed to support such alternative methods. Given the economic costs, the chances that such low-carbon methods will be expanded globally in the near future are limited – but can the world afford not to embrace this new technology?

Word count: 2498

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