MORE
Multimodal Optimisation of Roadspace in Europe

Carbon Values in the Complete Streetscape

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Table of Contents

1 Introduction

The objective of this additional task is to derive and apply indicative values to the individual components of a typical streetscape, to illustrate their individual and combined contribution to carbon emissions and energy consumption. Application of these values to a typical existing and a future streetscape (both virtual) provides an indication of the carbon savings achievable using interventions and investments already available, in addition to the savings to be had from changes to physical mobility. In order to reach an estimation of carbon savings from a typical streetscape (present day) to a future streetscape, a 1km linear stretch of street is considered.

Elements considered include road surfacing, capital carbon of the vehicles on that road, bus stops, vegetation, underground utilities etc. There is a degree of overlap between many of these elements such as electrical power supply (underground utility) serving bus stops as well as electric vehicle charging points. However, each have been addressed individually with an aim to provide a simplistic representation of the carbon savings to be had between a typical situation now, and a potential future situation, rather than comparison between each element themselves.

Capital and operational carbon values have been obtained through desk-top research focussing on case studies in the English language. Gaps in research and potential further workstreams have been identified and are explained in Section 6.

Capital carbon is also referred to as embodied or embedded carbon, and describes the carbon dioxide (CO_2) output of the manufacture of an element. In some cases only the material carbon footprint of an element is presented in research, which excludes factors such as carbon cost of delivery etc, and in other cases this is factored in to the capital carbon figure presented. In some instances the operational carbon is included to provide context such as emission values for motor vehicles. An attempt is made to conclude a carbon footprint value for the lifecycle of each streetscape element (from cradle to grave), however data to this effect was not always available.

Carbon dioxide (CO_2) and carbon dioxide equivalent (CO_2e) are both used in this report to refer to the carbon production in its various forms. CO_2e is commonly used in the reference material and is defined as a ‘unit comparing radiative forcing of a GHG (greenhouse gas) to carbon dioxide. The carbon dioxide equivalent is calculated using the mass of a given GHG multiplied by its global warming potential’[1].

[1] Kärnä, P, 2012. Carbon footprint of the raw materials of an urban transit bus: case study: diesel, hybrid, electric and converted electric bus.

2 The Typical Street

The ‘typical street’ is defined as a streetscape comprising elements typically found on the majority of urban streets today. The example used here depicts each element but may not be exhaustive in reflecting every streetscape. The ‘typical street’ is deliberately conservative so as to more clearly understand the overall change in carbon use from the situation now and in the future.

The ‘typical street’ is illustrated in Figure 1.

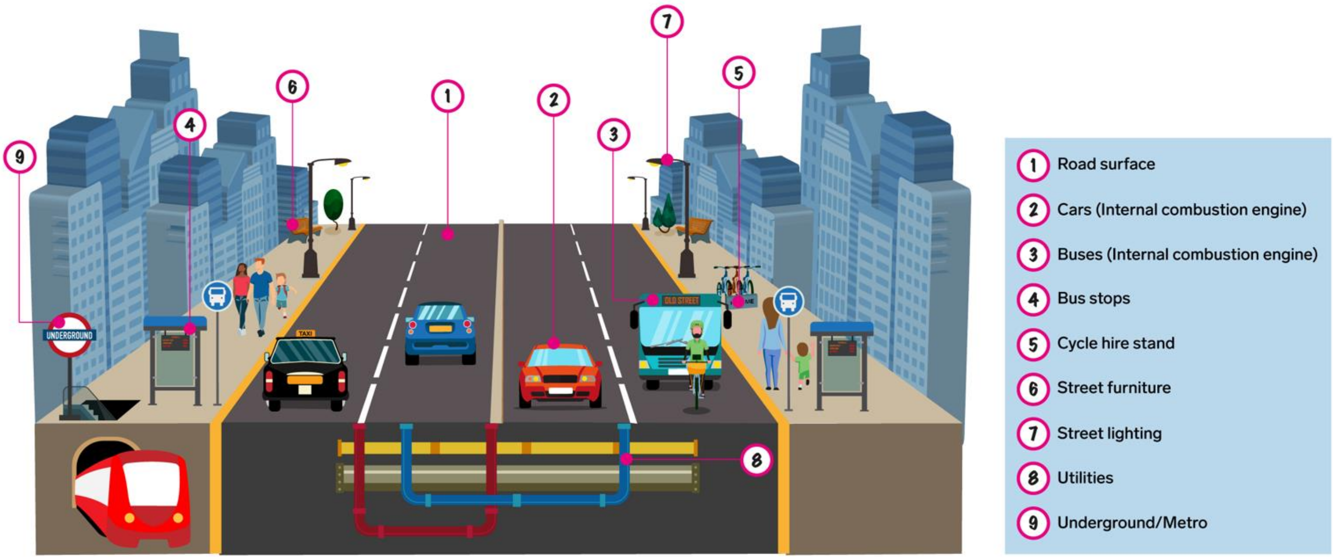

Figure 1 – The Typical Street

The individual streetscape components for which research material is available are demonstrated in Figure 1.

It is acknowledged that a wide array of vehicle types use a typical urban street frequently and that it is not just cars and buses, however this range is vast and for simplicity in this example only these two examples have been analysed. All vehicles in the ‘typical street’ scenario are internal combustion engine (petrol or diesel) as, whist this is rapidly changing, this represents the traditional composition of engine types on the roads currently. For instance, in the UK in 2021, whilst newly registered low emission vehicles (Battery Electric (BEVs), Hybrid Electric (HEVs) and Plug in Hybrid Electric (PHEVs) reached 27.5% of all car sales[2], the proportion of ICE vehicles on the road was still as high as 97.6%[3].

[2] Errity, S., 2022. Electric car sales UK: More EVs registered in 2021 than previous five years combined.
[3] Innovate UK, 2021. UK Transport Vision 2050: investing in the future of mobility.

The capital carbon and operational carbon emissions over a specific period are considered for each streetscape element where information is available, recognising that there are interdependencies and that the derived figures are indicative averages. Due to limiting research to the English language many of the case studies and research material are UK based.

2.1 The Streetscape

2.1.1 Road Surface

Research demonstrates that in the UK asphalt (or tarmac) is the most popular surfacing material and is used to construct over 95% of roads, with the remaining 5% being constructed of concrete.

Capital CO2e within asphalt derives from the aggregate and binder which together comprise 44% of the total volume of carbon, 42% is emitted through the heating and drying stage, and the remaining 14% derives from the mixing and delivery. This culminates in a capital carbon value of approximately 50 kg of CO2e per tonne of asphalt[4].

It is estimated that getting the asphalt required to resurface a mile of single lane carriageway (excluding transport to the site) can produce up to 26.5 tonnes of CO2[5], this equates to approximately **16.5 tonnes of CO2e per km of road**. This will vary depending on road width, depth, and any curves etc.

In England it is estimated that major roads need to be resurfaced every 10-12 years due to the effects of water, sun, and air, as well as the weight of traffic[6]. The surface will also be disrupted to maintain or install utilities over this time.

2.1.2 Cars

In the production stage it is reported than an average ICE (internal combustion engine) vehicle generates 720kg of carbon per £1,000 spent. This means that for example, a medium sized car worth £24,000 is approximated to generate more than 17 tonnes of CO2e before it drives its first mile.[7] However other sources have calculated a mid-sized ICE vehicle to generate around 5.6 tonnes of CO2e in its production phase alone[8], excluding the additional elements of manufacture such as travel. This second figure is widely cited in research pertaining to electric vehicle manufacture and use in the UK and is more applicable to other values stated (i.e. relates to the production in isolation) therefore it is used in further assessment for comparison purposes in this report.

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[4] Loveday, C., 2011. Driving Down Carbon on Recycled Roads.
[5] Cozier, M., 2021. New road surface is set to cut emissions.
[6] Highways England. 2021. Anti-ageing roads could keep roadworks at bay.
[7] Berners-Lee, M., 2020. How bad are bananas.
[8] Patterson, J., Alexander, M. and Gurr, A., 2011. Preparing for a Life Cycle CO2 Measure.

Over the lifetime of a car (on average 13.9 years and 154,859.9km driven) this medium sized car is estimated to produce a further 27 tonnes of CO_2e[9].

The theoretical capacity of a typical urban street in the UK, as a single carriageway (6.1m width) with a 30mph speed limit, is 900 vehicles per hour in one direction[10]. Assuming a 60:40 split in directional flow this is 1,500 vehicles on the road within an hour. As a worst case therefore the road could see up to 36,000 vehicles in one day (24 hours), and 13,140,000 vehicles in a year (365 days). This equates to a maximum potential capital carbon impact of **8,400 tonnes of CO2e** counting cars across an hour, and 73.58 million tonnes of CO2e counting cars in a year on the 'typical street'.

2.1.3 Buses

The CO2e produced in materials for a standard diesel bus at 12m is between 45.5 to 54 tonnes, made up of the metals (steel and aluminium chassis respectively), devices and batteries, plastics, lubricants, and other materials (such a plywood, double glass, bitumen).

Metals are reported to make up around 1/3rd of the capital CO2e (despite being circa 60-80% of the weight), followed by the electrical components and double glass. The materials ultimately form approximately 1/3rd of the emissions of the entire manufacture of a bus where transport and manufacture process costs are not accounted for. [11]

Whilst the material carbon footprint is notable, the majority of carbon emissions of a standard single decker bus results from its operational lifetime, this being an average of 822g of CO2e per km driven[12]. The average age of a bus in London in 2018/19 was 5.9 years old, and in non-metropolitan areas of England was 8.4 years. The average distance driven by London buses in 2018/19 was approximately 707,500 km per bus[13] in the year. Indicatively therefore, the lifetime carbon emissions (excluding capital carbon) are in the region of 3,431 tonnes of CO2e per bus.

The 1 km 'typical street' could see multiple buses at any one time and many buses across a typical day, this being dependent on number and frequency of services. Using a judgement of four buses being on the 'typical street' at any one time would therefore result in a maximum potential cost of **216 tonnes of CO2e per km of road**. As with cars, this figure would in actuality be higher as more buses route along the road across the day.

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[9] G., 2019. Carbon emissions in the lifetime of cars.
[10] Design Manual for Roads and Bridges (DMRB). Determination of Urban Road Capacity. TAA= 79/99. Volume 5: Section 1.
[11] Kärnä, P, 2012. Carbon footprint of the raw materials of an urban transit bus: case study: diesel, hybrid, electric and converted electric bus.
[12] DEFRA, 2007. Passenger transport emissions factors: Methodology paper.
[13] Transport for London, 2022. Buses performance data.

2.1.4 Bus Stops

CO_2 data for bus stops has been obtained for Transport for London (TfL) bus stops, which are reported to each contribute an average of 7.9 tonnes (8.7 tons) from their production phase[14].

Assuming a bus stop is located every 400m on any given bus route in an urban area, four bus stops would be expected to be on a 1km stretch of street. This is **31.6 tonnes of CO_2** in total for the 'typical street'.

2.1.5 Cycle Hire Stand

Whilst bicycles are more or less carbon neutral in use (not accounting for additional food to fuel the rider or heat produced), the material carbon footprint of the bicycles themselves is a consideration as is the maintenance of a hire scheme.

The maintenance of a bike hire scheme involves vehicles and trailers to rebalance the bikes around the scheme area, thus producing standard vehicle carbon emissions. Information on the typical distance driven to fulfil the rebalancing is not readily available.

Research of a scheme in Edinburgh demonstrates that over 5 years, one bike in the scheme will release 195 kg of CO_2e (based on 1,000 bikes), or 4.7g of CO_2e/km. Of this, 33.3% comprises the manufacturing stage and therefore represents the capital carbon, with transport making up 14.1% and usage of the bikes 49.9%, the remaining 2.7% considers the waste disposal. [15] As such it is estimated that the embodied carbon value (being 33.3%) is circa 65kg of CO_2e per bike.

Extrapolating these results and applying them to a different timeframe is difficult as the CO_2e values will adjust with the number of bikes included in the scheme and depending on the nature of the rebalancing. On the basis however of one cycle hire hub on the 'typical street' with 10 bikes docked, this would theoretically contribute just under 2 tonnes of CO_2e in 5 years, or 400 kg of CO_2e in 1 year. This research does not posit how the carbon value will change with increased years nor to the standard lifecycle of the elements of a bike sharing scheme. Applying just the capital value of 65kg of CO_2e to 10 bikes docked on the 'typical street' results in **650 kg of CO_2e**.

2.1.6 Street Furniture

Street furniture naturally varies enormously from decorative artwork to public benches to bins, and there is little research on the environmental impact of a typical steel bench for example. However there is data available for household furniture for which the average piece

[14] Natural Shelter, 2022. Natural Shelters Are Innovative.
[15] D'Almeida, L., Rye T., and Pomponi, F., 2021. Emissions assessment of bike sharing schemes: The case of Just Eat Cycles in Edinburgh, UK.

produces 47 kg of CO2e[16], and hence this has been used as a proxy in the place of more applicable data.

Assuming a bench is provided on average every 100m[17] on the 'typical street' a total of 20 benches would be available, resulting in **940 kg of capital CO2e**.

2.1.7 Street Lighting

LED (light emitting diode) bulbs have already begun to replace traditional bulbs (55% LED in 2020 in the UK[18]) in many places and savings in energy and cost are being made with about 90% of an incandescent bulb's energy being released as heat[19].

A non-street specific LED bulb is reported to emit between 167 and 264 kg of CO2e over a 20-year lifespan (European and USA studies respectively). Of this value 98% is the operational CO2e and 2% the embodied carbon equivalent meaning that each light produces around 3.34 to 5.3 kg of capital CO2e.[20] This does not include the lighting column.

The embodied carbon footprint of LEDs however are reportedly far higher than traditional bulbs[21], however it is understood that the operational emission savings outweigh the disbenefits of the embodied carbon figure.

In the UK the standard distance of street lights in an urban area is between 30 and 50m apart. Based on 30m spacing on one side of the road therefore the 'typical street' would have 33 street lights, equating to a maximum potential of **174.9 kg of capital CO2e**. The actual embodied carbon figure would be higher to account for the street column etc.

2.1.8 Utilities

This covers a wide range of different services including gas lines, electricity supply, broadband cables and housing, as well as drainage pipes etc. The exact composition of utilities under a typical street is difficult to estimate, however data is available on the capital carbon footprint of materials normally used for many of these purposes.

Graph 1 demonstrates the CO2e values based on a 12" diameter pipe and weight per linear foot used as a starting point for understanding the carbon impact. HDPE stands for high density polyethylene.

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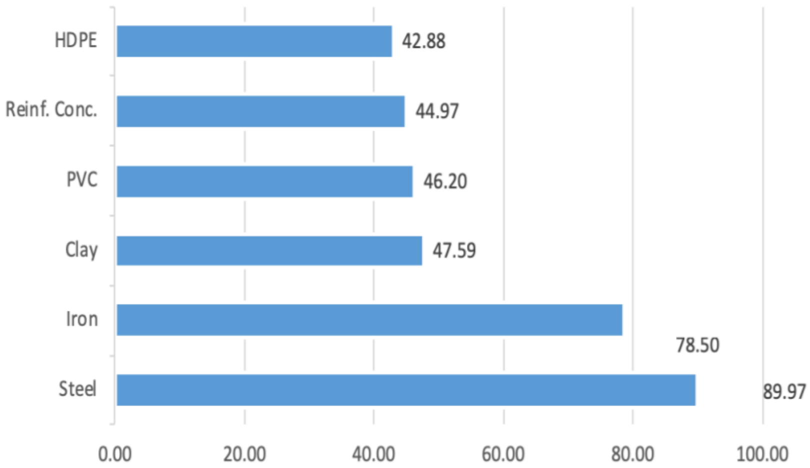
[16] MyToolShed, 2019. Furniture's Carbon Footprint and the Importance of Upcycling.
[17] Department for Transport, 2007. Manual for Streets.
[18] Ward, J., 2021. Saving costs and carbon by investing in street lighting.
[19] FSG, 2020. How Street Lighting Upgrades Can Have a Positive Impact on Our Climate.
[20] Finnegan, S., Jones, C. and Sharples S., 2018. The embodied CO2e of sustainable energy technologies used in buildings: A review article.
[21] Gray, A., 2020. Lighting's Dark Secret: Embodied Carbon in the LED Industry.



Graph 1 – Utility Materials Capital Carbon Equivalent per linear foot[22]

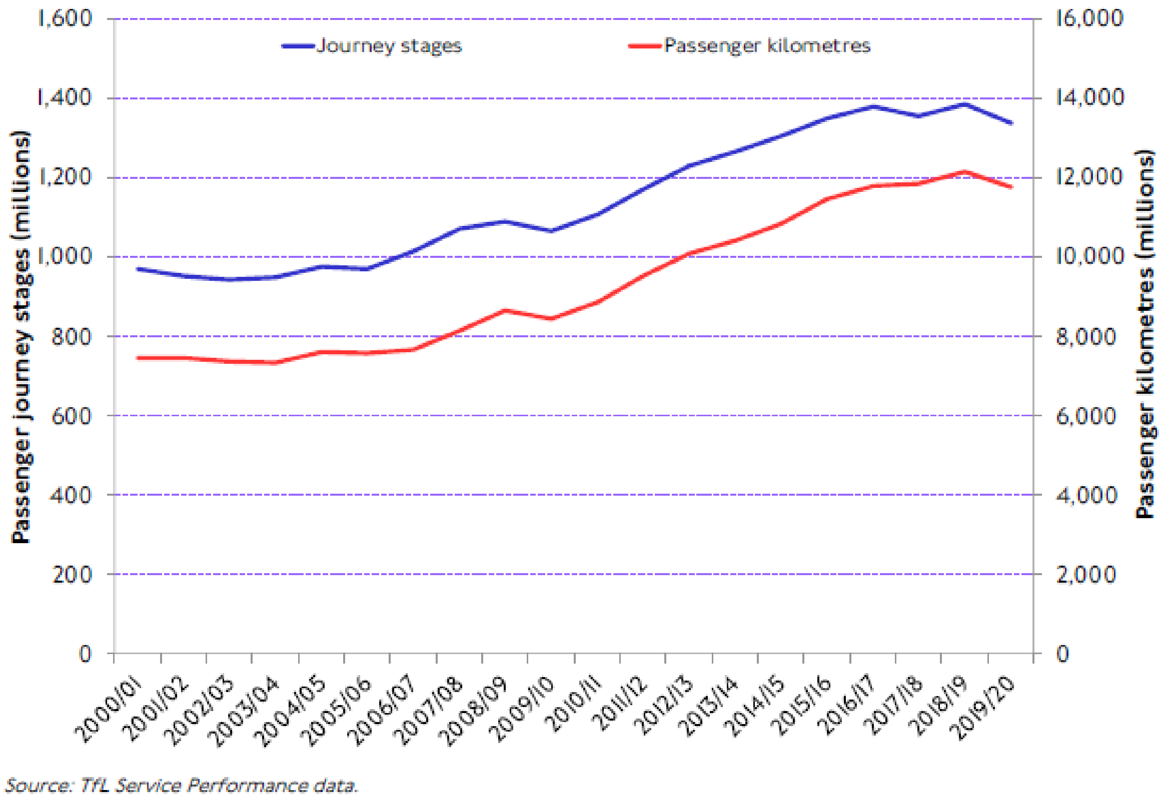
This graph demonstrates that an HDPE pipe will have the least CO2e impact whilst steel will have the maximum, however there are limitations in material choice dependent on the service itself, but also on the soil in which the pipes will sit[23].

Without any further information on average length of pipes, cables etc forming the suite of underground utilities, it is not possible to posit a capital carbon value for the 'typical street'. Nevertheless it is clear that where material changes can be made to encasement material there is a hierarchy of carbon savings to be had.

2.1.9 Underground/Metro

The underground figures are based on the London Underground, for which TfL reports uses more electricity than anything else in the city[24]. In 2008 the average tube journey was reported to generate 48g of CO2e with the total footprint for the underground being 754,437 tonnes of CO2e in 2007/8[25]. Graph 2 shows passenger km on the London Underground, and using 2007/8 as appropriate it is evident that just under 8,000 passenger kms were undertaken[26]. Applying the 8,000 passenger kms to the total CO2e emissions from this year indicates a value of 94 tonnes of CO2e per km in a year. This is the operational CO2e and no information has been found on the embodied carbon of the London Underground.

22 Mosier, R, Adhikari, S., and Mohanty, S., 2020. A comparison of the carbon footprint of pavement infrastructure and associated materials in Indiana and Oklahoma.
23 Mosier, R, Adhikari, S., and Mohanty, S., 2020. A comparison of the carbon footprint of pavement infrastructure and associated materials in Indiana and Oklahoma.
24 Katwala, A., 2018. London's wild plan to make the Tube carbon neutral by 2050.
25 Transport for London, 2008. LU Carbon footprint report 2008.
26 Transport for London, 2020. Travel in London Report 13.



Graph 2 – Passenger km and journey stages by London Underground, 2000/01-2019/20[27]

2.2 The Typical Street – Total Capital Carbon

Street Element	Capital Carbon	Operational Carbon (10 years)
Road Surface	16.5 tonnes	-
Cars	8,400 tonnes	3,547,800,000 tonnes
Buses	216 tonnes	686,200 tonnes
Bus Stops	31.6 tonnes	-
Cycle Hire Stand	650 kg	3.9 tonnes
Street Furniture	940 kg	-
Street Lighting	174.9 kg	-
Utilities	-	-
Underground	-	-
Estimated Total	**8,666 tonnes**	**3.5 billion tonnes**

Each component has been considered independently and estimated CO2 or CO2e values have been applied accordingly. Based on the aforementioned judgements on the likely

[27] Transport for London, 2020. Travel in London Report 13.

provision of each element on a 1km linear ‘typical street’, the total capital carbon figure attributed is approximately **8,666 tonnes of CO2e**, or **266 tonnes of CO2e excluding cars**. This excludes utilities or any operational carbon.

Furthermore, over a 10 year period the complete carbon emissions are generally estimated to be in the order of 3.5 billion tonnes of carbon based on the research obtained and presented in this report (and assuming a worst case whereby all cars visiting the typical street have not been counted before). This figure will be higher again due to the method of calculating cars and buses using the ‘typical street’, and due to hidden carbon costs such as lighting columns, the embodied carbon of the cycle hire docking furniture, electricity source etc. As such this should be used as an indication of impact for comparison with the ‘future street’ only.

3 The Future Street

The ‘future street’ is defined as a streetscape that improves upon the ‘typical street’ using a variety of interventions that are either already available and happening now, or are readily gaining traction. The purpose of presenting a ‘future street’ is to demonstrate the extent of decarbonisation that is feasible now or in the near future in just the streetscape itself. The ‘future street’ is therefore illustrated in Figure 2.

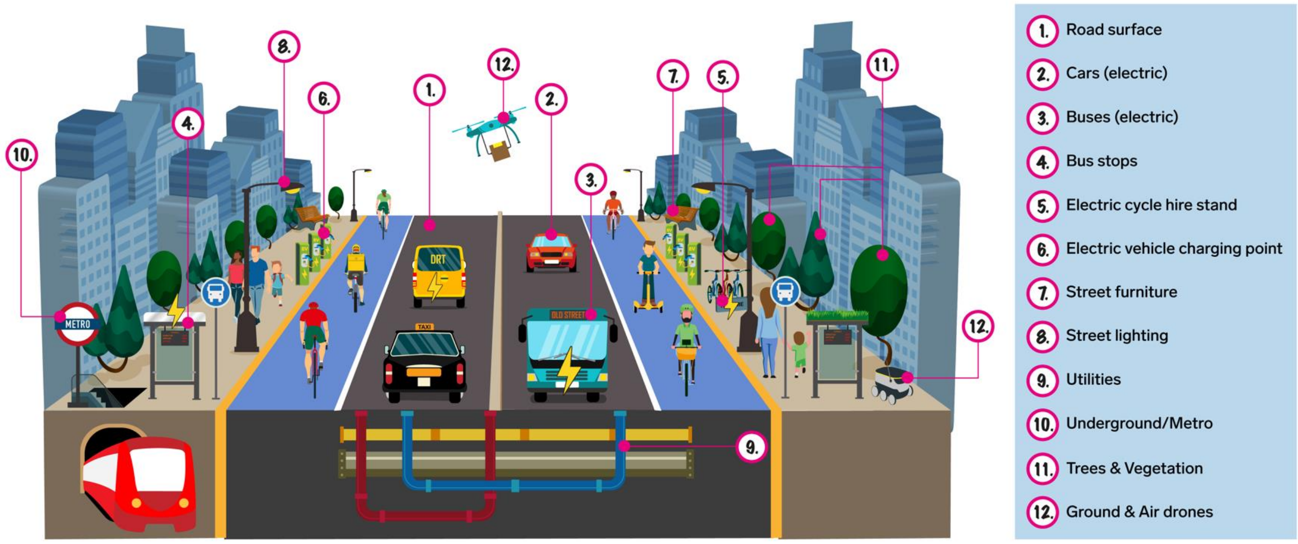


Figure 2 – The Future Street

The individual streetscape components for which research material is available are demonstrated in Figure 2. Some of these components are duplicated from the ‘typical street’, however many represent improved facilities in terms of carbon savings and additional elements have been added.

The capital and operational carbon emissions over a specific period are considered for each streetscape element, recognising that there are interdependencies and that the derived figures are indicative averages. Due to limiting research to the English language many of the case studies and research material are UK based but are anticipated to be applicable elsewhere.

3.1 The Streetscape

3.1.1 Road Surface

As noted for the 'typical street', asphalt is the most commonly used road surfacing material used in the UK. Asphalt is also recyclable with 100% of its materials suitable for reuse into new asphalt at the end of its lifespan. Following its initial creation, recycling of asphalt materials cuts 44% of carbon emissions compared to new asphalt due to this proportion of its total carbon contribution consisting of the aggregate and binder themselves.

The average asphalt road lasts for 18 years and after this new roads can be created using the original material[28], and based on 56% of the capital carbon relating to the processing (44% being recyclable materials), the recycled asphalt produces a capital cost of **9.24 tonnes of CO2e per km of road.**

Considering the carbon footprint of asphalt over its lifecycle, evidently its footprint is better the longer it remains in use. Thus it is important to future proof its production to extend its life. An example of this is an asphalt road with 50kg CO2e per tonne lasting for 20 years its footprint is effectively 2.5kg of CO2e per tonne per year. Using best practice however to extend its life to 40 years reduces this to 1.25kg CO2e per tonne per year. If this same asphalt is then recycled at the end of its lifespan the footprint reduces further to 0.7kg CO2e per tonne per year. [29]

Whilst asphalt is currently the most popular choice in the UK for road surfacing, research suggests that the colour of light concrete can help to reduce carbon impacts. Changing 1m^2 of black asphalt into a light concreate prevents the emission of 22.5 kg of CO2. This offsets 30 – 60% of the CO2 emitted during the manufacturing process of the cement used in the concrete. This also aids in saving on street lighting through higher levels of reflected light, allowing reductions of up to 35% in lighting.[30]

3.1.2 Cars

Comparison of the CO2 emitted during production is reported with a wide range, ranging from double of a medium-sized ICE vehicle, to less than an ICE vehicle. The battery is widely accepted to be CO2 intensive in production in a way that elements of an ICE vehicle are not.

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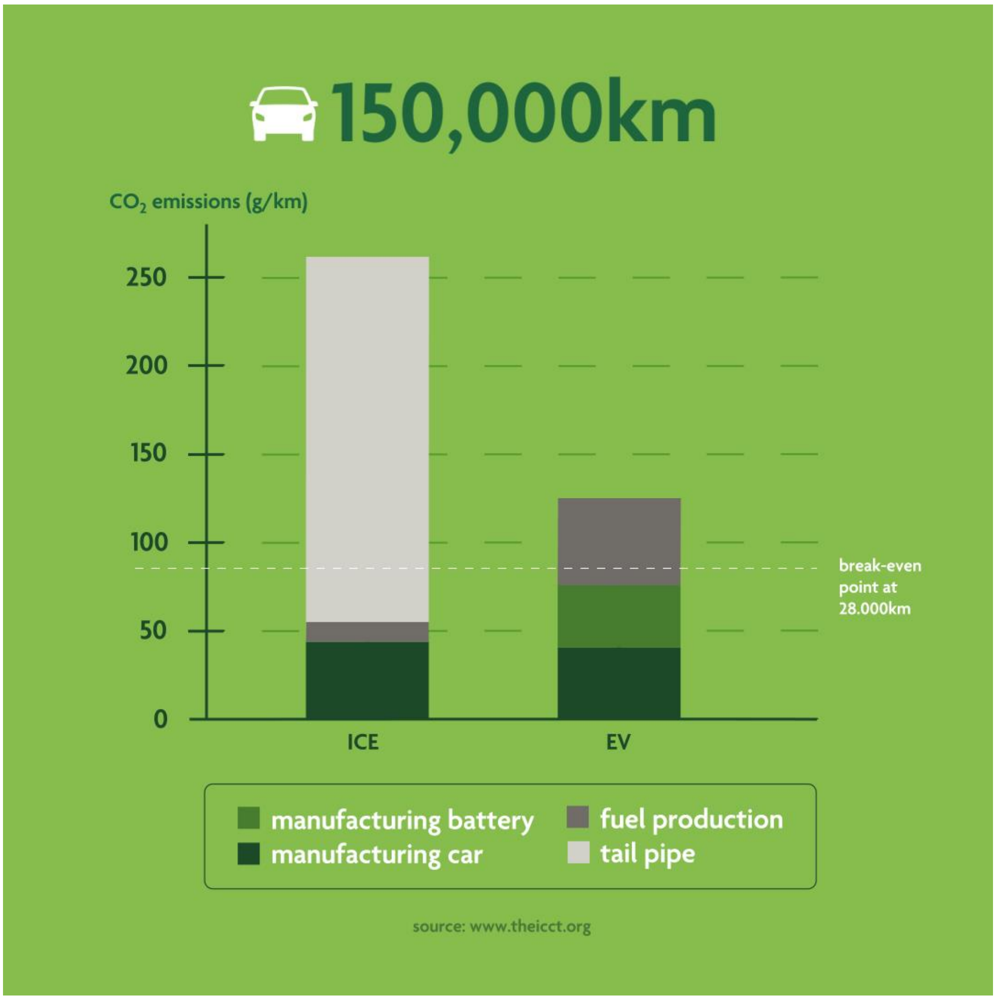
[28] Loveday, C., 2011. Driving Down Carbon on Recycled Roads.
[29] Loveday, C., 2011. Driving Down Carbon on Recycled Roads.
[30] European Concrete Paving Associating, 2020. Concrete roads can strongly contribute to reduction of CO2 emissions from road transport.

An indicative value for Electric vehicles (EV) in production has been derived at approximately 8.8 tonnes of CO2e[31], however once they are in use 28,000 km (achieved after an average 2 years of driving) is the average 'breakeven point' whereby after this stage, driving an EV has a positive carbon impact. This is dependent on the type of energy production used which is factored into the carbon emissions.

On this basis, with the average lifecycle of a vehicle in the UK being 8.5 years, for the final 6.5 years of driving an EV would have a positive impact over an ICE vehicle.[32] This is illustrated in Graph albeit this shows a slightly different capital carbon CO2 value than stated above.



Graph 3 – Breakeven point and CO2 emissions over 150,000 km[33]

This graph demonstrates that the carbon savings are in the order of 20.5 tonnes based on the lifecycle of a modern car. Although this is dependent on the source of electricity, it is

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[31] Patterson, J., Alexander, M. and Gurr, A., 2011. Preparing for a Life Cycle CO2 Measure.
[32] Allegro, 2019. At what point is your EV truly more sustainable than a fossil fuel car?
[33] Allegro, 2019. At what point is your EV truly more sustainable than a fossil fuel car?

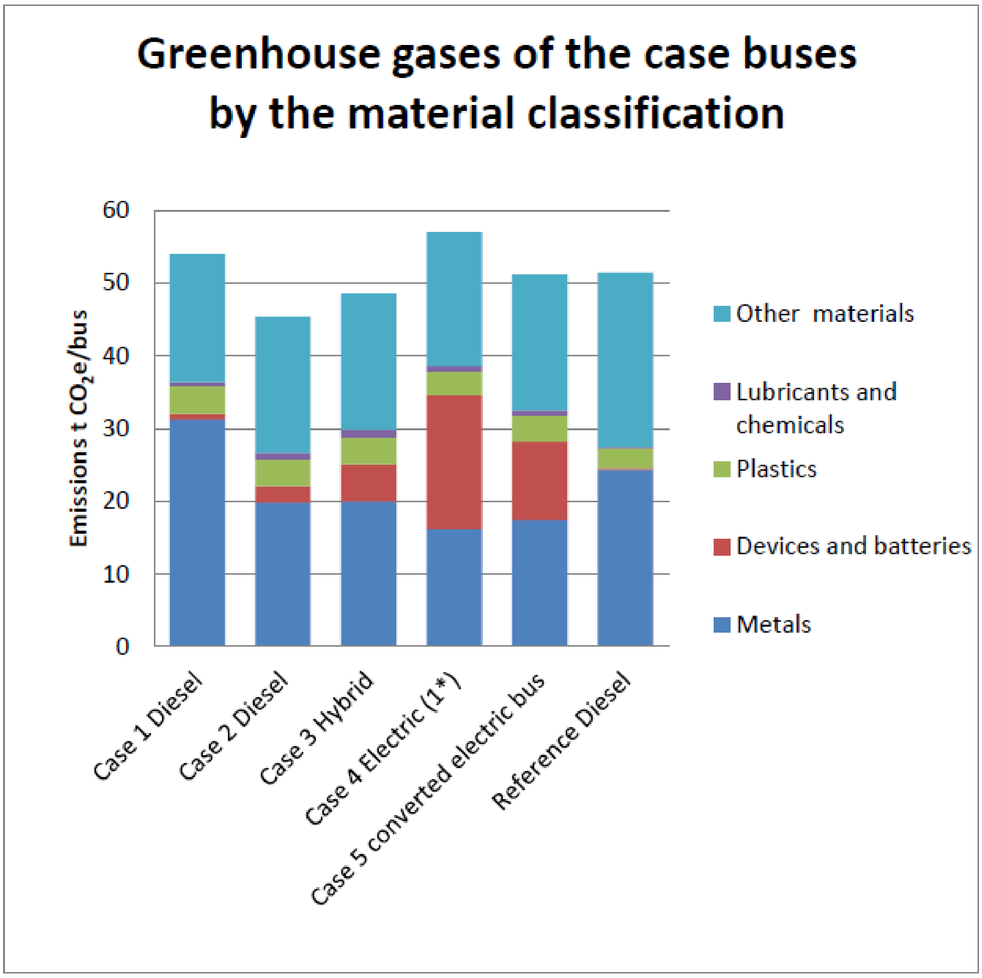
suggested that in 95% of the world, driving an EV is better than an ICE vehicle[34], and the carbon impact of driving an EV will continue to reduce as grid electricity production becomes cleaner[35].

Applying the same methodology as to the ‘typical street’ and assuming a maximum of 1,500 vehicles on the road within an hour (which is a worst case assessment), the total capital value would be **13,200 tonnes of CO2** counting cars across an hour. This equates to 115.63 million tonnes of CO2 counting cars in a year on the ‘future street’.

3.1.3 Buses

Research indicates that the material carbon footprint of a hybrid bus is 49 tonnes of CO2e, and for a fully converted electric bus is 51 tonnes of CO2e. An electric bus is calculated to produce 57 tonnes of CO2e. These refer to standard 12 metre buses as considered for the ‘typical street’. Graph 4 illustrates the composition of materials in relation to their CO23 emissions. [36]

[34] Knobloch, F. et al., 2020. Net emission reductions from electric cars and heat pumps in 59 world regions over time.
[35] Staffell, I. et al., 2019. April to June 2020 Electric Insights Quarterly.
[36] Kärnä, P, 2012. Carbon footprint of the raw materials of an urban transit bus: case study: diesel, hybrid, electric and converted electric bus.



(1*) Preliminary results

Graph 4 – Material carbon footprints of the case buses by the material classification[37]

Whilst the material carbon footprint is higher for electric buses due to the increased amount of electrical components, the majority of carbon emissions of a standard single decker bus result from its operational lifetime, these emissions being vastly reduced for an electric bus.

The operational phase of an electric bus is in theory carbon neutral, as are hydrogen buses both of which are already in operation in London. The average age of buses in London in 2018/19 was 5.9 years old, and the average distance driven by London buses in 2018/19 was approximately 707,500 km per bus[38] in the year. Lifetime carbon emissions are therefore cut from the 'typical street' by 3,431 tonnes of CO2e per bus, with CO2e production involved only in the renewal of the fleet. There is no data at this time to suggest that the lifecycle of an electric or indeed hydrogen bus will differ from a diesel bus, however it is reasonable to assume that there will be a variation.

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[37] Kärnä, P, 2012. Carbon footprint of the raw materials of an urban transit bus: case study: diesel, hybrid, electric and converted electric bus
[38] Transport for London, 2022. Buses performance data.

Based on the capital carbon production of a fully electric bus, and using the same methodology as for the 'typical street' by judging that four buses are present at any one time, the maximum potential cost is **228 tonnes of CO2e per km of road**. This is higher than for the 'typical street'.

3.1.4 Bus Stops

Negative carbon shelters are being developed for TfL which have a net gain of sequestered carbon amounting to 166kg per shelter, making it carbon negative.[39]

More carbon savings could potentially be made by combining this engineering with simple changes such as 'green roofs' of shelters, where sedum plants are grown. This type of initiative is being installed in Milton Keynes in the UK where existing bus shelters are being upgraded with green roofs. No CO2 saving has been quantified for this scheme but it will undoubtedly improve urban greening and does not require a new bus stop.[40]

On the basis of a bus stop located every 400m, four bus stops would be present on the 1km length of 'future street'. This is a net carbon **negative impact of 664 kg of CO2**.

3.1.5 Electric Cycle Hire Stand

Electric bike hire schemes operate in the same way as non-electric schemes, but with electric bikes. Therefore, the primary difference in capital carbon is the production of the electrical components of an e-bike and the power source to the docking station. Given the additional weight of an e-bike it is reasonable to judge that the rebalancing of bikes would use more fuel however research is limited on this.

A push bike is understood to produce around 4.7g of CO2e per km where an e-bike produces about 31.2g of CO2e per km over its operational lifetime including production[41]. In its production alone a standard commuting e-bike is reported to produce approximately 165 kg of CO2e[42].

Whilst it is clear that e-bikes produce more CO2e in their production (battery manufacture) and operational phases (recharge of the battery), they are more likely to replace car trips over public transport or other active travel trips given the extended range available over a push bike, as well as convenience and attractiveness. Therefore, the case can be made that in the context of the 'future street' they increase the CO2e value and yet have a wider positive impact on carbon savings. The watt-hours requited to travel 1 km is shown in Graph 5 to compare between modes.

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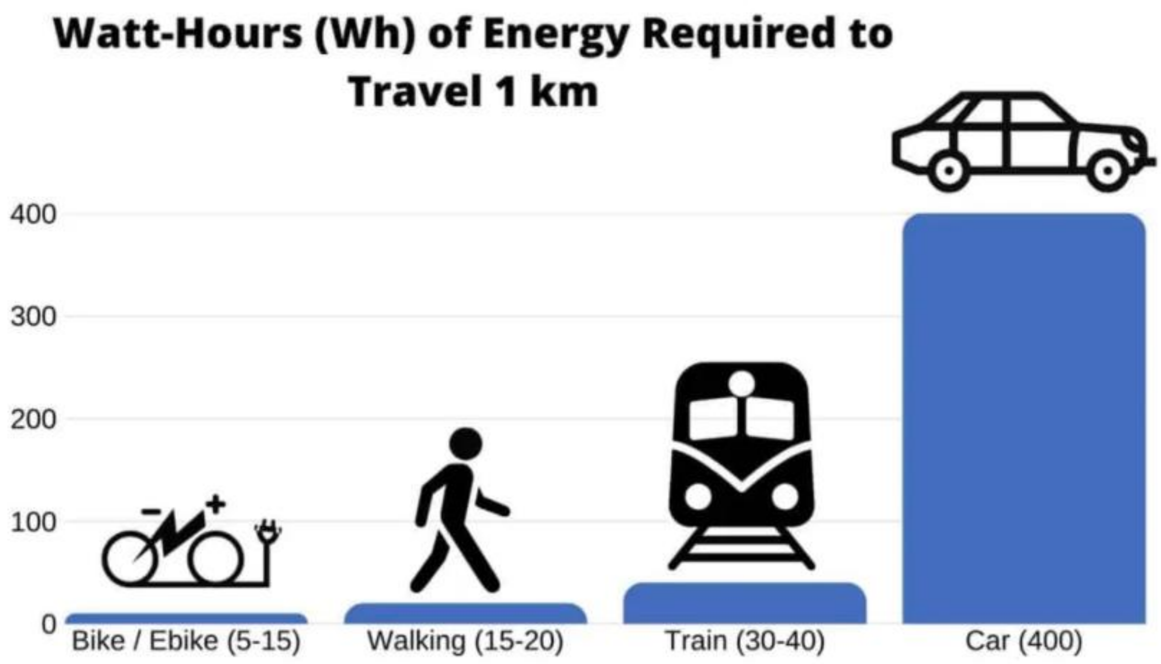
[39] Natural Shelter, 2022. Natural Shelters Are Innovative.
[40] Milton Keynes Council, 2021. Carbon reducing green bus shelters to be installed in Milton Keynes.
[41] D'Almeida, L., Rye T., and Pomponi, F., 2021. Emissions assessment of bike sharing schemes: The case of Just Eat Cycles in Edinburgh, UK.
[42] TREK, 2021. Sustainability Report and Corporate Commitment 2021.



Graph 5 – Watt Hours of Energy Required to Travel 1km[43]

Using a figure of 165 kg of embodied CO2e per e-bike results in in **1.65 tonnes of CO2e.**

3.1.6 Electric Vehicle Charging Point

Electric vehicle charging points add an element to the streetscape from the ‘typical street’, and therefore will add capital and operational carbon values to the street. However their benefit is clear, which is to facilitate the use of EVs within the street environment and these have already been demonstrated to have a medium to long term positive impact on emissions.

Data is not readily available on the capital carbon of the charging points themselves, and electrical power supply will contribute to this, however the footprint of the energy used itself depends entirely on how energy is made for the national grid. An EV charged using renewable energy is carbon neutral (in this respect), whereas using standard grid electricity results in around 40g of CO2 per km[44].

3.1.7 Street Furniture

Again considering benches as a standard item of street furniture, research demonstrates that wooden benches are carbon neutral, and can result in an average net gain of carbon

[43] eBikesHQ.com, 2022. Electric Bikes and the Environment? Carbon Footprint, Energy, Battery Disposal.
[44] Carbon Footprint, 2022. ELECTRIC VEHICLES Why Make the Move to Full Electric now?

amounting to 66.5kg per bench. This would equate to a saving of 113.5kg of carbon per bench. Carbon can be stored in wood furniture for about 30 years[45].

Assuming there are 20 benches on the 'future street' results in a **negative impact of 1.33 tonnes of capital CO2e.**

3.1.8 Street Lighting

LED bulbs are already becoming a popular choice for street lighting, where 1 LED bulb is reported to use 1/6th of the power of a traditional halogen lightbulb. The UK and many other countries are already in the process of switching to LED lighting, therefore the carbon value for street lighting remains the same as for the 'typical street' at **174 kg of capital CO2e**.

As with any element powered from the electrical grid, the operational carbon footprint of street lighting will depend on the source. As the grid decarbonises therefore operational carbon will become carbon neutral.

3.1.9 Utilities

The materials choice for utilities are very much restricted to the functional technical capabilities of each service.

As broadband technology evolves so do the materials used, where a shift from copper wiring to fibre optic wiring is almost commonplace. One of the benefits of doing this is to enable a reduction in exchanges as fibre optic networks can travel further than copper without losing performance. Fibre technology also produces less heat consequently requiring less cooling, thus using less energy. Additionally, the extraction of 2kg of copper required to produce a 200 foot length of wire produces around 1 tonne of CO2e. Production of the equivalent length of fibre optic cable produces 0.06kg of CO2e. This is a significant carbon saving.[46]

Without any further information on the number of underground utilities it is not possible to speculate as to the carbon impact to the 'future street', however research demonstrates that this sector is moving in the right direction to reduce carbon emissions.

3.1.10 Underground/Metro

Many schemes are in place to neutralise the carbon emissions of underground networks. In London one of the interventions is to use the tube to heat London homes as it is estimated that there is enough heat wasted in London to meet 38% of the city's heating demands.[47] This would work towards carbon neutrality although is not directly appliable to the 'future street' in isolation.

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[45] CINARK, The Royal Danish Academy and Vandkunsten Archtects, 2019. The construction material pyramid.
[46] TalkTalk, 2021. Making the 'climate case' for Full Fibre.
[47] TheCivilEngineer.org, 2019. Heat produced by an underground line to warm houses in London.

Another strategy to reducing energy use on the London Underground is reducing the need to use the trains' brakes, which are one of the main causes of the underground's heat. The plan is to do this through more use of coasting as well as regenerative braking systems that harvest some of the energy lost in braking and supply it back to the train.

Solar panels are also planned to be introduced alongside railway tracks, as well as building in battery storage on the network. This could allow energy to be bought at times when renewable energy is freely available (windy or sunny days for example) for use at peak times, rather than buying from the grid. Private wind farms are also being investigated.[48]

Whilst exact carbon savings could not be obtained, the intention in London is to make the underground carbon neutral by 2050. Assuming that this aspiration will succeed then the operational carbon impact applied to the 'future street' is **neutral**.

3.1.11 Trees & Vegetation

Many streets already have trees and grass verges, but in many cases more can be done to create carbon sinks within the streetscape.

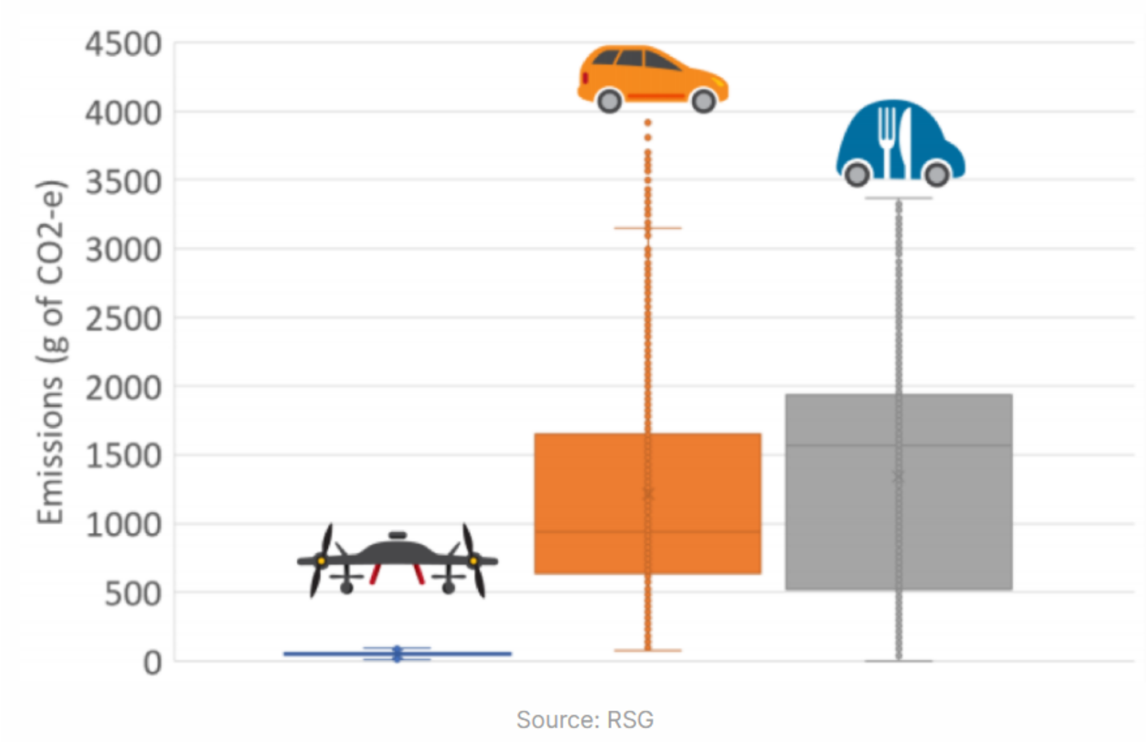
Trees are a good carbon sink however, they only sequester a meaningful amount of carbon once fully grown. A typical tree over its lifecycle (approximately 100 years) is estimated to sequester approximately 1 tonne of CO2[49].

Assuming trees can be positioned evenly every 5m on the virtual street, this is 400 trees on the 'future street', equating to sequestration of around **400 tonnes of CO2**.

3.1.12 Ground & Air Drones

Ground and air drones are a relatively new innovation but are rapidly gaining in popularity for deliveries, replacing car and van trips. A study undertaken in the USA found that an air drone was at least 26 times more efficient than the alternative mode, Graph 5 illustrates this.[50]

[48] Katwala, A., 2018. London's wild plan to make the Tube carbon neutral by 2050.
[49] Grantham Institute. 2015, How much CO2 can trees take up?
[50] Wygonik, E., 2020. Calculating the Climate Cost of Drone Delivery.



Graph 5 – Air drone compared to car delivery[51]

Being a fairly new innovation, there is little informal available on the embodied carbon of ground or air drones, but it is anticipated that the operational savings would offset this somewhat.

3.2 The Future Street – Total Capital Carbon

Street Element	Capital Carbon	Operational Carbon (10 years)
Road Surface	9.24 tonnes	-
Cars	13,200 tonnes	Neutral
Buses	228 tonnes	Neutral
Bus Stops	negative 664 kg	-
Cycle Hire Stand	1.65 tonnes	Neutral
EV Charging Point	-	-
Street Furniture	negative 1.33 tonnes	-
Street Lighting	174 kg	Neutral
Utilities	-	-
Underground	-	Neutral
Trees & Vegetation	negative 400 tonnes	-
Ground & Air Drones	-	-
Estimated Total	**13,037 tonnes**	**Neutral**

[51] Wygonik, E., 2020. Calculating the Climate Cost of Drone Delivery.

Each component has been considered independently and estimated CO_2 or CO_2e values have been applied accordingly. Based on the aforementioned judgements on the likely provision of each element on a 1km linear 'future street', the total capital carbon figure attributed is approximately **13,037 tonnes of CO_2e**. This excludes some elements where there was limited data or any operational carbon.

Furthermore, based on a future year where it is assumed the electrical grid supply will be carbon neutral, the operational carbon emissions will also be vastly carbon neutral. This is a simplistic figure that assumes aspirations and net zero targets will succeed. As such this should be used as an indication of impact for comparison with the 'typical street' only.

4 Carbon Savings in the Streetscape

Street Element	Capital Carbon	Operational Carbon (10 years)
Road Surface	-7.26 tonnes	-
Cars	4,800 tonnes	-3.5 billion tonnes
Buses	12 tonnes	-686,200 tonnes
Bus Stops	-32.3 tonnes	-
Cycle Hire Stand	1 tonne	-3.9 tonnes
EV Charging Point	-	-
Street Furniture	-1.5 tonnes	-
Street Lighting	-900 g	-
Utilities	-	-
Underground	-	-
Trees & Vegetation	-400 tonnes	-
Ground & Air Drones	-	-
Estimated Total	**4,371 tonnes**	**-3.5 billion tonnes**

Based on the data extracted and presented in the previous sections the total indicative capital carbon savings (excluding cars) from the 'typical street' to the 'future street' are **429 tonnes of CO_2e per km of road**. EVs have a higher capital carbon value than ICE vehicles and therefore the embodied carbon for the 'future street' could be in the order of 4,371 tonnes more than the 'typical street'

The estimated carbon savings including operational emissions are in the order of **3.5 billion tonnes of CO_2e per km of road** over a 10-year period on the basis of fully decarbonising the electrical grid. Capital carbon costs are not included in this figure. Over 20 years this is expected to decrease further and exponentially when capital carbon is factored in.

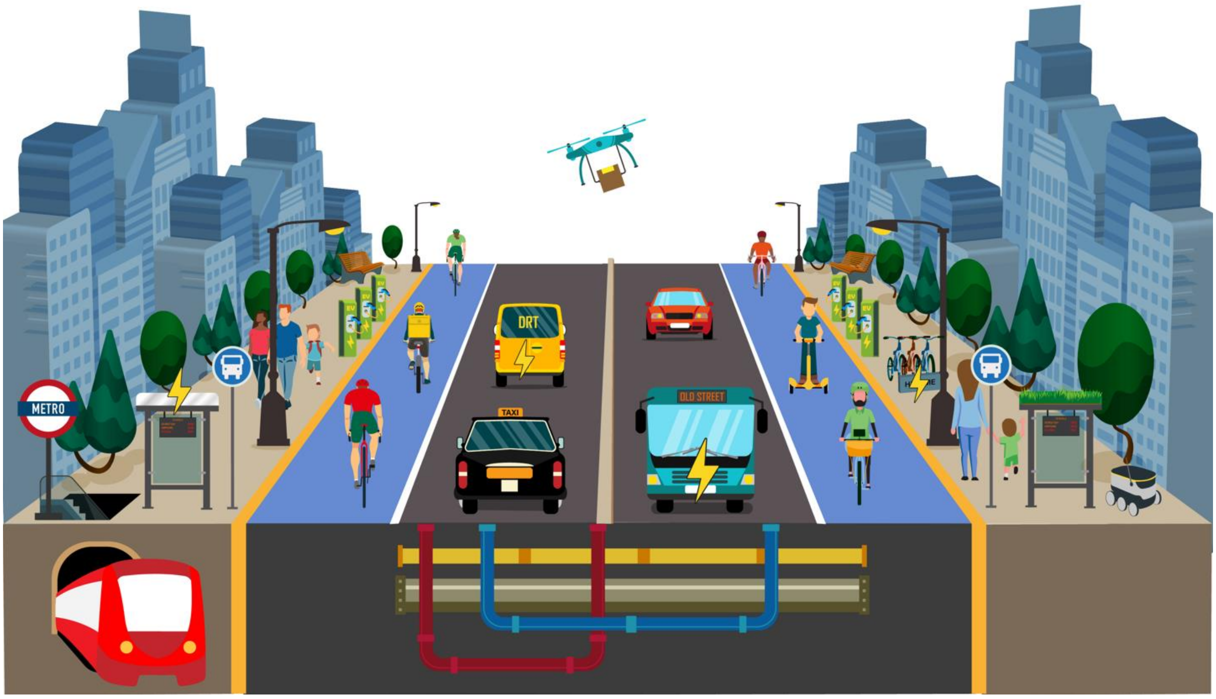


Figure 3 – The Future Street – Carbon Savings

5 Limitations & Future Research Needs

Specific limitations in the data available have been discussed where relevant with the primary points of note being the use of difference source material (each employing different methods of CO2/CO2e calculation), and different units of measurement over differing timeframes reported. The values reported are approximations and are intended to build an indicative picture of the virtual streets for comparison only. Average values have been used meaning that for some components there will be a wider range of values available.

From this desk-top assessment alone, gaps in research are apparent for a number of the elements considered; for street lighting there is a wealth of evidence relating to the benefits of LED when operational, but limited information on the embodied carbon related to the lighting (including lighting column etc).

The capital carbon make-up including both materials and manufacture of buses is an interesting topic of which further study would be beneficial, particularly how this might change with the increase carbon values of batteries over diesel vehicles.

As noted previously, there is little information on the embodied carbon of street furniture, however there is a clear path to decarbonisation in material use which is the use of wood over metals and plastics.

For the underground no data has been identified that considers the capital embedded carbon including train carriages, tracks, ventilation, manufacture, delivery, and fitting of new items and frequency of replacements etc. This therefore does not allow for a comparison to other modes of travel in terms of the lifecycle carbon emissions, where the underground has been demonstrated to have a far lesser impact on emissions than other non-active modes of travel, but with an unknown ongoing embodied carbon cost.

Ground and air drones are perhaps the newest technology discussed in this analysis and it is not evident through desk-top research that information is available on the capital carbon of drones.

As working from home or remotely becomes more popular it will mean a reduction in regular trips within the streetscape, whether that be car, bus, or active travel trips for example. This will have an impact on the carbon footprint of the streetscape however it would need to be offset against the higher energy spending within the home, as well as the extra elements of a journey to work such as food shopping and leisure trips.

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