ACTIVE TRAVEL STUDIES

Brand, C. 2021. Active Travel's Contribution to Climate Change Mitigation: Research Summary and Outlook. *Active Travel Studies: An Interdisciplinary Journal*, 1(1): 2, 1–13. DOI: https://doi.org/10.16997/ats.1036

VIEWPOINT

Active Travel's Contribution to Climate Change Mitigation: Research Summary and Outlook

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Active travel (walking, cycling or scooting for transport) is considered a healthy and sustainable form of getting from A to B. The net effects of active travel on mobility-related carbon dioxide (CO_2) emissions are complex and remarkably under-researched across a wide range of settings. This paper seeks to provide a summary of research on active travel as a low carbon mobility option in the context of the climate emergency. Key gaps are identified and discussed. The paper concludes with a projection of future research.

Keywords: CO_2 emissions; active travel; walking; cycling; climate change mitigation; review; research agenda

1 Introduction

> *"Policies that reduce overall vehicle use and increase walking and cycling will yield the greatest benefits in terms of reductions in greenhouse gas emissions and air pollution and the health advantages of increased physical activity."* The 2020 report of *The Lancet* Countdown on health and climate change: Responding to converging crises (Watts et al., 2021).

Modal shifts away from carbon-intensive to low-carbon modes of travel hold considerable potential to mitigate carbon emissions from transport (Cuenot, Fulton and Staub 2012). One of the more promising ways to reduce transport carbon dioxide (CO_2) emissions is to promote and invest in active travel (i.e. walking, cycling, e-biking, e-scooting) while "demoting" motorized modes that rely on fossil energy sources (Scheepers et al., 2014; ECF, 2011; de Nazelle et al., 2010; Goodman, Brand and Olgivie, 2012; Sælensminde, 2004; Quarmby, Santos and Mathias, 2019; Keall et al., 2018; Bearman and Singleton, 2014; Neves and Brand, 2019; Tainio et al., 2017; Woodcock et al., 2018; Frank et al., 2010; Castro et al., 2019). While cycling cannot be considered a "zero-carbon emissions" mode of transport due to the amount of carbon produced from vehicle manufacturing and energy supply, life cycle emissions from cycling can be more than ten times lower per passenger-km travelled than those from passenger cars (ECF, 2011).

To better understand the carbon-reduction impacts of active travel, it is important to assess the key determinants of (and changes in) travel carbon emissions and include a detailed, comparative analysis of the distribution and composition of emissions by transport mode (e.g. bike, car, van, public transport, e-bike) and journey purpose across a wide range of contexts (e.g. intra-urban, inter-urban, rural). With the increasing popularity of electrified forms of active travel that have zero emissions at point of use, it is also important to assess the key emissions *sources* (e.g., from vehicle use, energy supply or vehicle manufacturing).

This paper provides an overview of the current state (and gaps) of knowledge and looks ahead by suggesting a number of research topics. By doing so it provides a fresh perspective on new ideas that have not already been investigated in active travel studies.

2 Active travel and CO_2: What we know

2.1 Low prevalence, high variability and unequal distribution of active travel – what makes measuring and evaluating mobility-related carbon emissions a challenge

The complex relationships between carbon emissions and transport have been investigated for many years. Previous research has shown that travel carbon emissions are determined by transport mode choice and usage, which in turn are influenced by journey purpose (e.g. commuting, visiting friends and family, shopping), individual and household characteristics (e.g. location, socio-economic status, car ownership, type of car, bike access, perceptions related to the safety, convenience and social status associated with active travel), land use and built environment factors (which impact journey lengths and trip rates), accessibility to public transport, jobs and services and meteorological conditions (Carlsson-Kanyama and Linden, 1999; Stead, 1999; Timmermans et al., 2003; Cameron, Kenworthy and Lyons, 2003; Brand and Preston, 2010; Ko et al., 2011; Brand and Boardman, 2008; Nicolas and David, 2009; Adams, 2010; Alvanides, 2014; Bearman and Singleton, 2014; Anable and Brand, 2019).

Mobility-related carbon emissions are highly variable and distributed highly unequally across a wide range of contexts (Ko et al., 2011; Brand and Boardman, 2008; Büchs and Schnepf, 2013; Preston et al., 2013; Susilo and Stead, 2009). In many cases the prevalence of active modes is low, implying that measurement and detection of effects over time are a major challenge. Some people travel a lot, especially by motorized means, while others do not travel at all. A major European study found that the top 10% of survey participants were responsible for 59% of carbon emissions, and that those with better car access, higher incomes and poor bus accessibility producing higher emissions overall (Brand et al., 2021a). This is important for targeting mitigation efforts at the highest emitters while not increasing emissions of the lowest.

2.2 Methods: Existing and emerging

To assess the carbon effects of active travel it is important to understand why, where, when and how far people travel by active and motorized modes. The most common methods to derive carbon emissions effects of active travel are based on a combination of:

1. a measurement of travel activity across motorized and active modes, and;
2. an assessment of the associated carbon emissions at different points in time.

Travel activity measurement instruments include travel surveys, travel diaries, Global Positioning System (GPS) tracking and mode detection (Neves and Brand, 2019), route user surveys (Le Gouais et al., 2021), and street imagery using Google StreetView (GSV). While the former methods are well established, GSV images are a promising new big data source to predict urban mobility patterns, particularly for those modes that vary the most (cycle and bus)

(Goel et al., 2018). Goel et al. (Goel et al., 2018) reported a method that involved accessing thousands of GSV images from 1000 random locations in England, selecting archived images from time periods overlapping with the 2011 Census and the 2011–13 Active People Survey (APS), then manually annotating the images into seven categories of road users. Regression models were then developed with the counts of images of road users as predictors and Census-reported commute shares of four modes (combined walking plus public transport, cycling, motorcycle, and car), as well as APS-reported past-month participation in walking and cycling, as predictors. The authors found high correlations between GSV counts of cyclists and cycle commute mode share and past-month cycling. With its ability to identify mode of travel and capture street activity often excluded in routinely carried out surveys, GSV has the potential to be complementary to new and traditional data (Le Gouais et al., 2021).

The "state-of-the-art" carbon emissions assessment method converts the above travel activity into pollutant emissions, mainly from three emission sources: (1) operational (tailpipe, in-use) emissions, (2) energy/fuel production emissions and (3) emissions from vehicle manufacture and recycling/disposal. For operational emissions, either simple per-km emission factors or speed-emissions factors are commonly used. Speed-emission factors assume that the amount of carbon emitted by different modes of transport depends on three key factors: (1) distance and average trip lengths; (2) average speed; and (3) mode characteristics such as vehicle type, engine type, fuel type, vehicle age and vehicle occupancy (which can be very different for different journey purposes). This method considers the (changes in) observed mean speeds and vehicle types in the study area to calculate the "hot" carbon emission per km travelled. For cars, "cold-start" excess emissions (for the mileage running cold for each trip, typically the first 3–4 km "from cold") are added to this. The latter is important, since most of the cycling and walking trips are relatively short and within the cold-start distance range.

One example of a combined travel emissions assessment has recently been incorporated into the carbon assessment module of the WHO Health Economic Assessment Tool (HEAT) for walking and cycling (Götschi et al., 2020). The tool assesses carbon emissions saved, either from existing levels of walking and cycling (e.g. how much motorized travel has been avoided by active travel), or from modal shift from motorized transport to active transport (or vice versa) in a "before-after" assessment. In the latter, any induced travel by active modes and route substitution (as opposed to mode substitution) are taken into account. The carbon emissions factors used are context specific, i.e. they depend on local driving conditions, vehicle fleet composition, trip lengths, ambient temperatures, vehicle occupancy rates and embedded carbon in the supply of electricity (Kahlmeier et al., 2017).

2.3 Active travel generally substitutes for motorized travel thus lowering CO_2 emissions

For most journey purposes active travel covers short to medium length trips. Most studies focus on these "short" (up to 8 km) to "medium" (up to 20 km) length trips, as they are amenable to at least a partial modal shift towards active travel (Beckx et al., 2013; Carse et al., 2013; de Nazelle et al., 2010; Goodman, Sahliqvist and Olgivie, 2014; Keall et al., 2018; Neves and Brand, 2019; Vagane, 2007). Travel diary data from thousands of survey participants across seven European cities reported *mean* trip lengths of 1.1 km for walking, 4.8 km for cycling and 9.4 km for e-biking (Castro et al., 2019), with relatively wide distributions that suggest that some people travelled a lot further than the mean values suggest. Typically, the majority of trips in this range is made by car or bus (U.S. Department of Transportation, 2017; Beckx et al., 2013; Keall et al., 2018; Neves and Brand, 2019; JRC, 2013). In the UK, about 3 out of 5 car trips are under 8 km (5 miles), producing 21% of car CO_2 emissions (BEIS, 2019; DfT, 2018) – largely for commuting, shopping and personal business purposes. "Longer" trips (between 8 km and 16 km) produce a further 19% of car CO_2. So overall, trips up to 16 km in length represent the "price" to be had for substitution: 40% of car CO_2 or about 30% of all person transport CO_2.

In contrast, the 40–50% of mileage and carbon emissions from all person transport that come from long distance travel (i.e. over 100 km) are out of reach (van Goeverden, van Arem and van Nes, 2016).

2.3.1 "What if" scenario and potential impacts studies

Much of the work on climate change emissions impacts of active travel has been based on analyses of the *potential* for emissions mitigation (Yang, Wang and Liu, 2018) or the generation of "what if" scenarios that explore the likely impacts of hypothetical increases in active travel (Goodman et al., 2019; Lovelace et al., 2011; Woodcock et al., 2018; Tainio et al., 2017). At the European scale, the ECF estimated that the carbon emissions benefits of an annual cycled distance of 146 billion km for the EU28 (Steenberghen et al., 2017) amounts to about 16 million tons of carbon emissions per year (ECF, 2018). Assuming default settings in the latest HEAT (Götschi et al., 2020), this level of cycling amounts to about 12 million tons of carbon saved each year. At the national scale, a separate study estimated that if cycling's popularity returned to 1940s levels (when the average Brit cycled six times further per year than today) and these trips replaced car journeys, that would create a net saving of 7.7 million tons of CO_2 per year in the UK alone. At the global scale, Mason et al. (2015) developed a "high shift cycling scenario" and found that a 11% combined cycling/e-bike share of urban passenger travel distance worldwide by 2030 would cut CO_2 emissions from urban transport by about 7%, rising to a 14% combined cycling/e-bike share and a near 11% reduction by 2050.

Many studies to date have focused on commuting. Life cycle CO_2 emissions from social, shopping, personal business and recreational journeys have been shown to be more strongly associated to car use, and that shopping and personal business trips were found to be significantly shorter, therefore increasing the potential for mode shift to active travel (Brand et al., 2021a; Brand, Goodman and Olgivie, 2014; Brand et al., 2021b). This suggests that future work should go beyond the commute and include all journey purposes.

2.3.2 Empirical work: cross-sectional and longitudinal

Empirical evidence is rarer and often limited to smaller scale studies focusing on a single city or urban areas (Brand, Goodman and Olgivie, 2014). For instance, a longitudinal panel study of 50 participants in the Cardiff, Wales area showed that, taking into account individual travel patterns and constraints, walking or cycling can realistically substitute for between 41% and 69% of short car trips, saving between 5% and 10% of CO_2 emissions from car travel. This is on top of 5% of "avoided" emissions from cars due to existing walking and cycling. The high temporal and spatial level of detail here prevents such a study to be carried out at the national or even global level.

A notable exception is a recent study of daily travel behaviour (i.e. all trips recorded on a given weekday) of more than 3,500 participants across seven European cities, which found that "cyclists" had 84 percent lower life cycle CO_2 emissions from all daily travel than "non-cyclists" (Brand et al., 2021a). It also found that mobility-related life cycle CO_2 emissions were 14% lower for those participants who cycled one trip/day more, and 62% lower for those who used a car or van for one trip/day less (while keeping everything else constant).

By following nearly 2,000 urban dwellers over time, a separate analysis using longitudinal panel data found that increases in active travel significantly lowered carbon footprints, even in urban European contexts with a high incidence of walking and cycling (Brand et al., 2021b). The study found that an increase in cycling or walking at follow-up *independently* lowered mobility-related lifecycle CO_2 emissions, thus suggesting that active travel substituted for motorized travel and did not constitute additional, induced travel. It estimated that those who switch one trip per day from car driving to cycling for 200 days a year reduce their carbon footprint by about 0.5 tonnes over a year, representing a substantial share of average per capita CO_2 emissions. Overall, the study estimated that shifting to active transport could save as much as a quarter of CO_2 emissions from passenger transport (excl. international aviation and shipping) (Brand et al., 2021b).

E-bikes in particular have significant substitution potential, some call them a "game changer", as e-bikers have been found to take longer trips by e-bike and bicycle, compared to cyclists, with larger potential for mode substitution away from cars (Castro et al., 2019; Mason et al., 2015; Kroesen, 2017). It has been estimated that e-bikes, if used to replace car travel, have the "physical capability" (simulated as how far people are capable of travelling) to cut car CO_2 emissions in England by up to 50% (about 30 million tonnes per year) (Philips, Watling and Timms, 2018; Philips, Anable and Chatterton, 2020). The greatest opportunities were found to be in rural and sub-urban settings: city dwellers already have many low-carbon travel options, so the greatest impact would be on encouraging e-bike use outside urban areas. In Denmark they already know this (Hansen and Nielsen, 2014).

In sum, these studies provide empirical evidence that active travel substitutes, at least in parts, for motorized travel, that destinations are shifted "closer to home" due to regular active travel, and that increases in active travel are not just additional, induced travel or due to route substitution (which can be the case for new infrastructure developments where new routes show significant uptake of active travel). This means that even if not all car trips could be substituted by active travel the potential for decreasing emissions is considerable and, as shown above, range between 5% (real world observation, cycling, conservative) and 50% (scenario, e-bikes). Policy interventions that target mode shift and behaviour change have been shown to achieve emissions reductions closer to the bottom than the top of that range (Grischkat et al., 2014; Semenescu, Gavreliuc and Sârbescu, 2020), so policy ambition needs to rise sharply and involve a raft of bold "push" and "pull" measures that transform the mobility system and wean us off motorized mobility. Since the evidence on "real world" carbon effects of policy interventions that aim to reverse "car dependency" (ITF, 2021) is relatively weak, I have put this in the "further research" category, which is discussed next.

3 Active travel and CO_2: Where the evidence is 'weak'

3.1 The effects of active travel policy measures and interventions on CO_2 emissions. Do we need larger and/or more policy-focussed studies?

The short answer is yes. Any observable effects of some interventions and policies often only show up two or more years after the intervention was completed, particularly for infrastructure interventions (Goodman, Sahliqvist and Olgivie, 2014). There is some evidence on the effects of "pull" (e.g. high quality cycling infrastructure, personalised travel planning, cycling promotion campaigns) and "push" (e.g. car restraint in city centres) measures, but the evidence is generally weak or not generalisable. There is an on-going need for longitudinal data collection in applied natural experiment studies of interventions, with studies at sufficiently large scale, over longer time periods (5+ years to observe whether effects are sustained), and with systematic consideration of a range of relevant factors (Winters, Buehler and Götschi, 2017). But these are still rare as they are obviously more costly and resource intensive. Also, the effect sizes tend to be small in general population studies (with representative samples and often low prevalence of cycling), suggesting larger study populations. For instance, the UK "iConnect" study used a longitudinal panel design with random sampling of the general population over three waves and two years of study, but found that new active travel infrastructures in three case study locations had no statistically significant effect on lowering mobility-related CO_2 emissions (Brand, Goodman and Olgivie, 2014). This was largely due to the relatively small scope and "magnitude" of the policy intervention (with small effect sizes expected) and relatively small sample size of the panel (<2,000). Beyond general population studies, there is a need for smaller evaluation studies to learn what kind of policy interventions "work" and which "don't work" in promoting active travel (Bird et al., 2018) and reducing mobility-related carbon emissions. These should ideally have a control design and include a thorough evaluation of the context (circumstances), the mechanisms (methods) and the outcomes using the realist evaluation approach (Brown, Moodie and Carter, 2015; Ogilvie et al., 2011; Pawson and Tilley, 1997).

Other challenges of studying "natural experiments" are external factors (e.g. social and economic change) and timing. The aforementioned PASTA study aimed to measure the effects of a number of interventions and policies across seven cities using a longitudinal panel design. However, due to delays to policy implementation only two of the seven interventions were completed during the 4-year study period, so the learning in terms of policy effectiveness was somewhat limited. While this is a common problem, a more flexible and adaptive research design could potentially help in the future.

3.2 Does active travel lead to increased dietary intake? If so, what do active travellers eat and drink? Does this increase net carbon emissions?

We do not know for sure. The evidence is inconclusive on whether day-to-day active travel (as opposed to performance/sport activity) significantly increases overall dietary intake when compared to motorized travel (Tainio et al., 2017). When people burn more calories through exercise they do not typically consume as many extra calories in their diet (Elder and Roberts, 2007). Related to this, the effects of an increase in active travel on health outcomes such as BMI (essentially body weight) are inconclusive. One longitudinal study in the Netherlands reported no significant effects (Kroesen and De Vos, 2020) while another longitudinal study in European cities showed a significant, if small, effect of a decrease in BMI for those who travelled actively (Dons et al., 2018). A study using consumption data obtained from a consumer survey found that a 10% rise in active transport share was associated with a 1% *drop* in food-related emissions, which may be related to overall health awareness or concerns as well as impacts on well-being and mental health (Ivanova et al. 2018). Another recent study by Mizdrak et al. (2020) made the *explicit assumption* that increased energy expenditure is directly compensated with increased energy intake, while acknowledging that this is an unproven assumption. So, further research is needed to explore the effects of daily active travel (exposure) on changes in quantity and type of diet (outcome). Ideally this should be longitudinal cohort study with controls.

3.3 What is the role active travel in reducing CO_2 emissions in rural and sub-urban settings?

As mentioned above, people living in urban areas tend to have access to a range of low-carbon travel options and infrastructure, so the greatest impact would be on encouraging e-bike use outside urban areas. E-bikes offer an opportunity to substitute for fossil-fuel motorised mobility on "longer" journeys (defined here as in the 5–25 km range, based on mean speeds of 25 km/h and up to 1 hour travel time) but this may need a range of policy and planning "carrots" (in particular, safe and high-quality infrastructure and financial support to reduce the up-front costs) and "sticks" (restraint/no access for motorised mobility, reduced traffic speed via road design, speed limits/enforcement) to have any chance of success, particularly for transforming rural travel which is dominated by the car.

While the potential for e-bikes has been estimated, empirical work using robust methods has been scarce. One randomized controlled trial of 98 Swedish drivers investigated the effect of e-bike on modal choice, number of trips, distance travelled, and perceptions of e-bikes as a substitute for the car (Söderberg f.k.a. Andersson, Adell and Winslott Hiselius, 2021). The study found that the treatment group increased cycling on average with 1 trip and 6.5 km per day and person, which led to a 25% increase in total cycling, with the increase due to a reduction in car use by 1 trip and 14 km per person and day; a decrease in car mileage of 37%. Participants reported that e-bikes reduce barriers linked to time, distance, and physical exertion. The study further claimed that e-bike use was related to hedonic, rational, and altruistic gains by individuals. Given the small sample size further research with a larger group of drivers and non-drivers would be welcome. I would further propose a controlled study of uptake and use of e-bikes in rural and suburban settings, either as a mode in its own right or access mode to public transport hubs.

3.4 Are there any indirect effects of replacing motorised travel with active travel?

All of the work mentioned above has focussed on direct effects from substituting motorised with active travel. But there are potentially other effects such as "indirect rebounds" from changes in the time and cost spent travelling (Tranter and Tolley, 2020; Sorrell, Gatersleben and Druckman, 2020). For example, replacing car or bus journeys by walking or cycling reduces consumption of motor fuels or bus tickets. This frees up money that may be spent on, for example, purchasing extra clothes or flying on vacation. Alternatively, the money may be put into savings. Since all of these options lead to CO_2 emissions, total CO_2 savings may be less than anticipated. Indeed, in some instances, emissions may increase – a phenomenon known as "backfire" (Druckman et al., 2011). More broadly, there is some literature suggesting that some of the groups that are more likely to travel with active modes are also more likely to fly, e.g. people with strong environmental attitudes (Barr et al., 2010), students (Sippel, Meyer and Scholliers, 2018) and the residents of urban areas with good access to airports (Czepkiewicz, Heinonen and Ottelin., 2018; Ottelin, Heinonen and Junnila, 2014; Große et al., 2018). However, none of the studies have looked into a direct link (association) showing whether cyclists have higher emissions from air travel than non-cyclists while controlling for other factors such as urban density or accessibility to airports. Also, I have not seen a controlled *empirical* study on the indirect rebound effects on CO_2 emissions of a mode shift to active travel (causation). Druckman et al. (2011) derived a best estimate of the rebound effect of mode shift to active travel at about 25% (so only 75% of the direct transport cost savings would materialise if other activities were taken into account). Yet this was based on assumptions on what *could* happen, but not what *did* happen. Further evaluative work is needed here, likely requiring a mixed method longitudinal study design and larger, multi-centre samples.

4 Summary conclusions

It is well understood that active travel can have significant carbon reduction benefits for short to medium length trips across a range of urban settings. What is less clear (in terms of empirical evidence) is the role it can play in reducing carbon emissions from inter-urban and rural travel, and how soon – and how long – the effects materialise. Further evidence is required on a number of indirect effects such as dietary intake and indirect rebound. An improved knowledge of the effects of active travel will provide a more robust evidence base to underpin climate change mitigation strategies and pathways at the local, national (CCC, 2020) and international (IEA, 2020) levels.

For me the top 4 research needs are:

1. Understanding, measurement and evaluation of the role of active travel (particularly e-bikes) in lowering net carbon emissions in **inter-urban and rural settings** – including larger samples and different contexts.
2. **Longitudinal policy and intervention studies** that evaluate effectiveness over longer periods of time (5+ years); ideally using realist evaluation (Pawson and Tilley, 1997; Ogilvie et al., 2012; Ogilvie et al., 2011) to identify "what works in which circumstances and for whom?", rather than merely "does it work?"
3. Understanding the effects of daily active travel on changes in the **quantity and type of people's diets** – a longitudinal cohort study with controls is recommended.
4. A **more flexible and adaptive research design** to counter delays or cancellations of policy implementation – so often the bane of research designed around external projects.

Competing Interests

The author has no competing interests to declare.

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How to cite this article: Brand, C. 2021. Active Travel's Contribution to Climate Change Mitigation: Research Summary and Outlook. *Active Travel Studies: An Interdisciplinary Journal*, 1(1): 2, 1–13. DOI: https://doi.org/10.16997/ats.1036

Submitted: 22 March 2021 **Accepted:** 22 May 2021 **Published:** 11 August 2021

Active Travel Studies: An Interdisciplinary Journal is a peer-reviewed open access journal published by University of Westminster Press.