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A data-driven approach for estimating travel-related carbon emissions with high spatial and temporal granularity

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Abstract. The transport sector is the second-largest contributor to greenhouse gas emissions in the EU, with a high reliance on fossil fuels and increasing demand for transportation. In Finland, cars are the most common means of travel, accounting for 60% of overall domestic travel. Considering that a significant portion of the work-related trips in Finland (70%) are done by car, there exists great potential to reduce travel-related emissions by substituting short-distance work trips with active transport. Typically, the potential for reducing travel related carbon emissions are studied using travel surveys or other national level statistics. However, there is little geographical evidence regarding the extent of carbon reduction potential achieved through the shift to active transportation, i.e. *where* the carbon-reduction potential is highest?

This study aims to develop a data-driven method to assess the potential reduction of carbon emissions from commuters switching from car to more sustainable travel modes. As a case study, we investigate the carbon reduction potential in Otaniemi, Espoo (Finland) which is a major commuting hub with large business corporations and research institutes. More specifically, we analyze and simulate the influence of replacing short car-based commuting trips with trips done by electric bikes. Furthermore, we investigate the change in commute-related emissions to Otaniemi before and after the pandemic. Our results show that there were major changes in the work-related travel demand that significantly reduced the carbon footprint from commuting. In addition, our simulation shows that there exists significant potential to reduce travel-related emissions if short car trips (less than 5 km distance) would be done by e-bikes instead of cars. Our approach shows great potential for providing crucial place-based information for employers and policymakers to promote sustainable mobility cultures and effectively target climate mitigation policies.

Keywords. Transportation, CO_2 emissions, geospatial analysis, LCA, mobile phone data, scenario analysis

1 Introduction

Systemic changes in the transport sector are needed in order to meet climate mitigation goals (IPCC, 2022). Research on transitions in the energy and mobility sectors has found that a paradigm shift to sustainable mobility has not yet taken place, and a more radical approach is needed to tackle climate change (Banister, 2008; Khalaj et al., 2020). Transport is a challenging sector to decarbonize due to its complexity, and how it intertwines with all aspects of our society (Luè et al., 2016). Transport accounts for 23 % of global energy-related emissions (IPCC, 2022), and this share is expected to rise to 50 % of the global emission by 2030 (Hickman & Banister, 2019). Significant car use reduction potential lies in relatively short daily trips within city-regions. In Finland, a significant portion of the work-related trips (70%) are done by car, and the modal share of cars for trips between 1-3 km is 49 %, and 61 % for trips less than 5 km accordingly (Kallio & Kärkinen, 2023).

Although transport-related emissions are significant, a lack of relevant, measurable and easy to communicate sustainability indicators about human mobility has been widely acknowledged by scientists and practitioners (Holden et al., 2017, 2019). While most studies and reports focus on emissions on a national or city level (Moran et al., 2018), there is a need to analyze emissions at finer scales (Kissinger & Reznik, 2019). For instance, neighborhood or statistical grid level data about transport emissions could provide more useful information for scientists, as well as planners to design more sustainable cities (Morgan et al., 2021).

The wealth of digital traces generated by people through their mobile devices gives an unprecedented opportunity to monitor the mobility of human populations at a fine scale (Wang et al., 2018). In addition, advanced routing algorithms make it possible to model detailed travel routes between locations, while keeping track of the travel distance, time and carbon emissions by all travel modes (Tenkanen et al., 2016).

In this study, our goal is to investigate how sophisticated transport routing tools combined with Life Cycle Assessment (LCA) based vehicle emission factors, and mobility data obtained from a large Finnish Telecom operator can be used to estimate travel related carbon emissions with high spatial resolution. Furthermore, we combine these approaches with simulation to build a scenario that explores the carbon-reduction potential of switching from driving to electric bikes for commuters travelling to Otaniemi, Espoo.

2 Data & Methods

Estimating travel related carbon emissions at fine spatio-temporal granularity requires data from various sources. Our data sources include mobility data from Telia Crowd Insights that provide detailed information about the movements of people divided in zones (up to 250x250 meter) and reported at high temporal granularity (up to 15 minutes frequency). In this study, we used mobility data aggregated on a monthly level, showing the number of trips between given origin-destination zones. To understand which travel modes people use to commute to our study area, we utilize questionnaires gathered from the Leesman Campus Survey that was conducted during the years 2020 (before Covid) and 2021. To model the travel times and distances by different travel modes (car, transit and bike), we use OpenStreetMap and General Transit Feed Specification (GTFS) data. To estimate the carbon emissions, we use the Life Cycle Assessment (LCA) method and open source tool developed by International Transport Forum, which is a standardized framework to assess the environmental impact of transportation using emission factors measured in grams of CO2-equivalent per passenger kilometer. The LCA tool was configured based on the Finnish energy generation mix, and the tool accounts for energy needs and environmental effects occurring across different stages of the life cycle of the transport products and services, including vehicle, fuel, and infrastructure components. Hence, our methodology integrates routing algorithms, LCA, and open-source Python tools like r5py (Fink et al., 2022) and OSMnx (Boeing, 2017) to calculate emissions per passenger kilometer for the studied transport modes. All the methods used in this study are based on open source tools and data wherever possible (excluding the mobile phone data).

Using these data and methods, we constructed five distinct scenarios which we compare against each other. The tested scenarios include pre-COVID situation (scenarios 1-2) and post-COVID-19 timelines (scenarios 4-5) to compare carbon emissions. As in Finland the seasons have significant influence on the way people travel, we also made comparisons between winter (scenarios 1 and 4) and non-winter modal shares (scenarios 2 and 5). Our model uses travel demand information from the Telia Crowd Insights service, which covers origin, destination, and frequency. We then route origin-destination pairs across different transport modes and assigns trips based on the modal share scenarios to analyze emission variations and spatial distribution patterns based on the above-mentioned data. Lastly, we created one scenario (scenario 3) where we simulate the effect of swapping car trips into electric bikes for distances shorter than 5 km during non-winter months. E-bikes are becoming a popular travel mode in the city region which is the reason why we wanted to simulate its carbon-reduction potential.

3 Results

Our analyses reveal variations in daily trip emissions across scenarios and months (Figure 1). Scenarios with more trips showed notably higher emissions, with Scenario 1 having about 25% higher daily direct carbon emissions than scenario 2 (non-winter season). Replacing short car trips with e-bikes (scenario 3) leads to a 9% carbon reduction. Figure 1 reveals some slight variation between months, but only in June when the outside temperatures in Finland are more favorable for non-motorized travel (cycling, walking), there is a visible drop in travel related carbon emissions, spanning all five scenarios.

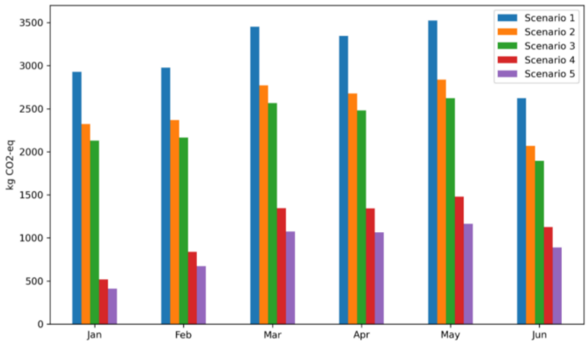

Figure 1. Monthly variation in travel related CO_2 emissions to Otaniemi by different scenarios.

Figure 2 shows more clearly how significantly the COVID-19 influenced carbon emissions due to the travel to Otaniemi: The overall carbon emissions in scenarios 4 and 5 are significantly lower compared to the first three. This difference between these two years is driven by the reduced travel demand (observed from mobile phone data) as people were still largely working remotely in 2021, even though there weren't any strict COVID-related travel restrictions in place.

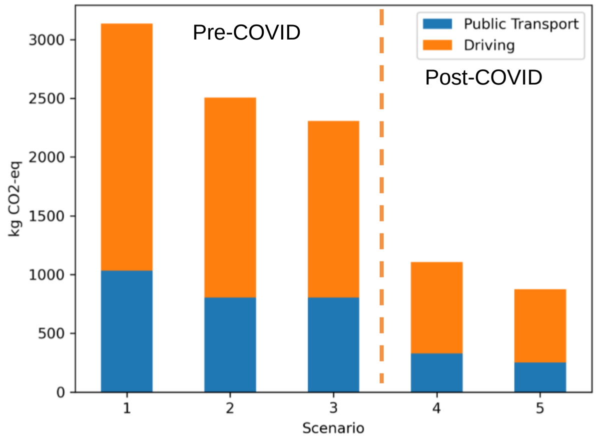

Figure 2. Comparison of average daily direct emissions by scenarios. The plot shows the average daily emissions with each bar representing the composition for transit and driving.

Our modeling approach also makes it possible to investigate how the travel related carbon emissions are distributed spatially. Figure 3 illustrates the difference between two scenarios and reveals the areas where the carbon emissions have dropped most significantly. Our results show that the districts of Matinkylä and Leppävaara in Espoo, as well as the city center of Helsinki, have the most significant difference in emissions, which is due to high travel demand from these areas (dark red areas). Matinkylä and Leppävaara exhibit the highest emissions, with notable differences in emissions between winter and non-winter seasons. Specifically, daily direct carbon emissions are about 30% lower in the non-winter season. Tapiola, which is a neighboring district to Otaniemi also has a high number of trips, but due to its proximity to Otaniemi, it has much lower emissions.

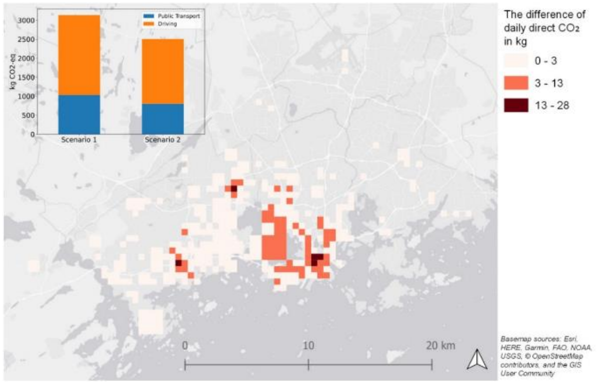

Figure 3. Map shows the areas where travel-related carbon emissions have dropped most significantly between two scenarios (Scenario 1 and 2).

4. Conclusions

Our research highlights how geospatial data-driven approaches can help to evaluate the spatial distribution of transport-related carbon emissions and monitor the changes in emission load between years and months. By quantifying emissions and exploring mitigation strategies, the study provides one approach among many (Tenkanen et al., 2023) that can help our societies to transition towards sustainable transportation systems. Furthermore, the study highlights the impact of COVID-19 on travel patterns and the need for better transportation planning and management. Looking forward, this study is also a first step towards understanding the environmental impacts of access (Willberg et al., 2023) and the methodological approaches used in this study enriched with socio-demographic would make it possible to understand also the social dimensions of sustainable mobility, i.e. who are able to access their daily needs or travel to their daily duties (work) using sustainable transport modes.

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