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PAPER • OPEN ACCESS

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To cite this article: S Somanath *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1078** 012088

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Effects of Sustainability Policy – Evaluating Social Consequences of Carbon Targets using Trip Completion Rates

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Abstract. Sustainability is widely recognised as having social, economic, and environmental dimensions. Strategies to combat global climate change inherently have an environmental focus. However, in line with the sustainability agenda, the social and economic dimensions must also be addressed. Evaluating the social consequences of decisions is often challenging due to a lack of relevant tools and indicators to measure and track them. This paper presents the Trip Completion Rate (TCR) as an indicator currently under development to evaluate the social consequences of climate change policies such as Personal Carbon Allowances (PCA). TCR is an accessibility indicator that evaluates the proportion of a population that can perform their daily activities against a performance metric. Two examples demonstrate the sensitivity of social impacts based on the geographic and demographic variations in different locations, one at the region level and another at the municipal level, through a national household travel survey (NHTS). The Västra Götaland region of Sweden is taken as a test case to illustrate how the indicator may be used, comparing TCR on the entire region and then comparing it to TCRs calculated at the municipal level. The greenhouse gas emissions of the trips are calculated based on assumptions for different modes of transport. Finally, the results are evaluated against a hypothetical PCA based on the climate goals for the city of Gothenburg, Sweden. The results show that the ability to satisfy one's daily travel needs depends on individual characteristics such as behavioural patterns of travel, travel mode choices and access to local amenities. We find that PCAs may disproportionately affect certain groups more than others. Policymakers must understand who is most affected by sustainability targets to ensure that disproportionately affected groups have an equal opportunity to achieve their daily needs and that adequate measures are taken to mitigate the local policy effects on social equity.

Keywords: neighbourhood, social sustainability, trip completion rate, scenario analyses, personal carbon allowance, social equity, travel survey

1. Introduction

Research has shown that delivering on the goal set in the Paris agreement defining the 1.5-degree global temperature scenario may not be feasible with current measures [1, 2]. To combat the worsening condition of the climate, the implementation of more stringent carbon management strategies on a large scale has been suggested [2]. One such proposed strategy is that of personal carbon allowances (PCA). Considering the challenges in achieving climate targets and the potentially stringent measures, the social

consequences of such strategies must be appropriately evaluated. However, evaluating the social consequences can be challenging.

1.1. Personal Carbon Allowance – an overview

PCA is a concept designed to aid in limiting a population's environmental impact. In a PCA scheme, individuals would initially be allotted a free [3], and a limited number of allowances for emitting emissions which would later be surrendered when purchasing energy for travelling or domestic use [4]. PCAs are designed to deliver emission reductions by altering a population's economical behaviour, cognitive awareness, and social norms [2]. PCAs were once considered a policy measure ahead of their time. This was primarily due to public acceptability, cost of implementation and enforcement, and the technology required to deliver a just and equitable policy was considered to be underdeveloped [3]. A decade later, PCAs have resurfaced as a potentially viable tool for managing the global carbon footprint. The drivers that contribute to this re-assessment are the current state of the climate goals, development in technological capabilities, increased public awareness of the climate crisis and understanding of the impact of individual actions on the public good as a result of COVID-19, among others. [2, 1, 5]. However, there are open questions regarding the implementation and enforcement of such ambitious goals; first, about how PCAs must be allocated and second, about specifics on the carbon accounting [6].

1.2. Social consequences of PCAs

Social sustainability in the built environment is a complex subject [7] primarily due to fuzzy boundaries and difficulty in measurement [8]. Quality of Life is often used as an indicator to assess the social impacts of urban development. Its relationship to mobility and the ability to achieve one's daily needs is an important driver of social sustainability. Quality of life is believed to be influenced by mobility, the built environment, attitudes, and social well-being [9]. Personal transportation is considered a basic need and essential to developing central capabilities. The concern is that extending PCAs to include personal transportation may result in some residents being unable to satisfy their basic needs or develop central capabilities because they are limited by their PCA [6]. Researchers have also drawn attention to the impact of PCAs on poverty, stating that affluent individuals may simply buy their way out of the constraints of PCAs. However, poor households would find it more challenging to purchase additional carbon points [10].

Kolodinsky et al. [9] identifies six drivers of quality of life: mobility, infrastructure, perceptions of safety, social networking, age, and weather. These drivers vary across geographies and demographics, making formulating an equitable carbon budgeting policy extremely challenging. Achieving daily needs is a vital component of social sustainability. Mobility provides physical, social, and psychological benefits [9]. Research has also shown that individuals with increased personal autonomy tend to report greater well-being [11].

Given the importance of personal transportation as a driver of Quality of Life, extending PCAs to include personal transportation can be seen as infringing on fundamental personal rights [4]. On the other hand, the transportation sector is also the second-highest contributor to the overall GHG emissions [4], hence the decision to include personal transportation in PCAs.

1.3. Trip Completion Rate

In this research, we present Trip Completion Rate (TCR) as an indicator to evaluate sustainability policy's social consequences and subsequently evaluate carbon budgets for a neighbourhood based on PCAs. TCR is an accessibility indicator that measures the percentage of a population that can perform their daily activities against a policy target. Using TCR, it is possible to evaluate the environmental impact of travel from individuals in a neighbourhood satisfying their daily needs and identify who and which of their needs are most affected by a policy target.

A TCR indicates the proportion of a population that can complete their assigned trips subject to an evaluation criterion. This calculation can be presented as a map visualisation using a bivariate colour

scheme or a two-dimensional matrix with a percentage number between 0 and 100. The individual cells of this matrix are also colour coded from red to green. Depending on the variables of interest, the TCR calculated may be represented in several two-dimensional matrices or map visualisations.

1.4. Aim

Though most of the technical challenges regarding operationalisation and implementation of PCAs can now be resolved, the questions regarding fair, equitable policy implementation require new evaluation methods. This paper aims to illustrate the application of TCR in the evaluation of climate policies and the effects of carbon budgeting strategies from an analytical lens to encourage constructive dialogue and evaluate issues on social equity.

• Illustrate the variations in individuals affected due to their travel behaviour and access to amenities by comparing the TCR for a hypothetical PCA calculated at a regional level to those calculated at a municipal level from a national household travel survey.

• Highlight important challenges in resolving climate and societal issues in tandem.

• Discuss the applicability of such a method through examples.

2. Research method

To illustrate the use of TCR to evaluate the ability of a resident to perform their daily needs, we use the Swedish National Household Travel Survey (NHTS). The data from the national survey are first aggregated at the regional level and then at the municipal level and then evaluated against a hypothetical PCA target using TCR. The results of the TCR calculations are then presented and evaluated.

2.1. Data

Statistical data representing the travel behaviour of residents in the Västra Götaland region of Sweden is from the Swedish NHTS [12]. Data on residents' travel patterns, including the time of a trip, mode of transportation, the purpose of the trip and duration of the is collected through a travel diary maintained by the study participants.

2.2. Area selection

The NHTS dataset for the Västra Götaland region covers 21 municipalities out of 49. Two of the most populated municipalities, Gothenburg and Borås, are selected for comparison with the aggregated TCR analysis (figure 1).

2.3. TCR Calculation

The NHTS data is processed using the Python programming language [13] using popular opensource packages such Pandas for data processing, and GeoPandas [14] for geospatial visualisation.

• The NHTS data uses null value identifiers such as 999999 and 999998 to denote missing entries. The entries with missing data are first removed. Further samples with blank entries are also identified and removed from the data set.

• The trip distance and the trip mode variables are identified, and a new variable for trip GWP is added. For the Global Warming Potential (GWP) calculations, we make assumptions based on data provided by the Department of Business, Energy, and Industrial Strategy for the UK [15] on the GWP of different modes of transport selected by the residents since a source covering all modes of transport was not found for Sweden.
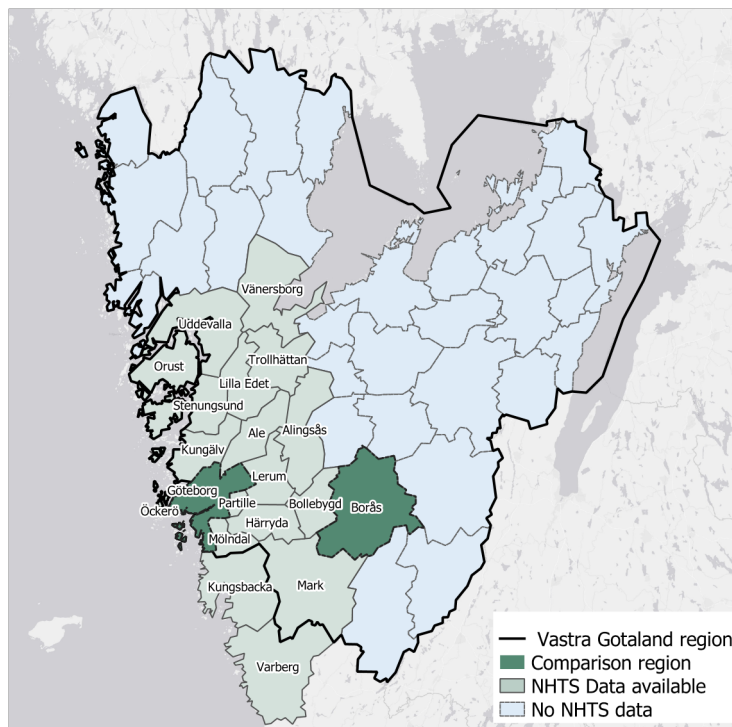
Figure 1 Map of the Västra Götaland region for which the NHTS data is filtered. The bold black line shows the boundary of the Västra Götaland region. The Gothenburg municipal region is shown in dark green, the municipalities with available data within the NHTS are shown in light green, and the municipalities with no data available are shown in light blue

- Next, all trips that exceed the hypothetical target of 0.65 kg CO2-e are identified by calculating the TCR and further aggregated across different variables.
- Finally, the regional and municipal averages are calculated and presented using a map visualisation and a matrix representation.

2.4. Evaluation of results

A hypothetical PCA target for personal transportation is set at 22.66 percent of the individual carbon target for 2030 set in the Environment and Climate Programme for the City of Gothenburg 2021–2030 [16], representative of the proportion of greenhouse gas emissions from personal transportation. The Environment and Climate Programme for the City of Gothenburg 2021–2030 outline the target of reducing the emission of greenhouse gases per inhabitant within the geographical area of Gothenburg from 4.2 tons in 2018 to 1.1 tons of carbon dioxide equivalents per inhabitant per year in 2030. The hypothetical PCA target for personal transportation is 0.65 kg CO2-e per day.

The TCR calculates the proportion of residents that can complete their daily tasks within the hypothetical PCA target. A TCR of 100 indicates that all residents in that category could perform their daily tasks. In contrast, a TCR of 0 indicates that none of the residents in that category was able to perform their daily tasks. Occasionally there is no data available for certain categories from the NHTS since no respondents from that category participated in the survey; in such cases, the missing data is left blank to differentiate it from a TCR of 0.
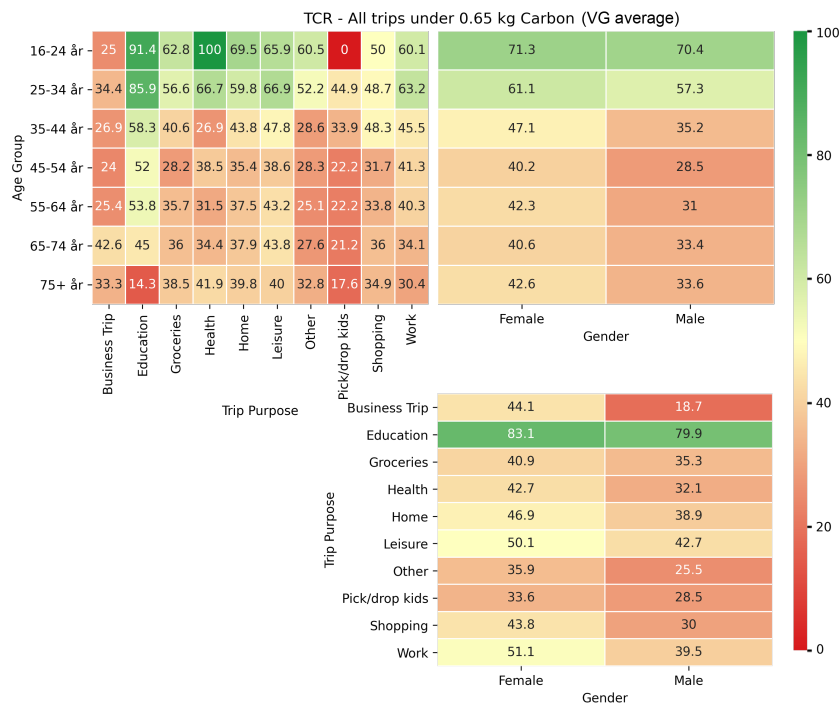
SBE-BERLIN-2022

IOP Conf. Series: Earth and Environmental Science   1078 (2022) 012088

IOP Publishing

doi:10.1088/1755-1315/1078/1/012088

Figure 2 Results of Trip Completion rates for 0.65 kg CO2-e/day across multiple dimensions from the national household travel survey. Data source - Swedish National Household survey [12]. Missing data is left blank

3.   **Results**

Figure 2 presents the TCR evaluated for a 0.65 kg CO2-e PCA policy target calculated from a National Household Travel Survey of Sweden for the Västra Götaland (VG) region. The results show variations in how much different individuals' abilities to achieve their daily travel needs are affected by the policy target. Female residents are generally less affected by implementing a carbon target of 0.65 kg CO2-e per day. This may be attributed to the distribution of mode choice between the male and female participants of the study. According to [12], on average, male respondents account for 54.53 per cent of car travel hence requiring larger amounts of GHG emissions for their daily needs. Across trip purposes, trips related to education are least affected, suggesting that most residents either make shorter trips or use low carbon modes of transport to achieve them, whereas business trips and picking up and dropping off children are most affected. Looking at results across age groups, younger residents are less affected than older residents, but the disparity between the genders increases as residents age. These variations across demographics are also captured in a similar study on the Finnish NHTS [1]. However, this is a generalised view of the entire population of the VG region and does not represent the effects of accessibility in individual municipalities.

TCR can be visualised using maps to provide an overview of the data and how policy affects residents living in different municipalities. Figure 3 presents the municipal differences based on gender as a result of PCAs. The results are aggregated and visualised using a bi-variate colour scheme where municipalities in grey have an overall low TCR and a low disparity between the genders. Municipalities in pink and blue show a higher disparity between TCR, illustrating the social equity issues arising from PCAs.

From the map overview, it is possible to retrieve further a detailed overview of a single municipality to explore the effects of PCAs on demographic groups. In figure 4, the TCR results
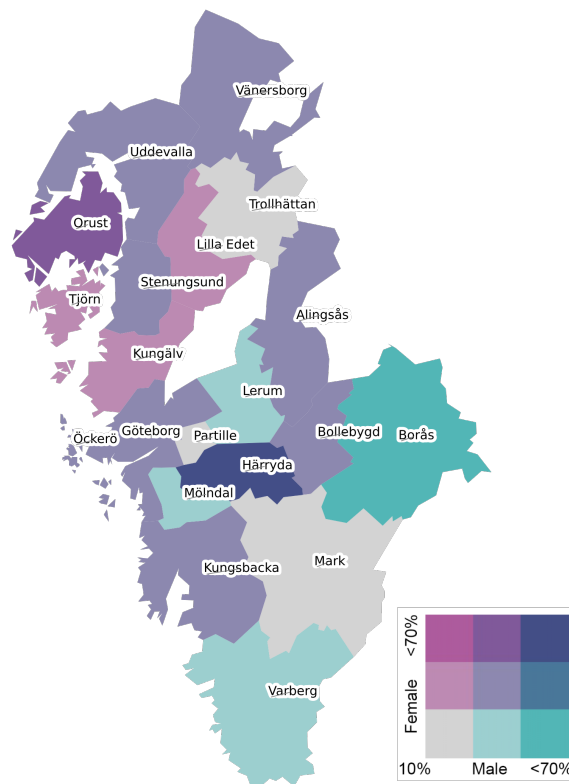
TCR for trips under 0.65 kg CO2-e - Comparing Gender

Figure 3 Municipal differences based on gender affected by PCAs. The data is represented using a bi-variate colour scheme. Grey shows municipalities where both men and women have low TCR for a 15-minute travel scenario, and purple shows municipalities where men and women have higher TCR. Whereas pink shows municipalities where women have a higher TCR than men, blue shows municipalities where men have a higher TCR than women.

are presented for age-trip purpose, age, gender, and trip purpose-gender for the Gothenburg municipality. The results show that trips related to education are the least affected by PCAs white picking up and dropping children are most affected. The disparity in TCR between male and female residents is negligible for younger age groups. However, as the age groups increase, there is a gap between male and female residents in their ability to fulfil their daily needs. Residents between 55 and 64 years are the most affected by PCAs across the genders.

Figure 5 shows the TCR results for the municipality of Borås. Residents aged 55 and 64 years are the most affected by PCAs. Looking at age and gender, similar patterns are observed at a younger age. There is little disparity between the genders, which grows as the age groups increase. Male residents between 25 and 34 years report a higher TCR than female residents, suggesting that they either travel shorter distances or use a mode of transport that is less carbon intensive.

4.   Discussion

The results show that the TCR calculated against a policy target on a national level is not entirely representative of the demographic and geographic variations at the municipal level. Figures 2, figure 4, and figure 5 show both similarities and subtle differences in the TCR results.
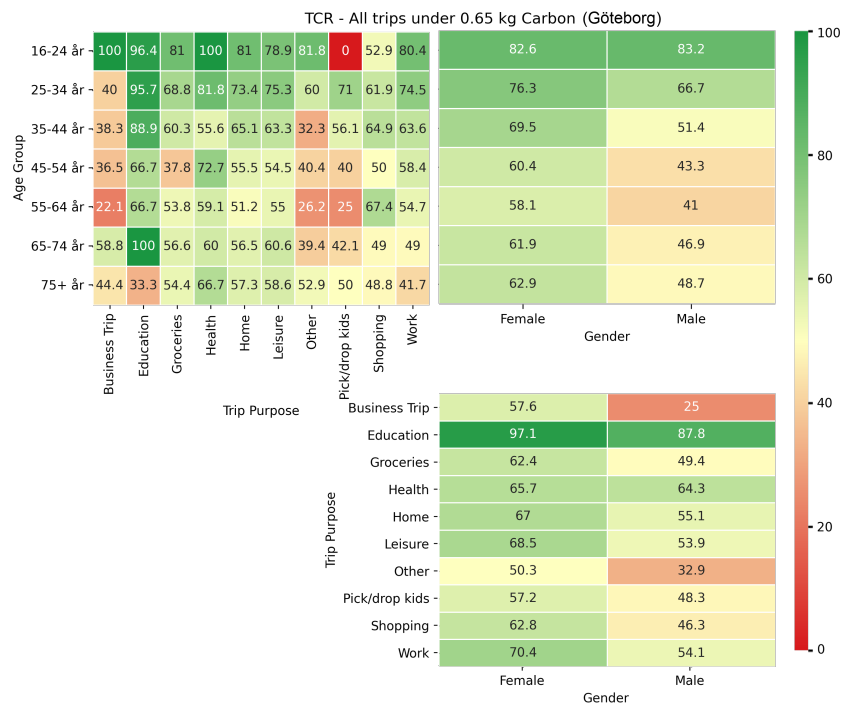
Figure 4 Results of Trip Completion rates in Gothenburg for 0.65 kg CO2-e/day across multiple dimensions from the national household travel survey. Data source - Swedish National Household survey [12]. Missing data is left blank

The differences are from the change in population demographics, travel behaviour and access to amenities in the different municipalities. The results show that the ability to satisfy one's daily travel needs depends on individual characteristics such as behavioural patterns of travel, travel mode choices, and access to local amenities. PCAs may disproportionately affect certain groups more than others. Policymakers must understand who is most affected by sustainability targets to ensure that disproportionately affected groups have an equal opportunity to achieve their daily needs. For a just and equitable transition to a low carbon future, PCAs as a policy tool must consider the social impact of doing so.

4.1. Advantages of the approach

Carbon budgets are an effective tool for setting goals and measuring progress towards global climate goals. However, policymakers must take a broader view of the problem and incorporate the social consequences of these decisions. Exploring alternate data sources makes it possible to evaluate the social consequences of these decisions from a bottom-up perspective. Evaluating the impact of policy scenarios on different areas due to their demographic composition and accessibility of amenities allows decision-makers to evaluate the social consequences of policy measures at a finer spatial scale than evaluating policy scenarios at the national level. Further, TCR can also be used as an indicator to evaluate policy scenarios for simulated data, allowing for the modelling of hypothetical – "what if" scenarios to evaluate potential solutions to mitigate the social consequences of environmental policies.

4.2. Limitations

Due to data availability at the time of conducting this research, comparable data of GWP of common modes of transport were not available for Sweden; hence data from the UK is used.
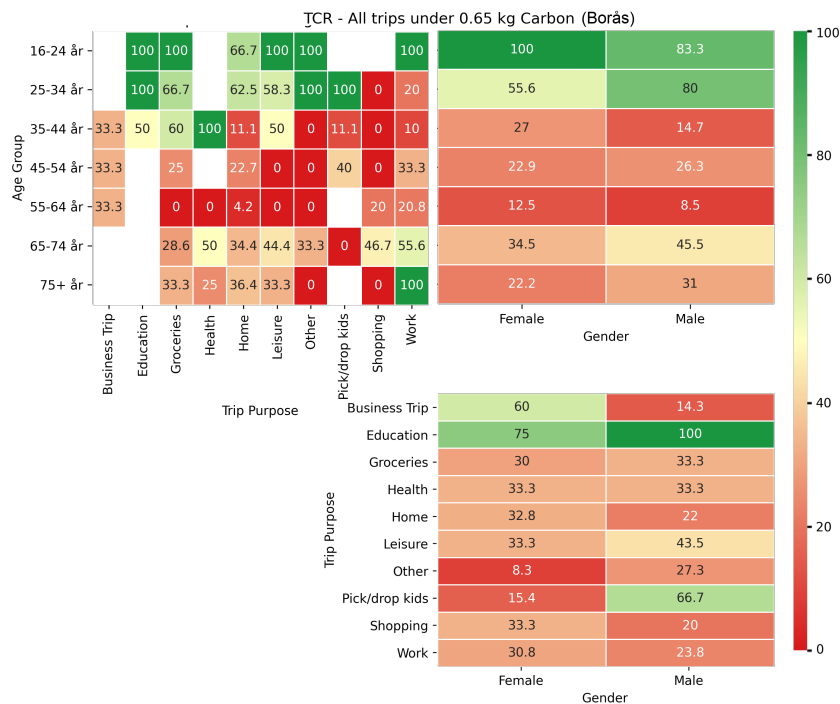
Figure 5 Results of Trip Completion rates in Borås for 0.65 kg CO2-e/day across multiple dimensions from the national household travel survey. Data source - Swedish National Household survey [12]. Missing data is left blank

There are considerable implications of doing so, namely, the difference in the composition of cars, the difference in electric vehicle coverage, and the grid mix that can affect the results. In future studies, data from Swedish transportation will evaluate different scenarios. The Swedish NHTS does not include economic information about the participants; hence, comparing the economic background of the agents affected by the policy is not yet possible. The evaluation of the NHTS data presented in this paper only looks at age, gender, and travel destination. However, the method illustrated in this study can be applied to other demographic dimensions and is only limited to data availability.

4.3. Outlook

The approach shows promising results in capturing the geographical and demographic variations across municipalities in the residents' abilities to fulfil their daily needs. While evaluating data at the municipal level provides a better insight into how policies affect one's ability to fulfil their daily needs, data collected at the neighbourhood scale could benefit stakeholders in making more nuanced decisions on the built environment. Using travel data in combination with agent-based models could allow stakeholders to improve the resolution of the data to evaluate TCR at smaller geographical scales. Visualising multivariate data can be challenging and overwhelming; alternate ways of visualising such results must be evaluated to ensure that stakeholders and decision-makers can easily interpret the data. In this paper, we illustrate two methods of visualising TCR.

5. **Conclusion**

Achieving one's daily needs is an important aspect of social sustainability in a community, and transportation plays a large role in making these choices possible. The location that an individual lives in, the choices available in that location, and the individual's behaviour patterns all contribute to determining whether an individual's quality to achieve their daily needs is diminished. A multidimensional assessment is required to evaluate the social impacts of carbon budgets. Using commonly available data sets such as the NHTS in combination with the TCR proposed in this paper allows the

examination of cross-sections across activities and demographies. TCR can be used to identify the populations that may be vulnerable to the negative social impacts of these policies and help highlight what measures may be taken to mitigate these impacts. The policy targets are evaluated across a regional level and municipalities using Trip Completion Rates to evaluate whether the proposed policy affects one group disproportionately compared to another. The digitalisation of the built environment can enable planners and policymakers to understand the social consequences of sustainability targets and provide equitable solutions to realise them at the early stages of the planning process [8].
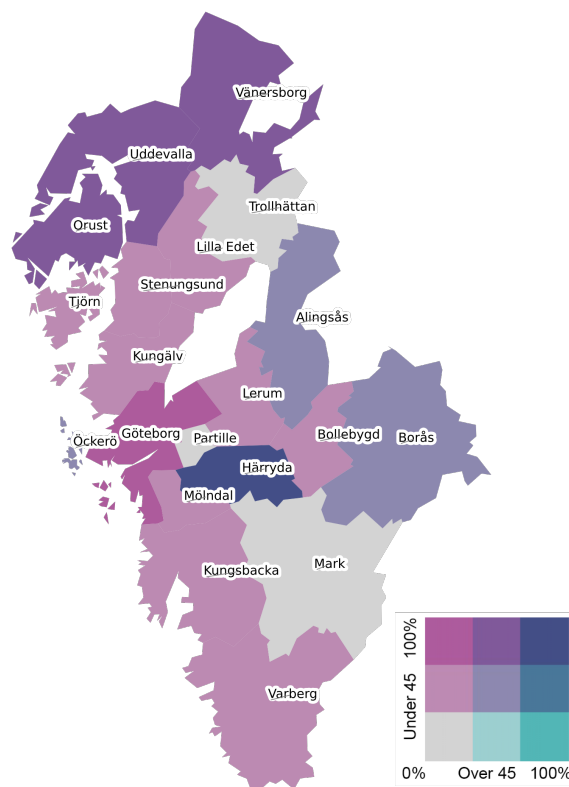
Acknowledgements

Appendix

Figure A.1 Municipal differences based on the age group affected by PCAs. The data is represented using a bi-variate colour scheme. Grey shows municipalities where both younger and older residents have low TCR for a 15-minute travel scenario, and purple shows municipalities with higher TCR. Whereas pink shows municipalities where younger residents have a higher TCR than the older, blue shows municipalities where older residents have a higher TCR than younger.

Disclosure

No potential conflict of interest was reported by the author(s).

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